6-2003

Defining Away the Hazard: The Department of Energy's Solution to the High-Level Waste Problem at INEEL

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June 2003

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This project was supported by a grant from the Citizens' Monitoring and Technical Assessment Fund.

Executive Summary

The Snake River Alliance, a public interest group based in Boise, Idaho, asked Radioactive Waste Management Associates (RWMA), to review the safety of the high-level waste (HLW) storage tanks at the Idaho National Engineering and Environmental Laboratory (INEEL). In a recent Environmental Impact Statement (EIS) and supporting documents, the U.S. Department of Energy (DOE) laid out plans for managing these wastes, some of which have already been evaporated and placed as solids in storage bins.

In this report, RWMA

- Evaluates the nature of the liquid high-level waste in the tanks in light of INEEL's recent reclassification of a portion of the HLW as "sodium-bearing waste" and its proposal to further reclassify this remaining HLW as waste incidental to reprocessing (WIR).
- Compares this waste to other waste in the DOE inventory and considers the short- and long-term risks posed.
- Reviews the risk assessment carried out by DOE, including assumptions and methods.
- Evaluates methods of near-term remediation (and their technical constraints) that do not prohibit more thorough cleanup as technologies develop.

The Idaho National Engineering and Environmental Laboratory (INEEL) is a federal facility operated by the DOE. The INEEL facility previously known as the Idaho Chemical Processing Plant (ICPP) operated since 1953 as a uranium reprocessing facility. Until 1992, INEEL chemically removed highly enriched uranium from used nuclear navy fuel; the remaining fission products and transuranics were put into underground high-level waste tanks and calcined into solid material. Since 1992, when INEEL ceased reprocessing spent nuclear fuel, liquid wastes have been added to the tanks from various processes treatment of other wastes and for decontamination of existing facilities.

All of the INEEL underground tanks were built from stainless steel and are housed in concrete vaults that sit on bedrock at about 45 feet below the surface, with the tops at about 10 feet below grade.

Under DOE plans, solidified high-level waste from operations at Idaho, Hanford, Savannah River, and West Valley would go to the proposed underground repository at Yucca Mountain, Nevada. Liquid high-level waste and INEEL's calcined high-level waste would be made into glass logs and buried along with commercial irradiated fuel assemblies. This method of disposal would be a massive and expensive undertaking. To reduce treatment and disposal costs, the DOE intends to redefine part of the high-level waste as waste incidental to reprocessing (WIR). WIR would then be handled as low-level or transuranic waste (Pu, Am, Np). The bottom heels of HLW remaining in the tanks would be classified as WIR, based on DOE Order 435.1, which governs much of the DOE's self-regulating waste management activities. This order states that "waste resulting from reprocessing spent nuclear fuel that is determined to be incidental to reprocessing is not high-level waste, and shall be managed under the DOE's regulatory authority in accordance with the requirements for transuranic waste or low-level waste, as appropriate."

Redefining HLW as WIR clearly would be less expensive for the DOE, but is it safe? To answer this question, the DOE evaluated the short- and long-term hazard of leaving WIR grouted in place within the tanks. The short-term hazard is primarily due to direct gamma radiation to anyone exposed to the tank contents. In a future-use scenario, the DOE and its contractors, assume a farmer (DOE calls this person an “intruder.”) digs a house foundation and uncovers the roof of the vault, receiving a dose of 19 rem in a single day. Compared to background radiation, medical X-rays and allowable limits for decommissioned nuclear facilities, this radiation dose is off the charts. For example, the radiation dose from a decommissioned nuclear facility must be less than 25 mrem per year, that is, the radiation dose from the decommissioned tanks would be more than 760 times greater and received in a single day. Clearly if the DOE proposal goes through, the DOE must retain administrative control of the INEEL high-level waste tanks for thousands of years into the future.

Examining the long-term hazard, DOE considers the potential for contaminants from high-level waste entering the Snake River Aquifer. This analysis requires computer codes, such as TETRAD and MEPAS, to model the movement of radionuclides through the vadose zone and into the aquifer. To simplify the task, the DOE screens the most important radionuclides to reduce the original list of 143 radionuclides now found in the tanks to those requiring further quantitative assessment. The screening reduced the radionuclides effectively to two, Tc-99 and I-129 for the groundwater pathway, and to 22 for external radiation. In comparing the EIS for the West Valley Demonstration Project to the EIS for INEEL, we question the screening process and the calculated hazard; it appears that important long-lived radionuclides, such as Am-241 and Np-237, were screened out in the INEEL analysis. This is due to assumptions about water infiltration and hydraulic conductivity made by DOE that result in a very long time period before contaminants reach the aquifer.

Rather than engage in the dubious process of redefining HLW as WIR, we encourage the DOE to develop the robotic technology to more effectively remove more HLW liquid from the tanks. It appears that the technology is available to do this. Redefining the hazard is not intellectually honest. It requires DOE and its contractors to engage in radionuclide screening games that are hidden from the public. But more important, redefining the hazard changes the names but will not protect public health and safety.

Chapter 1: Introduction

Site Description and History

The Idaho National Engineering and Environmental Laboratory (INEEL) is a federal facility operated by the US Department of Energy (DOE). The facility was previously known as the National Reactor Testing Station and then the Idaho National Engineering Laboratory. It was established by the U.S. Atomic Energy Commission (AEC) in 1949 to provide a place to build,

operate, and test nuclear reactors, fuel processing plants, and support facilities. Since its establishment, 52 reactors have been constructed at INEEL.

DOE manages INEEL through three DOE operations offices. These are the Idaho Operations Office (DOE-ID), the Idaho Branch Office of Pittsburgh Naval Reactors, and the Chicago Operations Office.

Bechtel-Babcock & Wilcox Idaho began operating the DOE-ID facilities on October 1, 1999. Previously, it was operated by Lockheed Martin Idaho Technologies Company (LMITCO) and earlier by other contractors.

The INEEL HLW program is located at the Idaho Nuclear Technology and Engineering Center (INTEC). Prior to 1998, this area of INEEL was known as the Idaho Chemical Processing Plant (ICPP). INTEC has been in operation since 1953 and has historically been a uranium reprocessing facility for defense projects and for research and storage of spent nuclear fuel. INEEL ceased reprocessing of spent nuclear fuel in 1992, which led to the phase-out of all fuel dissolution, solvent extraction, product denitration, and other processes. Since then, new wastes arise from various decontamination processes of the existing wastes and facilities. Fig. 1 shows a view of INTEC.

Over the past decades, there have been accidental and operational releases to the environment of radioactivity and other contaminants from the INTEC processing plants and support systems. A notable past practice, not illegal at the time, was direct disposal of hazardous and radioactive waste to the Snake River Plain Aquifer through injection wells.

INEEL currently manages waste from the reprocessing of spent nuclear reactor fuel, including high-level waste (HLW). When it is taken out of a reactor following irradiation, spent nuclear fuel contains unused enriched uranium, transuranics and radioactive fission products. Because of its high levels of direct radiation, it must be properly shielded. A large part of the radioactivity in the irradiated fuel is transferred to liquid HLW, which is stored in large underground tanks of the INEEL Tank Farm, discussed below.

Environmental Setting of the ICPP

The INEEL occupies 2,305 km^2 (890 mi^2) on the northern part of the Eastern Snake River Plain and is located in a topographically closed drainage basin[1]. Three intermittent streams, the Big Lost River, Little Lost River, and Birch Creek flow onto the INEEL. The Big Lost River is the principal surface water feature on INEEL, and a flood diversion system was constructed in 1958 to protect INEEL facilities from being flooded. The system consists of a dam to divert river flow to a series of spreading areas.

Since 1950, INEEL has experienced flooding events caused by early spring snow-melt in 1962, 1969, and 1984. The capability of the diversion dam built in 1958 is subject to much controversy. DOE cites a study[2] carried out by Bennet in 1986 that calculates a system capability of the dam to accommodate flows of up to 9,300 ft^3/s. On the other hand, a USGS study[3] estimated that of a

[1] US DOE, *Comprehensive RI/FS for the Idaho Chemical Processing Plant OU 3-13 at the INEEL – Part A*, RI/BRA, Books 1-4, DOE/ID-10534, prepared by R. R. Rodriguez, A. L. Schafer, J. McCarthy, P. Martian, D. E. Burns, D. E. Raunig, N. A. Burch, R. L. VanHorn, Nov 1997, p. 2-1.
[2] *Ibid*.
[3] USGS 1998.

7,260 ft^3/s flow upstream of the dam, the vast majority (6,220 ft^3/s) of the water would flow downstream and flood the northern half of INEEL with 4 ft of moving water. Another study by the U.S. Army Corps of Engineers[4] came to the conclusion that the diversion dam could fail if flows were to exceed 6,000 ft^3/s. The 95% confidence limits for a 100-y-flow are 3,150 and 11,600 ft^3/s.

A portion of the Snake River Plain Aquifer, which is a valuable regional water resource in southern Idaho, is located underneath INEEL. The Aquifer extends about 322 km from Ashton in the northeast to Hagerman in the southwest, and covers an area of about 25,900 km^2 (10,000 mi^2). EPA designated the Snake River Plain Aquifer as a sole source aquifer[5] because it is the only viable source of drinking water for more than 270,000 people.

In the vicinity of the INTEC, the top of the aquifer is about 138 m (450 ft) from the surface, which is at 1,494 m above median sea level[6]. The general flow of the groundwater in the aquifer is to the southwest, with a gradient[7] of about 4 ft/mi. The direction of the flow is locally affected by recharge and discharge.

Except for evapotranspiration, all of the water from the three rivers recharges the aquifer either directly by infiltration or indirectly by irrigation and subsequent infiltration. Precipitation averaged 8.3 in/y (22.1 cm/y) from 1950 through 1995, with the highest annual value reaching 14.40 inches in 1963[8].

There are several perched water bodies underneath INEEL, including some below the Tank Farm at ICPP. The uppermost perched water zones below the ICPP were found in the alluvium[9] at depths of 6.7 m (22 ft) and of 9.8 m (32 ft). Lower bodies of perched water were found in the Upper Basalt at depths of 38.4 - 53 m (125.4 -173.1 ft) and of 104 - 122 m (340 - 399 ft) below grade surface (Fig. 2). For a detailed, concise description of the hydrogeology at the ICPP, we refer to the IEER report[10]. In some of these perched water bodies, elevated concentrations of radionuclides are present due to discharge of contaminated water in a shallow seepage pit. However, even after the pit was closed, concentrations of Sr-90 remained high, probably due to other sources[11].

The fact that the origin of the water source for these perched water bodies was unclear plus discrepancies between the amount of water pumped from the aquifer and the amount disposed of at ICCP suggested that the plant lost water, though some loss could be due to evaporation. In addition, water seepage was found in the vaults of the HLW tanks. Seepage into the vaults could leach contaminants from the vicinity of the tanks to the perched water bodies and the aquifer. A study was carried out to examine these issues[12].

Some leaks that were found, such as leaks in the firewater and the potable water systems, have allegedly more recently been repaired, but they historically contributed about 4 million gallons/year to the perched water bodies[13]. The rate of seepage into the tank vaults was

[4] US Army, cited by EDI 1999
[5] US EPA, 56 FR 50634, October 7, 1991.
[6] US DOE 1997, p. 2-39.
[7] US DOE 1997, p. 2-27.
[8] US DOE 1997, p. 2-6 to 2.8.
[9] US DOE 1997, p. 2-56.
[10]. Makhijani et al, 2001.
[11] Robertson 1974.
[12] Richards 1994
[13] US DOE 1997, p. 2-11.

calculated to be about 29,000 gallons/y, with the two most important sources being infiltration of precipitation and nearby lawn irrigation. We'll discuss this issue in more detail below.

Closure of INTEC

In July 1989, INEEL was proposed to be added to the EPA National Priorities List (NPL) using Hazard Ranking System procedures from the National Contingency Plan[14]. After a review period, in November 1989 INEEL was indeed put on the list and became subject to the provisions of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), better known as Superfund. As a result DOE, EPA and the Idaho Department of Health and Welfare negotiated a Federal Facility Agreement and Consent Order (FFA/CO) and an Action Plan for cleanup and closure of the inactive facilities, including the HLW Tank Farm. The three negotiating parties agreed that INTEC should be remediated through the CERCLA-driven Remedial Investigation / Feasibility Study process.

The State of Idaho has issued a Consent Order concerning the operation of the Tank Farm, which allows a portion of it to operate until the year 2015. At that time, all the radioactive waste storage tanks must "cease use". Under the Consent Order, a phased closure will be implemented at the tank Farm. The stipulated deadline for the first five tanks to cease use is 2009, whereas the other tanks may continue to operate until 2015, when all tanks must be emptied to their heels[15]. After that, Resource Conservation and Recovery Act (RCRA) closure activities will be implemented, which will address the HLW tanks, the concrete vaults surrounding them, and associated pipelines.

In the draft[16] and the final[17] version of the Environmental Impact Statement (EIS), DOE presents several closure alternatives, both for waste disposal and for facility disposition. For each alternative, DOE calculates the potential total effective dose equivalent (TEDE) to differently exposed individuals and populations. The purpose of the EIS is to give information about various closure alternatives in order to make a decision. Therefore, the analysis in the EIS has a crucial influence on the final decision.

Objectives of This Report

The specific objectives of this analysis are to:

[14] US DOE 1997, p. 1-15.
[15] US DOE 1997, p. 1-20.
[16] US DOE, *Idaho High-Level Waste & Facilities Disposition Draft Environmental Impact Statement* (D-EIS), DOE/EIS-0287-D, December 1999.
[17] US DOE, *Idaho High-Level Waste & Facilities Disposition Final Environmental Impact Statement* (F-EIS), DOE/EIS-0287, September 2002.

- Evaluate the nature of the material in the tanks in light of the INEEL's recent reclassification of the HLW as "sodium-bearing waste" and its proposal to further reclassify it as waste incidental to reprocessing (WIR).
- Compare this waste to other waste in the DOE inventory and the short- and long-term risks posed.
- Review the risk assessment carried out by DOE, including assumptions and methods.
- Evaluate methods of near-term remediation (and their technical constraints) that do not prohibit more thorough cleanup as technologies develop.

Much of the information in this report is based on the Draft EIS (D-EIS). However, during the period of editing, DOE finished the Final EIS (F-EIS), dated September 2002. The majority of the contents remained unchanged, which is why we did not change all references from the D-EIS to the F-EIS. However, where new information became available, we refer to the final version.

Some of the most obvious changes between the D-EIS and the F-EIS risk calculations are that the radiation doses calculated for the resident farmer decreased, whereas the doses for the uninformed intruder increased. The post-closure inventory increased, and the relative contribution of specific radionuclides changed. Also, all assumptions that underlie DOE's calculation of the long-term dose due to the disposition of the Tank Farm were removed from the F-EIS and included in a separate document referred to as "Calculation Package", authored by a DOE contractor.[18] We had to obtain this document through a Freedom of Information Act request, as it is not available online or directly from the contractor. The same is now true for the D-EIS, for which one needs a DOE password to obtain it online, although it used to be readily available to the public.

It has to be noted that it is very difficult and time-consuming to locate information in the Calculation Package, because the page numbers do not correspond to those given in the table of contents, and the subchapters are not numbered. Also, no list of tables or figures is given, although tables occupy the majority of the space. Thus, one has to page through an entire chapter in order to find a specific section or table. Some tables in the Calculation Package are wrongly referred to in the text.[19] To make matters worse, the F-EIS refers to chapters in the Calculation Package that do not exist.[20]

As a result, the combination of F-EIS and Calculation Package appears as a rather unprofessional patchwork of data, which seems inappropriate for a DOE study that took many years and cost large amounts of money.

[18] US DOE, *Calculation Package for Appendix C.9 to the Idaho High-Level Waste and Facilities Disposition Final Environmental Impact Statement*, by Tetra Tech NUS, DOE/ID-10900, July 2001.

[19] For example on p. 4-43, Tables 4-19 and 4-20 are referred to as pertaining to the Tank Farm for radionuclide screening results with and without retardation, whereas Tables 4-21 and 4-22 are supposed to relate to the bin sets. However, as it turns out, this is not the case.

[20] For example, on p. C.9-9, the F-EIS refers to Section 3.6 of the Calcualtion Package, and on p. C.9-26, DOE refers to Section 5.3 of the same document ; however, neither section exists.

Chapter 2: HLW Tank Farm

Function of the Tank Farm

The Tank Farm received liquid wastes from the reprocessing of spent nuclear fuel, from the nuclear navy.[21] The reprocessing of spent fuel at INEEL can be described[22] as follows: First, the spent fuel, including the cladding, was dissolved in a heated nitric or hydrofluoric acid bath, depending on the type of cladding. The resulting aqueous solution—containing uranium, other actinides and fission products—was then mixed with kerosene plus tri-butyl-phosphate (TBP) in order to separate the nuclides using their chemical properties. The uranium, plutonium, and some of the technetium dissolved in the organic phase, whereas the other actinides and the fission products did not remain in the aqueous phase. The aqueous solution contained about 99.9 percent of the fission products[23] as well as most of the radioactivity, which was mainly found in the fission products. This first cycle of extraction waste was passed to a small, cooled interim storage tank and subsequently transferred to one of the large cooled tanks of the Tank Farm (INEEL recovered very little plutonium).

The organic phase was further purified by scrubbing with water, and the uranium was then stripped from the organic phase to an aqueous stream. This stripped uranium was extracted with organic solvent two or more times. Each sequence of extracting, scrubbing, and stripping is called an extraction cycle. The solutions underwent three extraction cycles. Wastes from the second and third cycle contain much less radioactivity than the first cycle. They were concentrated by evaporation and also disposed of in the Tank Farm, normally in non-cooled tanks.

As soon as enough HLW was accumulated, it was dried into a powder, called calcine, and stored in large stainless steel bin sets contained in thick-walled concrete silos (Fig. 3)[24]. The Tank Farm was therefore mainly a temporary, steadily used storage facility for HLW, with waste entering and leaving the tanks.

However, waste from other sources, mainly decontamination operations at INEEL, was also stored in the Tank Farm. This additional waste, called sodium-bearing waste, was concentrated before being transferred to the tanks and contained high levels of radioactivity. After 1992 (when reprocessing operations ceased), only sodium-bearing waste was added to the tanks. This newly generated waste will continuously be produced for years to come, until INTEC is closed.

Tank Design

All of the INTEC underground tanks were built from stainless steel and housed in concrete vaults[25]. The concrete vaults sit on bedrock about 45 feet below the surface, with the tops about

[21] The Tank Farm still receives liquid waste from ongoing, non-reprocessing activities.
[22] ERDA 1977.
[23] Ibid, p. 2-1.
[24] ERDA 1977, p. A-8
[25] US DOE 1997, p. 1-11.

10 feet below grade. This distance includes approximately 0.6 ft of soil over a synthetic membrane.

Stainless steel was used because of the very acidic (pH 1) waste to be stored in the tanks. Each tank is single-shelled and can hold about 300,000 gallons of waste. The concrete vaults consist of three designs: octagonal vaults (2 tanks), pillar and panel vaults (5 tanks), and cast-in-place square vaults (4 tanks)[26]. Cooling coils were installed on the floors and walls of 8 of the 11 tanks. The other three tanks are not cooled. The tanks were put into service between 1953 and 1966.

The oldest tanks, WM-180 and -181, were built from 1951 to 1952 and entered service in 1953. They are encased in cast-in-place (monolithic) octagonal concrete vaults. The tanks have 50-foot diameters; and the walls are 23 feet high, approximately the height of a two-story house. WM-180 had cooling coils installed. A picture of WM-180 while under construction is shown in Fig. 4.

The next five tanks (WM-182 to 186) were built from 1955 to 1957. They are housed in octagonal pillar and panel vaults, built with precast concrete components. The tanks have a 50-foot diameter, and the walls are 21 feet high. Except for Tanks WM-184 and WM-186, all of the tanks have cooling coils.

The last four tanks (WM-187 to 190) were built between 1958 and 1964 and are housed in rectangular, concrete cast-in-place vaults. Each vault contains two tanks and has a precast T-beam roof. Just like the pillar and panel vault tanks, the cast-in-place vault tanks have a 50-foot diameter and 21-foot-high walls. Each of these four tanks has cooling coils.

The tank bottom is a 50-ft- diameter circular area corresponding to a surface area of 1,963 ft^2 or about 183 m^2.

The tank vaults have a 10-foot covering layer of soil that contains a membrane to prevent water from leaching in. This membrane was installed after leaks had occurred and contaminated the perched water bodies and the groundwater[27]. However, it seems that water nevertheless infiltrates through perforations for pipe risers and valve boxes[28].

Liquid wastes were transferred to the Tank Farm from various INTEC areas through underground stainless steel lines. Also, there is a pipe system for the cooling water from the tanks. Cooling water from the secondary heat transfer system is routed directly to service waste without monitoring for radioactivity, because the primary systems are monitored[29].

Each tank has two tank risers, through which the tanks can be accessed from the outside. The risers have a diameter of 12 inches[30].

In 1999, DOE carried out a robotic tank inspection of WM-188 with a device called Robotic Tank Inspection End Effector (RTIEE), mounted on the Light Duty Utility Arm (LDUA). The waste heel in the tank was about 10 inches deep. The radioactivity from the waste led to “snow” in the camera view due to the bombardment of the camera by radioactive particles[31].

[26] TFA, available at www.pnl.gov/tfa/sites/ineel.stm, accessed on 9/21/01
[27] US DOE 1997, p. 10-5.
[28] US DOE 1997, p. 2-16.
[29] US DOE 1997, p. 1-12
[30] Bamberger et al, 2001, p. 3.9.
[31] TFA 1999, p. 8.

Types of Radioactive Waste

High level waste (HLW)

There are several competing definitions of radioactive waste. High-level waste (HLW), as defined by the Nuclear Waste Policy Act of 1982, as amended[32], is "(A): The highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and (B): Other highly radioactive material that the Commission, consistent with existing law, determines by rule requires permanent isolation." This definition was included in DOE order[33] 435.

The NRC[34] defined HLW in 1970 as "liquid wastes resulting from the operation of the first cycle solvent extraction system, or equivalent, and the concentrated wastes from the subsequent extraction cycles, or equivalent, in a facility for reprocessing irradiated reactor fuels". In 1972, spent fuel was included in the NRC's definition of HLW[35], and in 1980, the definition was broadened again[36] to include "such other material as the Commission designates as high level radioactive waste for the purposes of protecting the public health and safety".

In the HLW DEIS, DOE labels only the waste from the first extraction cycle as HLW, whereas the waste from the second and third cycle is labeled Sodium-bearing waste (see below). This definition has changed over the years. In a 1978 EIS for ICPP waste operations, all reprocessing waste, from the 1st to 3rd extraction cycles, was classified as HLW, with the differentiation into high-heat and low-heat HLW.[37]

Transuranic Waste

Transuranic waste contains α-emitting nuclides with an atomic number greater than that of uranium (92), i.e. Neptunium (Np), Plutonium (Pu), Americium (Am), Curium (Cm) etc. These radionuclides do not exist in nature; they are entirely produced in nuclear reactors when uranium is bombarded with electrons and neutrons. DOE defines transuranic waste as containing an activity of greater than 100 nCi/g (100,000 pCi/g) for the sum of all transuranics with half-lives greater than 20 years[38]. The previous definition of TRU in the Atomic Energy Act 10 nCi was changed to 100 nCi in 1984[39]. Waste that exceeds this limit is transuranic waste, except for:

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[32] Public Law 97-425 (96 Stat. 2201) enacted on January 7, 1983, and subsequent amendments. The Act was extensively amended in identical form by Public Law 100-202 (101 Stat. 1329-121) and Public Law 100-203 (101 Stat. 1330-243) on December 22, 1987.
[33] US DOE Order 435.1, 1999, p. II-1.
[34] 10 CFR Part 60.2.
[35] Marine Protection, Research, and Sanctuaries Act, 1972
[36] West Valley Demonstration Project Act, 1980.
[37] ERDA 1977
[38] DOE Order 435.1, Chapter 3.
[39] DOE Order 5820.2.

- High level waste (see above)
- Waste that the Secretary of Energy, in concurrence with EPA, has determined not to need the degree of isolation required by 40 CFR Part 191 disposal regulations
- Waste that the NRC has approved for disposal on a case-by-case basis

Sodium-bearing Waste (SBW)

Sodium-Bearing Waste (SBW) is not an official waste category in any regulation. DOE-INEEL introduced this term, apparently with the intention of changing the name of some of the waste in the HLW tanks. DOE describes SBW as containing hazardous and radioactive materials and being classified as mixed transuranic waste.[40]

According to the DOE, SBW is similar to HLW in its radionuclide inventory, but it is less concentrated, and it contains large quantities of sodium and potassium nitrates. In the EIS, it is described as "liquid waste produced from the second and third cycles of spent nuclear fuel reprocessing […]. Radionuclide concentrations of SBW are generally 10 to 1,000 times less than for liquid HLW". This is waste that was formerly called high-level waste.[41]

DOE divides all tank waste into the two categories HLW and SBW. Whereas HLW is directly stored in cooled underground tanks, SBW is concentrated in the Process Equipment Waste (PEW) Evaporator before being transferred to the Tank Farm, i.e. the tanks receive concentrated SBW. According to the EIS, HLW stems only from the first cycle of fuel reprocessing, whereas SBW has several sources. Besides the second and third cycles of fuel reprocessing, it also comes from decontamination solutions in the PEW evaporator. Additional wastes stored in the Tank Farm and treated as SBW in the EIS include fluoride and cadmium-bearing wastes from the fluorinel process, decontamination wastes containing fluoride from waste calcining, process salvage streams, and occasional transfers from waste disposal system facilities[42].

For purpose of comparison with the EIS, we adopt DOE-INEEL's practice of calling the waste from the second and third cycle SBW. While we believe that these wastes should still be treated as HLW, we agree that they contain less radioactivity than the wastes from the first extraction cycle.

Waste Incidental to Reprocessing (WIR)

A core supposition of the EIS is that the waste in the tanks should be declared Waste Incidental to Reprocessing (WIR). The State of Idaho, a cooperating agency on the study, and public interest groups, such as the Snake River Alliance and NRDC, do not agree with DOE. This classification of waste is based on DOE Order 435.1, which governs much of the DOE's self-

[40] US DOE, D-EIS 1999, p. 1-11.
[41] The Snake River Alliance does not accept INEEL's replacement of the term HLW with the newly defined SBW.
[42] US DOE 1997, p. 1-11f.

regulating waste management activities. This order states[43] that "waste resulting from reprocessing spent nuclear fuel that is determined to be incidental to reprocessing is not high-level waste, and shall be managed under DOE's regulatory authority in accordance with the requirements for transuranic waste or low-level waste, as appropriate". The effect of a WIR designation would be that waste in INEEL's Tank Farm could be abandoned on-site even though HLW and TRU must be removed and disposed of in deep geologic repositories.

DOE intends to apply the evaluation process as described in DOE Order 435.1. To determine whether nuclear waste corresponds to HLW or to WIR, two processes are described in the manual that supports DOE Order 435.1.

Citation. Waste incidental to reprocessing by citation includes spent nuclear fuel reprocessing plant wastes that meet the description included in the Notice of Proposed Rulemaking (34 FR8712) for proposed Appendix D, 10 CFR Part 50, Paragraphs 6 and 7. These radioactive wastes are the result of reprocessing plant operations, such as, but not limited to: contaminated job wastes including laboratory items such as clothing, tools, and equipment.

Evaluation. A determination by the evaluation process that any waste is incidental to reprocessing must be developed under good record-keeping practices, with an adequate quality assurance process, and shall be documented to support the determinations. The objective of this requirement is to ensure the implementation of a consistent and defensible process to make waste incidental to reprocessing determinations across the DOE complex. Implementation of the process will ensure DOE manages these waste streams within its regulatory authority for disposal. According to DOE, such wastes may include, but are not limited to, spent nuclear fuel reprocessing plant wastes that:

a.) Will be managed as low-level waste and meet the following criteria:

Have been processed, or will be processed, to remove key radionuclides to the maximum extent that is technically and economically practical; and

Will be managed to meet safety requirements comparable to the performance objectives set out in 10 CFR Part 61, Subpart C, Performance Objectives; and

Are to be managed, pursuant to DOE's authority under the Atomic Energy Act of 1954, as amended, and in accordance with the provisions of Chapter IV of this Manual, provided the waste will be incorporated in a solid physical form at a concentration that does not exceed the applicable concentration limits for Class C low-level waste as set out in 10 CFR 61.55, Waste Classification; or will meet alternative requirements for waste classification and characterization as DOE may authorize. As with this extremely broad definition and the ones below, the intent is to allow DOE the flexibility to manage waste as it sees fit, probably to minimize costs. But this flexible definition may not be DOE's to make, since the NRC has also defined waste categories.

b.) Will be managed as transuranic waste and meet the following criteria:

Have been processed, or will be processed, to remove key radionuclides to the maximum extent that is technically and economically practical; and

[43] DOE Order 435.1

> Will be incorporated in a solid physical form and meet alternative requirements for waste classification and characteristics, as DOE may authorize; and
>
> Are managed pursuant to DOE's authority under the Atomic Energy Act of 1954, as amended, in accordance with the provisions of Chapter III of this Manual, as appropriate.

Again, this DOE definition is so broad as to allow DOE maximum flexibility to do what it wants by redefining HLW into other, less expensive disposal forms.

DOE wants to declare the waste in the tanks as waste incidental to reprocessing through the a.) and b.) evaluation process. INEEL wants to declare the liquid waste in the tanks TRU, remove, treat and send it to WIPP. It wants to declare the heels low-level and leave them where they are.

We discuss this process in the context of the INEEL Tank Farm below (steps from HLW to WIR).

Tank Waste Inventory

Because the radioactivity in both the liquid and solid wastes is a function of time due to radioactive decay, it is important to compare radioactivity of different wastes at the same point in time. The year of comparison in the EIS is 2016. Hence, if not otherwise stated, all radioactive concentrations (Ci/gal or m^3) or total activities (Ci) that appear below are decayed to the year 2016.

Reported inventories

According to the F-EIS, DOE operated the waste calciner until June 1st, 2000, when it was put on standby. At that point, the tanks held a total of about 1 million gallons of liquid waste[44]. DOE claims that this waste corresponds to SBW, because by February 1998, all HLW (except the HLW heels) had been calcined and moved to the calcine bin sets. In 1998, there were still about 1.4 million gallons of what INEEL calls SBW, which contained a total of about 500,000 Ci, predominantly due to Sr-90 and Cs-137[45]. By 2016, this waste will have decayed to 321,000 Ci. The total activity currently in the tanks is not given in the F-EIS, but if the ratios remain the same, then the 1 million gallons of SBW currently in the tanks would contain about 229,000 Ci by 2016. SBW is presently mainly stored in five tanks[46], in WM-180, -181, -187, -188 and –189. All other tanks contain waste heels, except for tank WM-190, which contains Low-Activity Waste.

A 1977 ERDA (predecessor of DOE) study of INEEL reports that 3 million gallons of HLW had been calcined[47], and that the total amount of the resulting HLW calcine was 1,500 m^3. After calcining all of the HLW in 1998, and before calcining any of the 1.4 million gallons of SBW in the tanks, the total amount of HLW calcine[48] was given as 4,155 m^3. This translates to a total amount

[44] US DOE, F-EIS 2002, p. 2-12. Note: According to information by B. Brailsford, this quantity could be as low as 863,500 gallons as of June 30, 2002.
[45] LMITCO 1998.
[46] LMITCO 1998, App. C and D.
[47] *Ibid,* p. A-20f.
[48] US DOE, D-EIS, p. C.7-1.

of 8.3 million gallons HLW that had been calcined at INEEL. The total activity in the HLW calcine of the most important radionuclides, decayed to 2016, is $1.83 * 10^7$ Ci. Total waste volumes and activities ever produced at INEEL are shown in Table 1. In May 2000, after about 400,000 gallons of SBW had been calcined as well, the total amount of calcine was[49] 4,400 m^3. However, because the F-EIS does not give information about the total radioactivity currently in the bin sets or in the tanks, we will proceed with our calculations using the values given in the D-EIS.

Calcining of SBW requires mixing it with other substances. Unlike HLW, where the dry solids are resistant to temperatures of 500-600 °C, the solids in SBW melt at this temperature, which would shut down the calciner[50]. In the past, INEEL calcined one part of SBW together with three parts of HLW. The blending diluted the sodium and the potassium in the SBW enough to operate the calciner. Because there is no retrievable HLW left in the tanks, SBW will have to be mixed with other material, such as aluminum nitrate, in order to be calcined. Because of the cost to upgrade, it is problematic whether the calciner will ever be restarted.

We could not identify the amount of SBW that was calcined together with HLW prior to 1998. The 1977 study reports that the reprocessing operations produced between 10,000 and 35,000 gallons per year of concentrated waste from the second and third cycle[51]. In addition, 15,000 to 50,000 gallons per year of other waste were poured into the tanks (in the D-EIS 1999, DOE labeled all of this waste SBW). However, while decontamination operations are still taking place, calcining has ceased. For the 40 years of fuel reprocessing between 1953 and 1992, this translates to a range of 955,000 to 3,240,000 gallons of non-HLW waste. Since 1.4 million gallons of SBW were in the tanks in 1998, we replace the lower range with this number and obtain a range of 1.4 – 3.6 million gallons of non-HLW that were produced until 1998 (Table 1). This means that by 1998, up to 2.2 million gallons of SBW had been calcined along with the HLW.

Fraction of radioactivity in tanks due to HLW

At present, all tanks except for WL-182 and WL-190 contain SBW. It has to be noted that the underground tanks were not designed so that wastes from them could be fully retrieved using currently available technology. An extensive network of cooling pipes line the floors and walls, and the jet pumps that drain the tanks are not installed at floor level. The remaining content that cannot be drained is called a tank heel. The heel volume is different for each tank type, depending on its design, and ranges from 5,000 to 20,000 gallons[52]. The combined estimated tank heel volume of all tanks is 79,000 gallons[53] (Table 2). All cooled tanks (except for the spare tank WM-190), and the non-cooled tank WM-186, contained HLW at some point[54]. The combined heel from these eight tanks is 59,000 gallons. Even though some tanks were emptied to the heel and refilled several times, some HLW has not been retrieved from the tanks and is therefore part of the current inventory.

If we divide the total amount of radioactivity in the tanks in 1998, decayed to 2016, by the total waste volume in 1998 of 1.4 million gallons, we obtain an average activity of 0.227 Ci/gal, predominantly due to Sr-90 and Cs-137 (Table 3). Other radionuclides are also present, but their concentrations are much lower. However, for the long-term risk assessment, these radionuclides gain importance because of their long half-life.

[49] US DOE, F-EIS, p. 2-12.
[50] LMITCO 1998, p. 11.
[51] ERDA 1977
[52] US DOE, F-EIS p. 2-14.
[53] Beck 1999a.
[54] LMITCO 1998, Appendix D.

All tanks are different in terms of their content and operational history. According to INEEL, tanks WM-181 and –184 never contained HLW. However, according to INEEL documents, WM-181 contained PEW or Process Equipment Waste, which may be considered HLW. The radionuclide concentration (decayed to 2016) in these two tanks was 0.144 and 0.089 Ci/gal, respectively (Table 3). All other tanks clearly held HLW at one point, and as a consequence, their radionuclide concentrations are generally higher. The only exception is WM-180, with a concentration of 0.128 Ci/gal. WM-180 contained HLW until 1967 and since then it has been emptied and refilled with SBW three times, which may have diluted the heel.

In order to estimate the amount of radioactivity in the tanks in 1998 that was due to the HLW heels, we compare the average activity in the waste with the activity in HLW. We calculate the activity of HLW by assuming that 1.1 million gallons of SBW were processed along with the HLW, based on the average number of gallons of non-HLW ever produced (see above).

If these 1.1 million gallons of SBW had the average activity of the two tanks that contain exclusively SBW, i.e. 0.117 Ci/gal, then they account for ($0.117 * 1.1 * 10^6$) 128,000 Ci in the calcine. We then divide the remaining (18.3-0.13) 18.17 million Ci in the calcine by (8.3-1.1) 7.2 million gallons of HLW and obtain an average HLW concentration of 2.524 Ci/gal. The average concentration of HLW is (2.524/0.117) 22 times greater than the average activity of SBW.

If we further assume that of the total amount of 59,000 gallons HLW heels, 50 % are still in the tanks (the other 50 % were removed by mixing and draining), then 74,000 Ci (decayed to 2016) of the total 321,000 Ci in the tanks are due to HLW, or about 23 %. If more than 50 % of the original HLW heels are still present, then this percentage would be higher.

HLW / SBW ratio

As seen above, the radioactivity of HLW due to Sr-90 and Cs-137 is only about 22 times higher than that of SBW. This is still in agreement with INEEL's statement according to which SBW is 10-10,000 times less concentrated than HLW, even though it is at the lower end of the range. The low ratio could be explained by the concentration of SBW before pouring it into the tanks, i.e. the ratio of HLW/non-concentrated SBW could be much higher. The various stages of concentration are probably the reason for the broad range of the HLW/SBW factor in terms of activity.

However, the concentration of waste has no impact on the total amount of radioactivity produced. Therefore, we calculate the ratio of the total radioactivity in HLW and in SBW. Since more than 99.9 % of all fission products enter the first-cycle HLW[55], and almost all radioactivity of relatively fresh waste is in the fission products, this ratio should be at least 1,000.

If we again assume that 1.1 million gallons of SBW were calcined along with the HLW, and that 74,000 Ci of the waste currently in the tanks is actually HLW, then the HLW/SBW ratio is calculated as follows:

($18.17 * 10^6$ Ci in calcine + $7.45 * 10^4$ Ci in tanks) / ($1.28 * 10^5$ Ci in calcine + $2.47 * 10^5$ Ci in tanks) = 48.7.

[55] ERDA 1977, p. 2-1.

We obtain an upper bound for this ratio if we assume that no SBW has ever been calcined along with the HLW, and that all of the 59,000 gallons HLW-heel are still present in the tanks. Using these extreme assumptions, the HLW/SBW ratio is

(18.24 * 10^6 Ci in calcine + 1.29 * 10^5 Ci in tanks) / 1.92 * 10^5 Ci in tanks = 95.7.

Using the information from INEEL, the ratio of the total radioactivity in HLW to that in SBW cannot be higher than 96; the number is probably closer to 50, as calculated above. Since both numbers are significantly below the expected 1,000, we conclude that first-cycle HLW must have been mixed with SBW, and DOE called the resulting mix SBW. It also follows that more than 23 % of the radioactivity currently in the tanks is due to first-cycle HLW, and not second- and third-cycle SBW. It therefore does not seem appropriate to label the waste that is currently in the tanks as SBW.

Estimated post-closure waste inventory

DOE contractors calculated the post-closure contamination of the Tank Farm decayed to the year 2016.[56] For this, the department used a radionuclide inventory for SBW and normalized it to the concentration of Cs-137 measured in the tanks[57]. The SBW inventory was calculated based on a Tank Farm inventory from 1994 and the ORIGEN2 code[58] and is shown in Table 4, along with the updated post-closure inventory. The total radioactivity in the updated post-closure inventory is about 5 times greater than that presented in the D-EIS.

The calculated contamination of the starting heel is diluted by flushing and cleaning cycles, which are the decontamination procedures proposed by DOE. INEEL now assumes that the post-closure waste will consist of a 4-inch-layer of a solids/liquids mixture,[59] which translates to about 4,930 gallons per tank (tank radius of 25 feet). In previous calculations, DOE assumed 400 gallons of liquids and a 1-inch-layer of solids that remain in the tanks[60]. It is unclear why this change was made, as it was not discussed in the F-EIS.

Labeling of Tank Farm Waste

Steps from HLW to Waste Incidental to Reprocessing (WIR)

[56] US DOE / Tetra Tech Nus, July 2001, Table 4-7.
[57] US DOE, D-EIS, 1999, Appendix C.9, p. C.9-9
[58] Wenzel 1997.
[59] US DOE, F-EIS, 2002, Appendix C.9., p. C.9-15.
[60] Beck 1999a, p. 5

In an earlier study at INEEL, carried out by ERDA, DOE's predecessor, the authors stress the fact that all three extraction cycles are HLW[61]. In the Remedial Investigation and Baseline Risk Assessment carried out by DOE in 1999, waste from the first and second reprocessing cycles is considered HLW, whereas the third cycle is called intermediate-level wastes[62]. Finally, the D-EIS from 1999 only defines the waste from the first cycle as HLW, and the wastes from the subsequent cycles as SBW.

DOE states that during most of the fuel reprocessing period, the Tank Farm received HLW. In a very short statement, DOE claims that by February 1998, all liquid HLW had been removed and converted to calcine[63] and that the waste entering the tanks since then was mixed Transuranic Waste/SBW. There is no mention of HLW heels left in the tanks. Thereafter, DOE assumes in the EIS that the waste in the HLW tanks is not HLW, but SBW.

The NRC defines HLW as "waste from the first cycle of fuel reprocessing, and the concentrated waste from the subsequent cycles". With this definition, the waste that DOE calls SBW is in fact HLW. The State of Idaho has been attempting to determine the exact amount of liquid waste that has gone through the calciner.

The fact that all tanks are now alleged to contain SBW implies that SBW was poured on top of HLW heels, at least in the tanks that contained such HLW. It seems that DOE assumes that the entire waste is then SBW, and not HLW anymore. If HLW could be converted into another waste category by simply combining it with a lower-grade waste, then the nationwide HLW problem could be easily solved without building a geologic repository. We could just add LLW to HLW, call the resulting mix LLW and dispose of it in a landfill.

We compare the post-closure radionuclide concentration to that of SBW. In order to calculate this concentration, we divided total post-closure contamination by the total residual volume. The post-closure radionuclide concentration is about 47 times greater than that of the model-SBW, and about 74 times greater than the current radionuclide concentration (Table 4). This is only possible if the post-closure heel contains a significant fraction of HLW.

The concentration of I-129 and Tc-99 is similar in SBW, whereas in spent nuclear fuel, the concentration of I-129 is three orders of magnitude lower than that of Tc-99[64]. Interestingly, the ratio of Tc-99 to I-129 in the post-closure waste is 1,900 and resembles therefore that found in spent fuel, not SBW. The fact that the relative concentration in the post-closure waste of these two important radionuclides differ significantly from the SBW inventory raises the question about the suitability of SBW to represent the wastes in the tanks. For this reason, SBW should not be considered a separate waste "category;" rather than this ersatz waste category, DOE should return to the original HLW category.

The next step INEEL takes is to rename the tanks waste again and declare it WIR.

The strict meaning of Order 435.1 Condition b.1.)[65] demands that the wastes have been processed, or will be processed, to remove key radionuclides to the maximum extent that is technically and economically practical would probably not be fulfilled through INEEL's current closure plan. Wastes could probably be cleaned more effectively than by flushing and spraying

[61] ERDA 1977, p. 2-1, A-3, 10, 18.
[62] US DOE 1997, p. 1-11.
[63] US DOE, D-EIS 1999, p. 1-11.
[64] Gasteiger 1977, p. 37.
[65] Will be managed as transuranic waste and have been processed to remove key radionuclides to the maximum extent that is technically and economically practical.

with water, and then grouting them in place. There are certainly better cleaning processes available or at least in development.

Condition b.2.)[66] gives DOE broad authority as to how it wants to characterize the waste. Condition b.2) states that WIR has to be incorporated in a solid physical form and meet alternative requirements for waste classification and characteristics, as DOE may authorize. Under this exemption, even waste that exceeds radionuclide concentration levels of Class C low-level waste can be declared to be Waste Incidental to Reprocessing. This is important for INEEL, because the radionuclide activity in the residual heel exceeds the limit for class C, and therefore is not suitable for surface disposal[67].

Condition b.3.)[68] is a reference to CFR 10 Part 61 (low-level wastes) and CFR 40 Part 191 (transuranic waste), which regulate the standards for environmental radiation protection for management and disposal of radioactive waste. Both regulations state that the doses to the public should not exceed 25 mrem. As seen below, we question the results of the dose calculation for the maximally exposed resident that attempts to demonstrate that this limit will not be exceeded.

The NRC has not yet approved INEEL's evaluation process. On February 7, 2001, DOE requested consultation on and review of two draft incidental waste determinations for INEEL's tank wastes[69]. NRC responded by clarifying the criteria that it would use to review the incidental waste determinations. The first determination addresses management of liquid SBW as transuranic waste. NRC stated that their review would "only assess whether the SBW has been processed or will be processed to remove key radionuclides to the maximum extent that is technically and economically practical". This means that the NRC will not review the re-labeling of HLW to SBW, just the questions having to do with technology and money.

The second determination to be reviewed by NRC addresses the waste that will remain after closure of the Tank Farm. NRC staff stated that they would assess "whether the wastes in the Tank Farm had been or will be processed to remove key radionuclides to the maximum extent technically and economically practical, and whether the waste will be managed so that safety requirements comparable to the performance objectives in 10 CFR Part 61 are satisfied."

Other DOE sites are also in the process of labeling their HLW as WIR. Several sites have asked the NRC for a review of their evaluation process. As seen in the evaluation process undertaken at SRS (see below), economic considerations play an important role in determining whether HLW tank heels are considered WIR.

The intent of the EIS seems to be to label the waste in the INEEL Tank Farm (and other DOE-HLW tanks) as a relatively harmless substance. This path of argument finds its culmination in one of the facility disposition alternatives described in the EIS, the Closure to Landfill Standards Alternative. Needless to say, highly radioactive waste should not be disposed of in a regular landfill.

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[66] The HLW redefined as TRU waste will be incorporated in a solid physical form and meet alternative requirements for waste classification and characteristics, as DOE may authorize.
[67] 10 CFR Part 61.55.
[68] The redefined HLW are managed pursuant to DOE's authority under the Atomic Energy Act of 1954, as amended, in accordance with the provisions of Chapter III of this Manual, as appropriate.
[69] NRC, SECY-01-0150, 2001.

As further evidence of the high radioactivity of the "waste incidental to reprocessing" at INTEC, the Remedial Investigation/Baseline Risk Assessment (RI/BRA) report of 1997 describes incidental liquid waste as having radioactivity levels similar to high-level liquid waste[70]. Redefining high-level waste as waste incidental to reprocessing cannot redefine away the hazard.

Chapter 3: Facility Disposition Alternatives

In the Environmental Impact Statement, INEEL analyzed a number of different ways to close all the facilities at INTEC and dispose of reprocessing waste[71]. In this report, we focus on the facility disposition alternatives that affect the Tank Farm. For a detailed description of the entire INTEC closure we refer to the EIS.

For every facility disposition alternative, INEEL calculated the future impact on the environment and the population. It used various models and input parameters to calculate a radiation dose to future residents on or off the premises, workers, intruders and recreational users for a time period of 10,000 years.

As calculated by INEEL, most disposition alternatives do not cause any harm to people. In this chapter, we present and discuss the methods and assumptions that INEEL applied to obtain that result.

The various tank closure alternatives proposed by INEEL can be separated into three groups: Total cleanup (Clean Closure), no cleanup (No Action) and partial cleanup (Performance-based Closure and Closure to Landfill Standards).

Clean Closure

In this alternative, everything would be removed from INTEC, including the high level waste tanks. This alternative would lead to worker exposure during cleanup, but no long-term risk assessment is needed, because no contamination would be present in the future. However, no disposal facility exists for all existing wastes, existing facilities, or wastes produced during cleanup.

No Action

The second alternative analyzed is No Action, which is required under the National Environmental Policy Act. The No Action alternative is a baseline with which to compare other alternatives.

[70] US DOE, 1997, p. 1-12.
[71] US DOE, D-EIS 1999.

Under the No Action Alternative, DOE would not plan for disposition of its HLW facilities at INEEL. All present waste would remain in the Tank Farm. Use of the pillar and panel tanks (WM 182 to 186) would cease by June 2003. These tanks would each be flushed with 40,000 gallons of water and drained to heel level[72]. Newly generated wastes from decontamination processes at INTEC would be stored in tanks WM-180, -181, -187, -188 and WM-189. Tank WM-190 would remain empty as an emergency backup.[73] The new liquid would be lower in activity than the waste currently stored in the tanks.

The newly generated waste somewhat distorts the comparison between the No Action and the Performance-based Closure alternatives, because in the latter, these new wastes from decontamination operations would be stored in separate, new tanks, and are therefore not part of that alternative's long-term risk assessment.

The total radioactivity due to the most important radionuclides that would be left in place under the No Action Alternative, decayed to the year 2016, is $1.2 * 10^6$ Ci (Table 5). This is more than twice the estimate provided by J.T. Beck, which was the inventory referred to in the D-EIS.

Surprisingly, the total inventory for No Action is only about 1.4 times higher than in the Performance-based Closure, which assumes that most of the liquid is removed and the tanks washed. The total waste volume presented for the No Action Alternative is 1,402,000 gallons in the five full tanks, and another 25,000 gallons heel from the pillar-and-panel tanks, i.e. a total of 1,427,000 gallons of waste. This is about 26 times more than the combined residual heel of 4,930 gallons in each tank under the Performance-based Closure. It is not explained in the F-EIS, or in the Calculation Package, how this residual concentration was calculated.

The site would be monitored until 2095, which is the year to which DOE claims it would keep institutional control over the site. After that, no monitoring would take place. Over the following hundreds and thousands of years, all the waste would leave the tanks, migrate through the vadose zone and reach the aquifer.

Partial Cleanup (Performance Based Closures and Closure to Landfill Standards)

Short Description

This is a group of four alternatives that are similar in their exposure pathways and could be summarized as the Partial-Cleanup Alternatives. This group includes the alternatives "Performance-based Closure", "Closure to Landfill Standards", "Performance-based Closure with Grout A Disposal", and "Performance-based Closure with Grout C Disposal". INEEL states that the cleanup actions and therefore the doses and risks for the first two alternatives of this group

[72] NUS Tetra Tech 2001, p. 4-2.
[73] Beck 1999b

would be the same. The Performance-based Closure Alternative appears to be the option preferred by DOE.

Under both the performance-based closure and closure to landfill standards, INEEL assumes the high level waste tanks would be emptied to a 4-inch-layer and closed as soon as possible. This translates to a total residual waste volume of 4,930 gallons per tank. The newly generated liquid waste from decontamination operations would be put into new tanks and treated as low-level or transuranic waste, depending on their radionuclide concentration[74].

The tanks would be cleaned with the methods described below, subsequently filled with grout and left in place. Over time, the residual contaminants in the tanks could leach to the aquifer and eventually reach the public.

The last two sub-alternatives, class A or C grout, are similar to the performance-based closure, but instead of clean grout, INEEL would use grout already mixed with nuclear waste from other parts of INTEC to pour into the HLW-tanks. The resulting grout is either classified LLW class A or class C. The pathways for these latter two sub-alternatives are the same as for the performance-based closure, but the amount of radioactivity left in the tanks would be greater.

Tank cleaning and closure

The tanks have jet pumps to retrieve the liquid waste. They do not reach all the way to the tank bottoms to prevent clogging. When all the liquid that can be jet pumped is out of the tank, there is a residual heel in the tanks between 5,000 and 12,000 gallons, depending on each tank (Table 1). For the performance-based closure, the tanks would be jet pumped, flushed and jet pumped again. In the D-EIS, DOE is considering applying additional pumps to remove more waste, but for the estimation of the post-closure contamination, this possibility is discarded, leaving the jet pumps as the only removal system[75].

In a recent document that reviews the retrieval and closure plans at INEEL, more cleaning processes than just flushing are described. The tank closure process described in this document[76] consists of the following steps:

- Removal of current waste with existing steam jet pumps, leaving a heel 3-10 inches deep
- Video inspection and physical sampling of each tank
- Flushing of the tanks and their piping with demineralized water
- Removal of slurry with existing steam jet pumps, leaving a heel 3-10 inches deep
- Washing of tank with wash ball and directional nozzles, raising pH to >2
- Existing fixed steam jets are replaced with variable depth steam jets
- Video inspection and physical sampling of each tank

[74] US DOE, D-EIS 1999, p. 3-11.
[75] Beck 1999, p. 1.
[76] Bamberger et al, 2001, p. 3.2.

The wash ball is an off-the-shelf tank cleaning system and consists of two opposed, rotating nozzles that spray water to all sides (Fig. 5). The wash ball rotation is powered by the water flow. It is made of stainless steel and operates over the pressure range of 60 to 100 psi and flow rates of 60 to 75 gallons per minute. The time expected to wet the tank is about 14 minutes.

Because the wash ball does not selectively clean specific spots, two directional nozzles are also to be used. They would be placed in the two outer risers, 3 ft from the tank wall and 15 ft above the tank bottom.[77] They each have a movable nozzle with a water pressure of 120 psi and a flow rate of 40 gallons per minute. Next to the nozzles, a light and a video camera are installed, and operators control the nozzle remotely to clean heavily contaminated tank areas selectively.

The 2-inch-diameter variable depth steam jet would utilize the existing jet steam supply and could be adjusted over a range of 6 to 10 inches. The jets are remotely controlled and suck waste from the tank and eject it with steam pressure through an ejection pipe. When the waste level sinks, the jets are also lowered.

After cleaning, enough grout will be injected to cover all the piping in the tank bottom. The proposed method is to inject it in five portions, in the shape of a star,[78] so that it pushes the remaining liquid toward the jet pumps. DOE originally expected the pumps to be clogged by the grout with 400 gallons of liquid and a 1-inch-layer of solids remaining in each tank[79]. In the F-EIS, the department changed this assumption to an average of 4 inches of a solids/liquids mix per tank.[80]

After this first disc of grout in the tank, the space between the vault and the tank, and finally the entire vault and tank are filled with grout. Fig. 6 shows a DOE diagram of the planned tank closure. The resulting monolith would be left in place forever.

Residual contamination

In Table 6 we present the post-closure inventory in relation to existing NRC limits for waste classification[81]. For the calculation of radionuclide concentrations in nCi/g, we used INEEL's estimated total residual heel volume of 4,930 gallons per tank and a waste density of 1.28 g/cm^3, as given by INEEL[82]. It can be seen that radionuclide concentration of transuranics in the post-closure waste is far in excess of the LLW Class C limit, which means that the waste is not acceptable for near-surface disposal. The legal limit for the sum of all α-emitting TRU combined is 100 nCi/g waste, in comparison to the combined activity of the α-emitting TRU left in the tanks (Np-237, Pu-238, Pu-239, Pu-240 and Am-241) of 5,070 nCi/g. Also, the limit for the β-emitting Pu-241 of 3,500 nCi/g is exceeded (7,590 nCi/g).

In any case, as seen below in the risk assessment, INEEL assumes that practically nothing or only traces of contamination will ever reach the aquifer below the HLW tanks.

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[77] *Ibid*, p. 3.5.
[78] Bamberger et al, 2001, p. 3.13.
[79] Beck 1999a, p. 5.
[80] US DOE, F-EIS 2002, Appendix C.9, p.C.9-15.
[81] 10 CFR Part 61.55.
[82] Beck 1999a.

Chapter 4: Risk assessment at INEEL

In our discussion of the risk assessment carried out by DOE, we focus on the performance-based alternatives, which are the most likely to be implemented, and refer to the Clean Closure and the No Action Alternatives mainly as points of reference.

We present and discuss the assumptions that were made for the risk assessment, followed by the groundwater pathway analysis and the resulting doses to the potential receptors. The inhalation and direct radiation exposure pathways are much less important for the dose calculation and described in the end.

Assumptions

For the performance-based closure alternative at INEEL, DOE made the following assumptions:

a) Institutional control would be maintained until the year 2095. After that, the area could be used for any purpose, including farming. The time frame that was examined was 10,000 years.

b) Facilities will never be exposed to surface water in the examined time frame.

c) All residual contaminants would remain on the floor of the tanks, not on the walls.

d) At 500 years, concrete and grout assumes the same hydrogeologic transport characteristics as the surrounding soil, but its chemical properties remain stable during the entire 10,000 years.

e) An infiltration rate of 1.6 inches per year (rainfall minus evapotranspiration and runoff).

f) Present environmental conditions (temperature, rainfall, wind, etc.) remain the same during the entire 10,000 years.

g) No precipitation occurs when pH in tank heels is raised from 1 to 2.

h) 4 inches of waste remain in each tank after closure

Some of these assumptions are not conservative. We discuss these assumptions in the following paragraphs:

Assumption a.) Loss of institutional control in 2095

Loss of institutional control after 100 years is standard practice.

Assumption b): Surface water

The assumption that the Tank Farm at INTEC will never get in contact with surface water is hard to sustain in a closed drainage basin that receives water from three rivers. All of the water that reaches the basin enters the soil and recharges the groundwater. As discussed earlier, several flooding events have taken place at INEEL, and the capacity of the diversion dam is well below the upper 95 % interval for a 100-year-flow. The time frame of the risk assessment is 10,000 years (assumption a.), and it can be expected that 100-y flows occur 100 times in this period if present ecological conditions persist. This again is by no means certain, given the possible climate change towards more extreme weather events due to the greenhouse effect. In this respect, assumption f.) has to be questioned as well. It is important to state that the 100- and 500-year floodplain would inundate the Tank Farm according to D-EIS Figure 4-13.

Assumption c.): Contamination on tank walls

The probability that all contamination will be washed off the tank walls is very small, given the extensive net of cooling coils along the tank walls in 8 of the 11 tanks (Fig. 4). Flushing operations may clean some of this contamination, but it will be almost impossible to clean it all. However, we doubt that this faulty assumption has a significant impact on the risk calculation.

Assumption d.): Grout structure and tanks stable for 500 years, reducing ability for 10,000 years: limits of release

Human experience with concrete dates back about 150 years, and is therefore much shorter than the expected lifetime even of the structure.

In Chapter 5, we compare the modeling by DOE in the D-EIS for the West Valley Demonstration Project (WVDP) with modeling at INEEL. West Valley was a former reprocessing facility in which high-level waste were stored in tanks, similar to the situation at INEEL. At West Valley, the tanks are assumed to disintegrate in the beginning. However, the difference in assumed hydraulic conductivity of concrete is not important in comparing the release from the two DOE sites, because WVDP uses a completely different model approach, where diffusion is assumed to be the main release factor, as opposed to conductivity (see below).

After placement, the grout will be irradiated for many years. It is very difficult to foresee how it will react to such a prolonged exposure. Besides the physical integrity, the grout could also lose some of its chemical integrity. The claim of stable chemical characteristics translates into a claim of stable distribution coefficients (Kd's), because the Kd's depend on the valence state of an element, which in turn is controlled by the chemical properties of its surroundings. Thus, if the chemical properties of the grout change over time, the valence state and therefore the distribution coefficients of the waste will change as well. Also, once contaminants are leached out of the tanks, the reducing ability of the grout would have no more influence on the waste even if it persists, and the radionuclides' Kd's could change with a changing pH.

Assumption e.): Annual infiltration of 1.6 inches per year

This assumption is based on a calculation that subtracts evapotranspiration from the actual precipitation[83] of 8.3 in/y. The net infiltration rate of 1.6 inches per year could be an underestimate of the amount of water that actually moves downwards. Evaporation can only be subtracted from rainfall if the water does not reach the contaminants because it evaporates earlier. If it does reach the contaminants, however, it dissolves them and moves them downward by force of gravity. When the water evaporates at a later time, it leaves the contaminants in their new, deeper, location. Thus, contaminants can move downwards during every rainfall or flooding event, but never move upwards. Due to this asymmetrical transport, contaminants can gradually migrate towards the aquifer even with a low infiltration rate, as long as the water can reach them during rainfall or flooding events.

During the winter, melting of snow implies a high infiltration rate, but during the summer, evapotranspiration is predominant, and any water that has not moved downward, may rise to the surface and evaporate.

The infiltration (or recharge) rate is an important input parameter for the contaminant release model described below, and has a direct effect on the dose received by a potential receptor.

In addition, there seem to be sources of water other than precipitation that seep into the tank vaults. Of a calculated amount of 29,000 gallons that enter the vaults every year, only 41 % was due to precipitation, whereas the remaining 59 % came from other sources[84], though some of he other sources will shrink/cease as INTEC is closed.

Assumption f.): Environmental conditions remain unchanged

This assumption cannot be made for a period of 10,000 years, as seen in the international debate about processes such as global warming, desertification, more frequent occurrence of extreme weather events etc. See also assumption b.)

Assumption g.): No precipitation

Apparently, the assumption that no solid particles would form and precipitate out when the pH is raised[85] from 1 to 2 has been verified by calculations[86], even though the EIS does not reveal how or by whom. In a saturated solution of metal ions, even a minimal increase of the pH causes some precipitation, because the solubility of the dissolved material changes with the concentration of protons (H^+). By increasing the pH from 1 to 2, the proton concentration drops by 90 %. Therefore, a rise in the pH of this magnitude has to lead to some precipitation unless the solution is by no means saturated, which is unlikely given the amount of non-dissolved radionuclides, or unless there is some buffer substance dissolved in the liquid waste.

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[83] US DOE, D-EIS, 1999, p. C.9-6.
[84] US DOE 1997, p. 2-16.
[85] The pH rises because neutral water is added for the wash solution.
[86] Beck 1999a, p. 2.

If more solids precipitate, then the post-closure inventory would be greater, because all solids are estimated to remain in the tanks during cleaning operations.

Assumption h.): Four inches of waste remaining in each tank

DOE assumes a 10-inch heel that is reduced to 4 inches at the time of grouting[87], using a well-planned system to pour the grout. Such a heel corresponds to about 4,930 gallons of waste per tank. A previous analysis calculated that the remaining liquids in each tank would be only 400 gallons, plus one inch of solids[88], which would amount to 1,230 gallons of waste, or almost exactly 4 times less than assumed in the F-EIS.

Potential Receptors

The receptors that potentially could receive a dose from the radioactivity released from INEEL are the following[89]:

Maximally exposed resident: A resident farmer who lives in a dwelling constructed on the site after the period of institutional control ends (2095) and who uses the land for subsistence. This receptor would obtain all of his domestic and agricultural water supply from a well drilled into the aquifer, although he would not drill into the HLW tanks. The average exposed resident is exposed both during childhood and as an adult.

Future industrial worker: An adult who would have authorized access to the site after 2095, but who is considered to be a member of the public for compliance purposes.

Intruder: Accesses closed facilities after DOE loses institutional control. The intruder –for whatever reason- removes the overburden that separates him from the top of the HLW tanks. Since this overburden is only 10 feet thick, this is a perfectly reasonable assumption even for a resident, who might build a basement for his house. The intruder, let us call him a farmer, is assumed to be exposed during 1 day. DOE assumes that the farmer's total dose is mainly due to direct radiation coming off the unshielded tanks. Even though DOE did not state this, there is in principle no difference between the uninformed intruder and an uninformed resident. Therefore, the exposure period could be much longer than 1 day. The 1 day assumption is based on some unstated assumptions – that a person discovers the concrete vault roof, checks his deed, and then stays away. Other scenarios are possible. A farmer could become curious and dig into the vault, spending many days near the high-level waste.

Recreational user: A person who would routinely visit the affected area after 2095 and use the area for recreational activities, including camping, hiking, and hunting.

[87] US DOE, F-EIS 2002, Appendix C.9, p. C.9-15.
[88] Beck 1999a, p. 5.
[89] US DOE, F-EIS, 2002, Appendix C.9, p. C.9-9.

It is probable that sometime in the future, people will be living on the current INEEL site, and therefore we are interested in the dose to the maximally exposed resident. This receptor lives, works and grows food on the INEEL site. He might even build his house right on top of the tanks, although this assumption was not made in the EIS. This scenario may seem far-fetched at the moment, but may well appear less so 100, 200 or 500 years from now. We also consider the possibility of a resident building a basement on top of the tank farm, i.e. we combine the resident and the intruder scenarios.

All potential receptors are exposed to radionuclides through three main release pathways: groundwater, air and direct radiation. The air pathway was thought to be relevant only for the HLW-bin sets in the No Action Alternative and not for the Tank Farm. We therefore did not further examine this pathway.

Groundwater Pathway

The groundwater pathway included the consumption of contaminated groundwater, of crops irrigated with contaminated groundwater, and of products from animals that were fed with plants irrigated with contaminated groundwater. The basis for all of these sub-pathways is the release of radionuclides into the groundwater.

Due to the tremendous radioactive inventory of the wastes present at INEEL, the HLW tanks pose the greatest threat to groundwater contamination.

To estimate the dose for a potential receptor due to the release of radionuclides from the Tank Farm to groundwater, DOE applied six steps of analysis:

1. Radionuclide screening to reduce the original list of radionuclides now found in the tanks to those requiring further quantitative assessment.
2. Release model for the radionuclides that were identified in the first step. The release from the Tank Farm into the unsaturated soil (vadose zone) was modeled with the computer software MEPAS. This program calculates movement of substances that are subject to one-dimensional active transport (such as gravity), but allows for three-dimensional dispersion as a result of this one-dimensional force. Besides the starting inventory, MEPAS requires inputs such as partition coefficients (Kd's), porosity, hydraulic conductivity, water infiltration rate and dispersivity coefficients in order to calculate the amount of leaching that occurs from the tanks into the vadose zone as a function of time.
3. Migration of the released radionuclides through the vadose zone into the aquifer was modeled using the computer software TETRAD. This is a three-dimensional model that calculates the migration and dispersion of contaminants that includes the inputs used for MEPAS, but in addition also incorporates fluctuating transport velocities and water recharges from sources other than precipitation such nearby rivers.
4. Calculation of dispersion and concentration of radionuclides in the aquifer as a function of time and location, with TETRAD. Calculation of peak groundwater concentrations for each contaminant of concern.
5. Uptake assessment of radionuclides for different potential receptors through ingestion of contaminated water and plants, animals and animal products that were contaminated by irrigation with contaminated water.

6. Dose calculation for different potential receptors.

1. Radionuclide screening

For the groundwater pathway, INEEL carried out a radionuclide screening to reduce the number of radionuclides that had to be quantitatively assessed[90]:

- Radionuclides with t ½ < 10 years were eliminated.
- Radionuclides with activity of less than one-billionth (10^{-9}) of the total activity remaining in the tanks were eliminated
- Multiplication of the activity of the remaining radionuclides with their respective ground burial screening factor from NCRP Publication No. 123[91], divided by a retardation factor for transport in soil. Results ranked by cumulative score contribution, and the radionuclides contributing to 99.99 % of total score selected for further analysis. As a result of this screening, the list of radionuclides included in the groundwater analysis of the Tank Farm disposition to be assessed was:[92] Am-241, I-129, Nb-94, Np-237, Pu-238, Pu-238, Pu-240, Sn-126, Sr-90, Tc-99, U-234 and U-238.
- MEPAS release modeling: Elimination of radionuclides with releases of less than 1 % of releases assumed in DOE's 1997 RI/FS.
- TETRAD modeling: Transport through vadose zone into groundwater; elimination of radionuclides with peak groundwater concentration of "less than small fraction of drinking water standard"

As a result of this screening process, radiation doses from the groundwater pathway were only calculated for I-129 and Tc-99. All other radionuclides were eliminated from the groundwater analysis. As seen below, more radionuclides were included in the assessment of the external dose.

It has to be noted that Am-241 has been identified as one of the most important of the alpha-emitting radionuclides in terms of its potential to contaminate the Snake River Plain aquifer[93]. Its half-life is 432 years, but water travels from under INEEL to the Magic Valley in about half that time. However, Am-241 is eliminated during the screening process, due to the long time calculated before it reaches the aquifer. If DOE used different release assumptions under which Am-241 would reach the aquifer at a much earlier time, it would become a contaminant of great potential concern.

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[90] US DOE, F-EIS, 2002, Appendix C.9, p. C.9-26.
[91] NCRP, *Screening Models for Release of Radionuclides to Atmosphere, Surface Water, and Ground*, Report No. 123, Washington, DC.
[92] NUS Tetra Tech, 2001, Table 4-23.
[93] Makhijani et al, 2001, p. 10.

2. Release of radionuclides from the tanks to the vadose zone

The key parameters that influence the radionuclide release modeled by MEPAS are distribution coefficients K_d (in cm^3/g), conductivity (cm/s), infiltration rate (cm/y), porosity (%), and durability of concrete (years). Distribution coefficients are the equilibrium ratio of radioactive concentration in a solid to radionuclide concentration in liquid; if the distribution coefficient is greater, less radioactivity would be in solution. The input parameters for MEPAS were the following[94]:

- 3 zones: grout zone (30 ft), contaminated zone (4 inches), vault (2.6 ft); no credit was taken for the stainless steel tanks
- Loss of physical characteristics of grout and vault after 500 years; chemical (reducing) characteristics maintained indefinitely
- Conductivity: $5 * 10^{-6}$ cm/s in contaminated zone and $1.0 * 10^{-10}$ cm/s in grout and vault for first 500 years; $1 * 10^{-3}$ cm/s thereafter in all three zones
- K_d = 500 cm^3/g for Tc-99 and 2 cm^3/g for I-129 (applies only to contaminated zone and vault)
- Reducing characteristics in grout also applicable for contaminated zone
- Infiltration rate: 1.6 in/y
- porosity of 26 % in contaminated zone and of 15 % in grout and vault for the first 500 years, and 38 % thereafter in all three zones

The model assumes that, by and large, the radionuclides will be held in place for 500 years. The conductivity above the vadose zone (vault, grout, concrete disc below tanks) is 1 cm in 317 years, and this is the only assumed movement during the 500 years for which DOE assumes that the concrete remains unchanged.

Even if INEEL's assumption of very low conductivity during 500 years were realistic, it is questionable whether the radionuclides would remain in place. If conductivity is sufficiently low, diffusion through the pore network is the limiting factor for the movement of radionuclides[95]. WVDP considered this fact and calculated the waste flux from its HLW tanks by diffusion as opposed to the flux from other facilities that were not separated from groundwater by concrete, where a conductivity-limited flow was assumed.

If release due to diffusion had been taken into account, INEEL probably would not have been able to eliminate it analysis to two radionuclides.

3. Transport through the vadose zone into the aquifer

The flux out of the facility release calculated by MEPAS was used as the input for TETRAD, which calculates the transport through the vadose zone.

[94] NUS Tetra Tech, 2001, Section 2.
[95] US DOE 1996a, Appendix E, p. E-7 to E-13

DOE states that contaminant transport through the vadose zone was the most challenging step of the analysis. The original model involved solving a series of nonlinear mass balance equations, which requires intensive computation and extensive resources. For every facility and every radionuclide, the model needed 2 to 3 weeks to calculate the activity that would arrive at the vadose zone/aquifer interface[96].

In order to achieve linearity, DOE neglected anthropogenic sources and assumed a steady-state condition. Transport was then a tortuous function of advection, dispersion, adsorption, and decay. At low concentrations, DOE assumed the flow paths were not influenced much by dispersion. As a result, the arrival of mass and activity at the vadose zone-aquifer interface was reduced to being a function of adsorption, decay, the location of the source at the surface, and the steady state velocity[97].

While we have no reason to doubt the accuracy of the model itself, we question the applied assumptions. As mentioned above, the vaults do not currently prevent 29,000 gallons/y of water seeping into them. Also, as indicated earlier, it is very uncertain that concrete remains in perfect shape during 500 years and hence blocks water effectively from the zone beneath the tanks.

Seeping of surface water into the tanks as a result from large flood events could dramatically increase the amount of waste that is leached out of the tanks.

Changing all these assumptions will have a great impact on the steady-state velocity applied in the model, and therefore on the amount and activity of radionuclides that reach the aquifer.

4. Dispersion and concentration of radionuclides in the aquifer

TETRAD calculates the dispersion of radionuclides in all three dimensions, using site-specific information such as fluctuations in transport velocities, lithology, and other water sources that enter the aquifer, such as rivers and perched water. The output of TETRAD is a concentration estimate of all contaminants of concern, including the radionuclides I-129 and Tc-99, at different times and locations in the groundwater.

We do not question the assumptions made for this step of the analysis. We just note that with a greater input, the output from this model will also be greater. However, we don't know if this effect is linear, i.e., if by assuming ten times more radioactivity is released, the resulting concentration is ten times greater.

5. Uptake of radionuclides by potential receptors

For the groundwater pathway, potential receptors ingest radionuclides either by drinking contaminated water, or by consuming crops, animals and animal products that were produced on land irrigated with contaminated water. We focus on the assumptions for the maximally exposed

[96] Schafer 1999, p. 2.
[97] Schafer 1999, p. 2.

resident farmer, because he is the receptor for whom the calculated received dose was the highest. In the following, we present the most important uptake parameters used by DOE[98], together with a short discussion:

- Averaging time for carcinogens: 70 y.
- Exposure duration of 30 years (350 d/y) for water ingestion, 24 years (350 d/y) for incidental soil ingestion. 30 years is the average residence time of a U.S. farmer. However, we are calculating the dose to the maximally, not average, exposed resident, and it is perfectly possible that a farmer lives and works on the same land for longer than 30 years. We propose an exposure duration of 70 y, equal to the averaging time for carcinogens.
- Groundwater intake rate: 2 l/d. This is the default value used by EPA.
- Incidental soil ingestion: 100 mg/d. This value is the average indoor incidental soil intake rate as given by EPA[99]. For a farmer, EPA's incidental soil ingestion rate for outdoor yard work of 480 mg/d would be more appropriate, because a farmer in a dry region certainly ingests much more soil/dust than the average U.S. resident.
- Food consumption: 0.39 kg/d of root crops/vegetables/fruits, 0.05 kg/d of leafy vegetables, 0.097 kg/d of grains, 0.23 kg/d of meat, 0.026 kg/d of poultry, and 0.31 l/d of milk. The vegetable intake rates seem rather low in comparison to the value of 190 kg/y suggested by EPA[100].
- Soil-root uptake factor: 40 and 0.4 pCi/g plant per pCi/g soil for Tc-99 and I-129, respectively.

6. Calculation of radiation dose due to ingestion of radionuclides

From the uptake of radionuclides, the total effective radiation dose is calculated using dose conversion factors (DCF). DOE used EPA's DCF for ingestion[101] which are $1.46 * 10^{-6}$ and $2.76 * 10^{-4}$ mrem/pCi for Tc-99 and I-129, respectively. These are similar to DCF for ingestion given by the International Commission on Radiological Protection (ICRP), which are $2.37 * 10^{-6}$ and $4.07 * 10^{-4}$ mrem/pCi for Tc-99 and I-129, respectively.[102]

For the total dose, the uptake from other pathways was added to the groundwater/ingestion pathway. These other pathways included entirely different contamination routes such as direct gamma and airborne particulates coming from the Tank Farm and other facilities, but also sub-pathways for the groundwater pathway other than ingestion, such as dermal absorption and inhalation of resuspended particulates deposited by irrigation.

[98] US DOE, D-EIS 1999, p. C.9-49 to 52.
[99] US EPA, Exposure Factors Handbook Vol. I, 1997, p. 4-17.
[100] US EPA, Exposure Factors Handbook Vol. III, 1997.
[101] US EPA, Federal Guidance Report Nr. 11, 1988.
[102] ICRP 72, 1996.

Direct Radiation Pathway

For this pathway, 22 radionuclides are included, i.e. 20 more than for the groundwater pathway. These additional radionuclides include various transuranics (isotopes with a greater atomic weight than U-238 such as plutonium, neptunium and americium), as well as uranium and its decay products (such as thorium, radium and protactinium), fission products (such as technetium, iodine and barium) and indirectly formed radionuclides (such as cobalt).[103]

DOE calculates three different pathways involving direct radiation: (a) radiation from soil that was irrigated with contaminated groundwater, (b) direct gamma from closed facilities, and (c) direct gamma from facilities used for radioactive waste disposal. For the performance-based closure alternative, the doses from the HLW tanks would come from (b), whereas if Class A through C low level waste is disposed of in the tanks, the doses would come from (b) and (c).

External radiation doses from the closed Tank Farm were calculated using the geometry and post-closure inventory of waste tank WM-183, the tank with the highest residual contamination.[104] The waste was assumed to be evenly distributed throughout the tank volume.

DOE included the stainless steel tank wall as a factor in the calculation of the external radiation, in spite of the fact that for the groundwater analysis, the tanks were assumed to disintegrate rather quickly.[105] Shielding with 0.021 feet (1/4 inch) of steel will reduce the external gamma dose by about[106] 25 %.

Doses to the Receptors Calculated by DOE

DOE presented the long-term peak groundwater concentrations of I-129 and Tc-99 for each scenario, and the resulting doses per receptor and scenario.[107] Table 7 shows a summary of the results.

Although DOE's table header (Table C.9-6 in FEIS) reads "Lifetime radiation dose (millirem) for Tc-99 and I-129…", on p. C.9-30 DOE writes that external doses from other radionuclides are included in that table. It is therefore not clear which radionuclides contribute to the final dose, as the dose is not broken down into different radionuclides' contributions. Only the total dose is given. However, from the relatively high dose for the intruder who is almost exclusively exposed to external radiation, we infer that the table header must be wrong, and that other radionuclides are included in the final dose. Further support for this assumption comes from Table 6-46 in NUS Tetra Tech's Calculation Package, where doses from the groundwater pathway are given. These doses are lower than the doses presented in Table C.9-6.

In the D-EIS, relative importance of I-129 for the total radiation dose was much greater than that of Tc-99, as the former contributed about 10,000 times more to the total dose than the latter.[108]

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[103] US DOE, F-EIS 2002, Table C.9-4.
[104] NUS Tetra Tech 2001, p. 5-64.
[105] NUS Tetra Tech 2001, Table 5-15.
[106] Shleien et al, *Handbook of Health Physics and Radiological Health*, Third Edition, 1998, p. 6-41.
[107] US DOE, F-EIS, 2002, Appendix C.9 Table C.9-6.

This changed in the F-EIS, where doses due to Tc-99 are higher than those due to I-129.[109] This abrupt change between the two radionuclides of concern is rather surprising, but not explained in the F-EIS. The dose contributions in the F-EIS are more believable, since they are similar to those found in the EIS of the proposed Yucca Mountain facility, where calculated doses due to Tc-99 are also far greater than those due to I-129. It is therefore likely that the results in the D-EIS were probably wrong, and it is unfortunate (and somewhat unprofessional) that DOE did not discuss this point.

This goes to the credibility of DOE and its contractors. They should have discussed why the D-EIS was in error, and why they believed that these errors have been corrected in the F-EIS.

No Action

In the D-EIS, the lifetime dose to the resident farmer under this alternative was lower than under the Performance-based Closure and Closure to Landfill Standards alternatives. This flies in the face of commonsense, and we had difficulties finding an explanation for this. In the F-EIS, however, the doses under this alternative are greater than those in any other alternative, as can be expected due to the larger release inventories and the lack of any type of barriers. Again, DOE did not specify what led to their apparently erroneous calculations presented in the D-EIS.

Maximum lifetime doses to the resident farmer (who does not build a basement, see comments under “Performance-based Closure”), to the future industrial worker, to the recreational user and to the intruder are calculated to be 84, 4.4, 0.64 and 51,000 mrem, respectively (Table 7). The dose to the resident who builds a basement on top of the HLW tanks (for detailed assumptions, see results for Performance-based Closure) would be 10,284 mrem.

Groundwater doses to the resident farmer due to Tc-99 and I-129 are 82 and 2.1 mrem, respectively.[110]

Performance-based Closure / Closure to Landfill Standards

The long-term dose due to the disposition of the Tank Farm is the same for the Performance-based Closure and the Closure to Landfill Standards alternatives.

DOE calculated the lifetime radiation dose for the maximally exposed resident farmer due to the Tank Farm to be 4.4 mrem, much below background (Table 7). Calculated doses to the future industrial worker and the recreational user are lower with 0.36 and 0.057 mrem, respectively. However, the 1-day dose for an intruder is 19,000 mrem. This dose is far higher than calculated by the NRC in its F-EIS for a low-level waste landfill.

The dose to the resident farmer from the tank farm due to Tc-99 and I-129 is 2.8 and 1.4 mrem, respectively.[111]

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[108] US DOE D-EIS 1999, p. C.9-56.
[109] NUS Tetra Tech 2001, Table 6-46
[110] *Ibid*

The lifetime dose for this scenario calculated in the D-EIS was 13 mrem from all facilities, i.e. including the Bin Sets, the New Waste Calcining Facility, and the Process Equipment Waste Evaporator. The dose in the F-EIS from all facilities is 5.8 mrem, i.e. less than half. From reviewing the F-EIS, it is not clear what the reasons were for this decrease, especially given the fact that the post-closure inventory increased in relation to the D-EIS.

In contrast, the dose to the intruder is greatly increased in the F-EIS. The one-day dose of 19 rem is very high, and would even be more important if one assumes an exposure period longer than one day. The one-day exposure assumes that someone digs down to the tanks and upon finding them he checks the property deed, after which he realizes what he found and covers up the whole. This assumption is based on the belief that property deeds exist at all times in the future, that they include information about a facility that may have been closed for hundreds of years, and that the psychological structure of the future intruder will be such that upon finding a concrete slab down in the earth, he immediately decides to research property documents.

These assumptions will not necessarily hold true. Who knows at what point in the future someone will dig his way down to the tanks? Property deeds issued in 2095 may not be available or valid by the time of intrusion, or they may be written in a language that the property owner does not understand. If for some reason the intruder trying to build a basement for his house does not have access to the proper information or simply does not try researching it (because he thinks that a warm basement floor will help him heat the house and could therefore be quite convenient, or that an existing concrete surface will save him the effort of pouring in cement himself), then the dose will not occur over one day, but over a much longer time period.

It is obvious from these deliberations that the intruder could be the same person as the maximally exposed resident, and that their doses should not be exclusive, but added to each other. However, the underlying assumptions for the intruder receptor would have to be adjusted. DOE does not take into account shielding with the 1.5-foot concrete vault roof when calculating the dose to the intruder. If a basement is to be constructed, then it is probable that the bottom would be filled with concrete if the vault has disintegrated, or built on top of the vault roof if it still intact. Shielding would therefore have to be taken into account.

On average, gamma radiation from different radionuclides is reduced by half for every 5-cm layer of concrete[112]. External radiation from the tanks would therefore be attenuated by a factor of 2^9 or about 500. For a resident who builds his basement on top of a HLW tank, either on top of the vault roof or after constructing a concrete floor of 1.5 feet would be 500 times smaller per day than the dose to the intruder calculated by DOE. However, this resident would also spend significantly more time in the basement than 1 day, the DOE assumption. If the resident spends a total of 100 days in the basement during construction and 30 years of use, then his "basement" lifetime dose under the Performance-based Closure / Closure to Landfill Standards alternatives would be (19,000/500*100 + 4.4) 3,804 mrem (Table 7). If shielding with ¼ inch of steel, as assumed by DOE, were removed from the calculation, this dose would be even greater.

DOE concludes that intrusion barriers would have to be put in place to prevent the intruder scenario from happening.[113] They do not say how exactly this should be done.

These doses from these closure alternatives to the resident (who does not build a basement), to the future industrial workers and the recreational user are all very low and, in our opinion, a

[111] *Ibid*
[112] Shleien B. et al, Handbook of Health Physics and Radiological Health, Third Edition, Williams & Wilkins, Baltimore (MD), 1998, p. 6-15.
[113] US DOE, F-EIS 2002, p. C.9-34.

product of several underestimates and a non-conservative release model approach. This is important because one of these closure alternatives appear to be DOE's preferred alternative (although this is not clear, see below).

Clean Closure

For this alternative, only short-term doses for INEEL workers were calculated, because there are no long-term impacts by definition of the alternative (cleanup to ensure that there are no impacts).

The annual average number of workers for the Tank Farm clean closure is 280, and the annual collective worker dose is 280 person-rem. This means that on average, each worker receives 1,000 mrem/y during the tank closure process. The total collective dose for the disposition period is 7,600 person-rem or an average of 1,000 mrem/y during 27 years for 280 workers.

While we believe that there could be a significant health risks for INEEL workers under the Clean Closure Alternative, the contrast between the dose results for the Clean Closure and the Performance-based Closure seem to have the intention of proving that the contamination at INEEL should not be cleaned up. As discussed earlier, we question the dose calculated under the Performance-based Alternative and therefore also question the thesis that contamination should not be cleaned up for people's health's sake.

Preferred Alternative

One of the changes between the D-EIS and the F-EIS is that DOE and the State of Idaho have identified their preferred alternatives.

For existing facilities, Performance-based Closure was selected, whereas for new facilities, DOE and the state preferred Clean Closure.[114]

[114] US DOE, F-EIS 2002, p. 3-46.

Chapter 5: Comparison to D-EIS at the West Valley Demonstration Project (WVDP)

We compare the risk assessment for the INEEL facility closure alternatives with that carried out at WVDP[115], because this DOE facility also reprocessed spent nuclear fuel and its closure process is some years ahead of INEEL's.

WVDP's proposal to leave the residual contamination in its HLW tanks and stabilize it with grout is much like the Performance-based Closure at INEEL. But the release model that was applied by DOE at WVDP is different from that used at INEEL, and the calculated doses to the maximally exposed resident are much larger. As seen in the preceding chapter, INEEL calculated a lifetime dose from all the facilities to the maximally exposed resident farmer of 5.8 mrem, mostly due to Tc-99 (again, it must be noted that in the D-EIS, the dose was mainly due to I-129). This dose would occur in 600 - 700 years from now.

WVDP, on the other hand, calculated a maximum annual dose of $8.9 * 10^{7}$ mrem for the same receptor, from the HLW tanks only, mainly due to Cs-137 and Sr-90. The maximum yearly dose occurred in 2108, 100 years after the planned end of the implementation phase in 2008.

In this chapter, we present the situation at WVDP and the most important points of risk assessment carried out by DOE, and compare it to that done for INEEL.

HLW Tank Farm at WVDP

WVDP Tank Structure

At WVDP, about 600,000 gallons of HLW from irradiated fuel reprocessing was stored in underground tanks. After completion of current WVDP remediation plans, most of this waste should be solidified[116].

There are two large and two small HLW tanks. The two large tanks, 8D-1 and 8D-2, are identical in size and construction. They are made of carbon steel, measure 70 ft in diameter and 27 ft in height, and have a capacity of 750,000 gallons, 2.5 times more than the tanks at INEEL. Both tanks are contained in a single underground concrete vault. Tank 8D-1 was built as a duplicate spare to tank 8D-2 and was not originally used for HLW storage, but it was contaminated by condensate from tank 8D-1 and radionuclide-loaded zeolite from supernatant treatment system processing. These two large tanks contain residual contamination (a heel) that consists of a sludge phase and a supernatant. Both phases are washed plutonium uranium extraction (PUREX) waste.

The two small tanks, 8D-3 and 8D-4, measure 12 ft in diameter, 16 ft in height, and have a capacity of 15,500 gallons. They contain liquid waste from acidic thorium extraction (THOREX). Again, one tank was built as a spare duplicate for the other and not used to store HLW, but

[115] DOE 1996a, Appendix C, p. C-24
[116] DOE 1996a, Appendix C, p. C-23.

nevertheless was contaminated in the supernatant treatment system process. Both tanks also sit in a single concrete vault.

The total tank volume at WVDP is 1,527,000 gallons, less than half of the 3,300,000 gallons at INEEL.

WVDP Tank farm inventory

According to DOE, The overall residual activity for the WVDP-tanks estimated in the D-EIS[117] in 1996 is 606,000 Ci. Decayed to the year 2016 for purposes of comparison using the formula below, the residual radioactivity at WVDP is 417,000 Ci (Table 8).

$R_i(t) = R_i(0) * e^{-\lambda t}$

Where	$R_i(t)$	Activity of radionuclide i at time t
	Ri (0)	Activity of radionuclide i at time t = 0
	λ	Decay constant of radionuclide i

Newer data from WVDP[118] suggest that the residual contamination in tank 8D-2 is about 1,000,000 Ci, with 600,000 Ci contributed by Cs-137 and Sr-90. This not only raises the total residual contamination by 150 %, but it also indicates that the residual activity of radionuclides other than Cs-137 and Sr-90 is much higher than previously estimated.

Declaration of the waste as WIR

At WVDP, DOE is also in the process of declaring HLW as WIR. A weekly NRC memo[119] from August 31, 2001, states that DOE-WV has conducted a technical review of the West Valley Nuclear Services procedure for making incidental waste determinations at the site. After DOE-WV and DOE's Ohio Field Office, which oversees the West Valley operation, have accepted the procedure, they plan to submit it to the NRC with a sample evaluation for review and comment.

Without declaring the waste left in the tanks to be WIR, Alternative III (see below) would not be legal, because wastes with radionuclide concentration that exceed the standard for Class C low-level waste are not acceptable for near-surface disposal.[120] Renaming a particular radioactive waste stream has no impact on the risk assessment or the dose calculated for the public.

[117] DOE 1996a, Appendix C, P. C-24.
[118] Personal communication between MR and John Chamberlain, WVDP, Mai 30 2001
[119] NRC, Office of Nuclear Material Safety and Safeguards, weekly report, August 2001.
[120] 10 CFR Part 60.

Facility Disposition Alternatives at WVDP

In the presentation of the facility disposition alternatives proposed for WVDP, we again focus on the HLW-Tank Farm closure, rather than on the disposal of existing solidified waste.

WVDP differentiated between two major future developments. Under the Expected Conditions Scenario, DOE will keep institutional control over the premises as long as they present a danger to the public. This implies that for certain disposition alternatives, DOE would have to retain control over the site for thousands or millions of years to come. DOE could decide where future residents will be allowed to live, farm, drill, etc.

Under the Loss of Institutional Control Scenario, DOE loses institutional control 100 years after the implementation phase in 2008. This resembles the time frame assumption applied at INEEL, where institutional control would be lost in 2095. We focus on the latter scenario, because it is more probable to happen, and because of its similarity to the assumptions at INEEL.

Alternative I: Removal and Release to Allow Unrestricted Use

Under this alternative, waste and contamination would be removed from the site to the extent feasible or necessary to allow release of the area for unrestricted use[121]. All wastes and contaminated facilities are transported to an off-site disposal facility. This approach assumes that enough contamination would be removed from released areas that the dose to the maximally exposed resident farmer would be below 15 mrem/y.

This alternative is very similar to the Clean Closure Alternative at INEEL. The radiation doses calculated for this alternative are mainly doses to the workers during cleanup. Another similarity is that there is no solution as of yet where all the wastes and contaminated facilities would be sent.

Alternative II: Removal, On-Premises Waste Storage, and Partial Release to Allow Unrestricted Use

This alternative is similar to Alternative I, except all waste exhumed or generated during the implementation phase of closure would be stored on the Project Premises rather than being transported to an off-site disposal facility. After the implementation phase, individuals could establish homes and garden on all areas of the site not occupied by the retrievable storage areas. This assumes that these retrievable areas are vacated before DOE loses institutional control over them.

Again, the maximally exposed resident farmer is supposed to not receive a radiation dose greater than 15 mrem.

[121] US DOE 1996a, Appendix D, p. D-28.

Alternative III: In-Place Stabilization and On-Premises Low-Level Waste Disposal

As for the closure of the Tank Farm, this alternative is very similar to the Performance-based closure Alternative at INEEL. The tanks would be minimally decontaminated by flushing the supernatant of the tank heels, and then would be filled with a clean stabilizing grout. [122]

Over time, the residual contamination in the tank heels would be released to the groundwater and transported to onsite or off-site residents. The potential radiation dose from the HLW tanks to the maximally exposed resident farmer is calculated to be $8.9 * 10^7$ mrem/y, whereas the off-site resident receives an annual dose of 541 mrem/y.

Alternative IV: No Action: Monitoring and Maintenance

This alternative assumes that the HLW tanks are maintained in their present condition, and that DOE keeps institutional control forever (millions of years). A further assumption is that no contaminants would be released to the environment, and therefore no dose has to be calculated for the resident farmer.

We don't consider this alternative to be related to real-life expectations and hence do not discuss it any further.

Risk assessment at WVDP

Separate risk assessments were undertaken for the onsite and offsite populations. The assumptions and the release model used were the same for these two sets of receptors, but the transportation and uptake models differed. For the purpose of comparison, we concentrate on the maximally exposed resident farmer, who is an on-site resident. In comparison, the off-site dose at INEEL was calculated only due to airborne emissions, i.e. the off-site dose due to contamination of the groundwater was not assessed.[123]

Doses for on-site residents occur at the earliest at the moment when institutional control is lost, which is the year 2108.

Assumptions

[122] US DOE 1996a, Appendix D. p. D-30.
[123] US DOE F-EIS, p. C.5-74.

For Alternative III, the following assumptions were made:

- Loss of institutional control may or may not occur 100 years after the end of implementation phase (expected/unexpected conditions scenario). The time frame during which long-term effects were calculated was 10,000 years.
- Surface water pathways were included for other parts of the facility, but not for the Tank Farm.
- All residual contamination is contained in a 1-m layer of sludge at the bottom of the big tanks
- The tanks degrade in the beginning and offer no resistance to release of radionuclides, as the relatively thin steel walls are expected to disintegrate quicker than the tank vaults.
- Radionuclide release through diffusion starts at once.
- The gravel layer below the tanks is saturated with water and provides a mixing zone for radionuclides diffusing through the grout and the vault.
- Precipitation is 40 in/y.
- The maximally exposed resident farmer drills a groundwater well 50 m from the outer boundary of the HLW Tank Farm.

Even though DOE describes the loss of institutional control to be the unexpected case, it seems very likely that at some point in the future, DOE (or its successor) will in fact lose control over the site. We therefore concentrate on that scenario.

Surface water pathways were not included in the risk assessment of the Tank Farm. However, in this case, this underestimate probably has little consequence, because the tanks are assumed to be in constant direct contact with the groundwater. Whatever contamination would have been leached out of the tanks from a flooding event will also be leached out by the groundwater.

There is a significant difference between the amount of sludge presumed to be in the high level waste tanks at WVDP (1 meter) and at INEEL (4 inches or about 0.1 m). That difference arises from a key difference between the two sites' wastes. WVDP stores mainly PUREX wastes in its big tanks, in a neutral pH, INEEL's high-level waste, on the other hand, is very acidic (pH 1). Fewer solids precipitate out of acidic solutions to form sludge

Perhaps the most important difference between the two risk assessment approaches is the release assumption. INEEL assumes that the contamination in the tanks remains in place until the concrete in the tanks disintegrates after 500 years. WVDP, on the other hand, assumes that radionuclide release starts right at the beginning, due to diffusion. In addition, the groundwater at West Valley is in direct contact with the mixing layer beneath the tanks, whereas at INEEL, there is a thick vadose (or unsaturated) zone between the soil surface and the aquifer.

Precipitation is not immediately connected to the leaching of contaminants out of the HLW tanks, because this release depends only on diffusion into the groundwater and not on conductivity. (Conductivity is a measure of how well water can penetrate a medium, under the assumption that the contaminants are in the aqueous phase. In contrast, diffusion does not depend on water movement, but on contaminants traveling within a medium from a higher to a lower concentration,

i.e. along a concentration gradient). Hence, the assumed precipitation rate is not as important for the WVDP model as it is for the INEEL model.

Radionuclide screening

As a first step, DOE carried out a radionuclide screening at WVDP to reduce the risk assessment to the radionuclides that could have relevant consequences on human health[124]. The screening eliminated the following radionuclides (R_i):

- R_i with a half-life of less than 1 year
- R_i with a half-life between 1 and 3 years, if the quantities remaining at the end of solidification would be insignificant in relation to similar radionuclides.
- R_i that always appear in insignificant quantities with respect to similar radioisotopes (for example, Cs-135 activities are always several orders of magnitude less than Cs-137 activities
- R_i with total site-wide activities of less than 10 μCi
- R_i for which the doses of a preliminary modeling with RESRAD and GENII from both the air and groundwater pathway were at least four orders of magnitude lower than doses from other R_i, or for which the dose was similar or less than that of another R_i that was more abundant by two or more orders of magnitude.

After this screening process, 30 radionuclides were considered in the risk assessment, including Sr-90, Tc-99, I-129, Cs-137, Np-237, Pu-238, Pu-239, Pu-240, Pu-241, and Am-241, all of which were also part of the radionuclide inventory at INEEL. As seen below, the most important dose contribution came from Sr-90 and Cs-137, both of which were excluded in the radionuclide screening at INEEL.

Release model

The release model used for the Tank Farm at WVDP differs from that used at INEEL. DOE states that, for concrete waste forms, the hydraulic conductivity of concrete is low enough that under most circumstances the release rate of radionuclides dissolved in the pore water is determined by diffusion of the radionuclide through the pore network[125]. The proposed grouting of the HLW tanks would produce a horizontal slab encapsulating radionuclides left in the facilities. The encapsulated radionuclides could diffuse downward into the groundwater flowing below the slab.

[124] US DOE 1996a, Appendix E, p. E-1f
[125] *Ibid*, p. E-7f.

Release rates from slab-type waste forms were estimated for WVDP assuming a one-dimensional conceptual model, in which flowing groundwater maintains radionuclide concentration at one face of the slab at a low value providing a concentration gradient driving force for release of the radionuclides.

This is a somewhat different situation from that at INEEL, where the aquifer is much deeper in the ground. However, it is conceivable that water would leach out the radionuclides from beneath the INEEL tanks and therefore keep a concentration gradient in place.

Depending on the amount of residual inventory, two different situations could develop. In the first case, the amount of radionuclides may be small enough in relation to the volume of cement and pore water that the entire radionuclide inventory would dissolve and distribute between aqueous and cement-adsorbed phases. At WVDP, DOE expected this situation for the Process Building.

The second situation occurs if the amount of residual inventory is too large to fully dissolve, and a sludge phase remains encapsulated with the liquid in the concrete. This situation was assumed for the WVDP HLW tanks.

DOE combined the activity balances between the aqueous and cement-absorbed phases into a single differential balance, which was solved for the radionuclide concentration profile and related release rate. DOE simplified the differential balance by representing the radionuclide inventory and diffusional resistances as occupying separate portions of the waste volume. This type of model is termed a shrinking-core model and is easier to evaluate than the equivalent distributed parameter model[126].

$$-eA_w \frac{D}{T}\frac{C}{H-z} - eA_w z R_d LC = eA_w R_d \frac{\partial Cz}{\partial t}$$

The equation is solved for the thickness of the shrinking core:

$$z = H - \sqrt{\frac{2D}{R_d T}t}$$

The release was then calculated from the thickness of the core and the decay-dependent concentration of a radionuclide in the core. For a detailed description of the release model, we refer to the D-EIS at WVDP.

[126] *Ibid*, p. E-10

Transport, uptake and dose

For the on-site population, the exposure to radioactivity was calculated with the RESRAD code. The applicable exposure pathways include direct gamma radiation, inhalation of dust, and ingestion of contaminated food and water. For biological transport parameters, dose conversion factors, and human ingestion and inhalation parameters, default values given by RESRAD were used. All other input parameters were site-specific and used as calculated in the D-EIS.

The dose to the potential receptors was then calculated as the maximum yearly dose (the highest annual dose of all annual doses for the next 10,000 years).

Calculated Doses

The maximum annual dose that DOE calculated for the maximally exposed resident farmer under the unexpected conditions scenario (loss of institutional control) for Alternative III is 89,000 rem (Table 9).

This is a tremendous dose, actually unrealistic in its magnitude, because a person would not survive an entire year after receiving this annual dose. However, this dose is the maximum dose right after the loss of institutional control. The extremely high dose shows that even if institutional control were lost later than assumed by DOE in this scenario (and it probably will be lost at some point), the dose from the West Valley HLW Tank Farm would still be substantial. Obviously, in the case that institutional control is never lost, no dose is calculated for a resident farmer, but one cannot realistically assume that DOE will control this facility for the next few thousand years.

Chapter 6: Other DOE Sites

Savannah River Site (SRS)

DOE is also in the process of closing its HLW Tank Farm at the Savannah River Site. Even though some of the waste is different, there are several parallels, especially in the declaration of the waste as waste incidental to reprocessing.

SRS HLW Tank Farm

The Tank Farm at the Savannah River Site (SRS) has more tanks than INEEL and WVDP. Like INEEL, the waste stems from reprocessing of spent nuclear fuel for nuclear weapons production. SRS has 51 high-level tanks in two separate Tank Farms. Two of the tanks have already been closed. There are four different tank designs, with volumes between 750,000 and 1,300,000 gallons. The tanks are all made of carbon steel, in contrast to the stainless steel tanks for INEEL's acidic waste. The combined storage volume of all tanks is 58,620,000 gallons, almost 18 times more than at INEEL. In November 2000, about 34 million gallons of HLW were stored in the Tank Farms.[127]

There are three different types of waste forms at the SRS Tank Farm: sludge, salt, and liquid[128]. The sludge is solid material that has precipitated and settled to the bottom of the tanks. The salt is comprised of salt compounds that have crystallized as a result of concentrating the liquid by evaporation. The liquid is a highly concentrated solution of salt compounds in water. Although some tanks contain all three forms, many tanks are considered primarily sludge tanks, while others are considered salt tanks, containing both salt and liquid.

SRS Tank Farm closure

The D-EIS for SRS details a tank closure plan that is similar to those for INEEL and WVDP: Draining of the tanks as much as possible, followed by a limited cleaning procedure, and finally the "stabilization" of the waste with grout.

SRS's planned tank cleaning process consists of spray washing using hot water in rotary spray jets and then pumping out the resulting slurry. The amount of waste left after spray washing is estimated at 3,500 – 4,000 gallons, depending on the tank size. This is comparable to the estimated residual volume of 4,930 gallons per tank at INEEL.

[127] US DOE 2000, p. S-1.
[128] *Ibid*, p. S-2.

DOE also considers repeating the washing process with oxalic acid[129]. Tests have indicated that this would be about twice as effective as spray washing with just water. However, it is much more expensive, at $1,050,000 per tank. In addition, there is also a possibility that a technical constraint on the practicality of oxalic acid cleaning, as there is the possibility that a nuclear criticality could occur during this process.

The potential doses calculated in the SRS risk assessment are lower than the results at INEEL. The lifetime dose for the maximally exposed resident farmer is calculated to be 1.9 mrem (Table 10). However, the yearly dose due to groundwater ingestion from a well that is drilled right next to the Tank Farm (1 m) is 100,000 mrem/y, and from a well at 100 m, the annual dose is 300 mrem/y. Apparently, the drilling of a groundwater well on or near the premises is not included in the exposure of the maximally exposed resident farmer. It is important to add that some of the tanks at SRP are in the water table.

SRS Classification of remaining wastes to Waste Incidental to Reprocessing

DOE also intends to declare the waste remaining in the SRS tanks as WIR, using the evaluation process described in DOE Order 435.1. DOE asked the NRC to review the evaluation process. Three staff members of the NRC carried out a study and published a paper[130], in which they concluded that the proposed tank closure process fulfilled criteria b.1.) and b.3.) of the evaluation process described by DOE order 435.1 and that it therefore could be considered low-level waste.

The authors declared criterion b.1.), “removal of key nuclides to the extent technically and economically practical”, to be fulfilled if DOE-SRS cleaned the tanks with spray water and in addition cleaned some especially contaminated tanks with oxalic acid. The second cleaning step was not seen as practical for all the tanks, because this technology is cost-intensive. The NRC clearly approved of SRS’s proposed cleaning process on economic rather than technical grounds.

Criterion b.3.) of the evaluation process demands that management of the wastes meet performance objectives similar to those provided in 10 CFR 61, i.e., the annual dose to the public must not exceed 25 mrem. Based on the risk assessment carried out by DOE-SRS, the NRC staff concluded this criterion was fulfilled—despite the annual radiation doses of up to 100,000 mrem from wells drilled near the Tank Farm.

The NRC interprets criterion b.2.) somewhat differently from the DOE. In the NRC’s interpretation, this criterion requires that the waste not exceed concentration limits set for Class C waste. However, the authors state that it is permissible to include the stabilizing material, in this case the grout, into the waste volume, which naturally decreases its radionuclide concentration. Apparently, this “concentration averaging” is not questioned, but endorsed by the NRC. In addition, the authors encourage diluting the waste concentration further by including the dirt above it, which would be excavated together with the waste in any future use scenario (since the waste could not be excavated without excavating the overburden as well). NRC assumes the addition of this dirt further dilutes the radionuclide concentration of the waste by a factor of 10.

[129] *Ibid*, p. S-10.
[130] Davis 2001.

Another method to make the waste in the tanks meet Class C definitions proposed by NRC is to change the total allowable α-emitting TRU concentration limits to those for specific radionuclides. With individual α-emitters less than 100 nCi/g, the waste would no longer be considered transuranic waste, and would fit within the low-level waste category and would fit within the class C category.

The inclusion of the dirt dilution factor and the nuclide-specific values for α-emitting TRU are called “alternative standards”, which is in compliance with DOE order 435.1. That is, DOE is allowed, according to their rules, to rewrite their regulations whenever and however they wish.

This whole maneuver reveals DOE and NRC working together in a desperate attempt to justify the declaration of highly radioactive waste as WIR (subtype low-level waste) so it can be disposed of more cheaply.

Hanford

HLW Tanks

Hanford has 177 underground HLW tanks--even more than SRS. Chemical reprocessing of spent fuel generated approximately $4 * 10^{8}$ gallons of nuclear waste[131]. Throughout Hanford’s production period, more than $3 * 10^{8}$ gallons of waste was sent to underground storage tanks. DOE applied volume-reduction practices in order to maintain waste volumes within available tank space. Hanford has both single-shell tanks (SSTs) and double-shell tanks (DSTs). Through evaporation, concentration, and the discharge of dilute waste directly on the ground, the waste volume has been reduced to approximately $5.6 * 10^{7}$ gallons. Discharging SST liquid to the ground was stopped in 1966.

The first 149 waste storage tanks constructed were carbon steel SSTs. An SST is an underground storage tank with a carbon steel pan under the tank and surrounded by a reinforced concrete shell. The tanks are buried so that their tops are approximately 8 feet below ground for radiation shielding. Sixty-seven of the SSTs are known or assumed to have leaked 600,000 to 900,000 gallons of liquids.

The last 28 tanks constructed were DSTs, which have two carbon-steel tanks inside a reinforced concrete shell. This design provides improved leak detection and containment of the waste. To the present time, no leaks have been detected in the annulus, the space between the inner and outer tanks. The space between the tanks houses equipment to detect and recover waste in the event that the inner tank does develop a leak. Like the SSTs, the DSTs are buried below ground and have risers for tank monitoring and access.

The tanks are arranged in several Tank Farms consisting of 2 to 18 tanks each. Also included in the Tank Farm system are approximately 40 inactive and 20 active miscellaneous underground storage tanks (MUSTs). The inactive MUSTs, which are smaller than the SSTs and DSTs, had a variety of purposes and were used for settling solids out of liquid waste before decanting the liquid to cribs (that is, seepage beds for direct disposal of waste into the ground), reducing the

[131] US DOE 1996b.

acidity of process waste, uranium recovery operations, collecting waste transfer leakage, and waste handling and experimentation. The active MUSTs still are used as receiver tanks during waste transfer activities or as catch tanks to collect potential spills and leaks. The volume of waste in all the MUSTs combined is less than one-half of 1 percent of the total tank inventory.

Tank waste description

Hanford's high level waste is categorized as liquid, sludge, or salt cake and is more similar to the waste at SRS than to INEEL's acidic waste. Liquid is present in the tanks as either free standing, where the liquid volume is relatively free of solid particles, or as interstitial liquid, where the liquid volume is contained within the void spaces surrounding the sludge and salt cake particles. Sludge is a mixture of insoluble (i.e., will not dissolve in tank liquid) metal salt compounds that have precipitated and settled out of solution after the waste was made alkaline. Salt cake is primarily sodium and aluminum salt that crystallizes out of solution following evaporation.

These three types of waste exist in the tanks in numerous combinations and proportions, which results in complex combinations of waste with varied physical and chemical properties. Sludge has been found with consistencies from mud to hardened clay. Layers of organic compounds have been found in some tanks floating on top of solid waste. Solid crusts on top of the liquid have formed in some tanks.

DOE intends to either extract as much as possible and grout the remaining heels in the tanks (ex-situ)[132], or grout the wastes directly, without prior extraction (in-situ)[133]. The former alternative resembles those proposed for INEEL, WVDP and SRS, whereas the latter leaves much more waste in the tanks. Of course, it is also true that the vitrification plant must also be decontaminated and dismantled.

Regarding the labeling of the waste in the tanks, the situation at the Hanford site is similar to INEEL, WVDP and SRS. In a response to public comments[134] on DOE Order 435.1, DOE cites the Hanford Final Environmental Impact Statement, which included two specific assumptions:

Residual waste remaining in the tanks after removal of as much of the waste as practicable would be considered WIR and would be disposed of in-place as low-level waste; and

Low-activity wastes remaining after processing the high-level waste tank waste to remove as much of the high-level radioactivity as practicable should be considered WIR.

[132] US DOE 1996b, 3.4.6
[133] US DOE 1996b, 3.4.4
[134] US DOE, Office of Environmental Management, www.em.dow.gov/em30/pubsum16.html, cited on 10/4/01

Chapter 7: Cleanup Alternatives

There are two underlying problems for the tank closure alternatives discussed at INEEL and the other sites. For one, there are technological difficulties in retrieving the tank heels from the tanks. On the other hand, even when cleaning technologies for certain tasks are available, a waste removal “as good as technically practicable” might be rejected for economic considerations, because DOE wants to spend as little money as possible for the closure process.

Technological Difficulties

The waste cannot be totally retrieved from the tanks due to their design. Tank jets are not installed at the very bottom of the tanks, but a little higher. As proposed by INEEL, this could be addressed with new, adjustable jet pumps. Other draining obstacles are the cooling coils, precipitation of solids, and the formation of sludge (in non-acidic wastes).

The tanks are much too radioactive to send workers in to clean up the heels, even if they took shifts. This is an argument for not cleaning the tanks, because nobody wants to sacrifice human health or even lives in a cleanup process. At the same time, it is a strong argument for not leaving such contamination for future generations. Some of the radionuclides have half-lives of thousands and even millions of years, which is far beyond any human planning horizon. DOE’s assumption that institutional control will never be lost at WVDP is patently unrealistic.

Chemical agents could help clean the tanks. At SRS, flushing with oxalic acid proved to be twice as effective as cleaning with water. However, there is a possibility of a nuclear criticality using this technique, and it is very costly.

Another problem is the solubility of the remaining waste. As seen at Hanford, some of the waste is as hard as dry clay and is stuck to the bottom, the walls or the cooling pipes inside the tanks. This material cannot be flushed or washed out with water. Possibly, chemical agents could address this matter, but again, nuclear criticality and the containment strength of the tanks have to be considered.

More flushing/cleaning cycles could further reduce the amount of waste left in the tanks. Because of the design of the tanks, there will always remain some contamination in the tanks, no matter how many cycles are applied, even though the radionuclide concentration would decrease with each cycle.

DOE also considered mechanical approaches to stir up, mix and retrieve solid wastes. In any case, the limiting factor for any physical or chemical method applied to retrieve the tank heels is the structure of the tanks. Most of the DOE HLW tanks are single-shelled, and a rupture of the shell during the cleaning process due to too much physical impact or a too strong chemical agent could result in substantial environmental contamination.

Another very important problem is that of waste production. Every gallon of flush water, every chemical agent and any other equipment that is used for the tank cleaning is turned into nuclear waste. Storage space for all these new wastes produced in the cleaning process does not exist at this point. It is a problem inherent in radioactive waste management: by cleaning contamination, new contamination is produced, because the radionuclides will not just disappear. Radionuclides

only lose their danger when they decay. Heat of chemical processes can only displace the nuclides to another waste form, but they can neither accelerate nor slow the nuclides' decay rate. Even with all possible technological progress, we will never be able to really clean radioactive waste; all we can do is retrieve, stabilize, store and monitor the waste at places that are better suited than others, like a geologic repository. However, a completely safe storage place does not exist.

Technological Options

To retrieve the waste from decades of reprocessing, all technical options presently available will have to be included in the decision process, and future technical innovations should be considered wherever possible. Much of the cleaning can be carried out with conventional methods, as described above. For the remaining waste, new technologies have to be developed and applied.

One technological field that could fill in the gap is that of robotics. Robots have been used to inspect the interior of the tanks at Hanford and INEEL[135]. The proposed cleaning process for INEEL includes remotely operated cleaning devices, such as the wash ball and the directional nozzle. It is conceivable that remotely controlled machines could clean up the contaminated tank bottoms, if not completely, then at least to the point where the tanks can be cut up and transported away. The challenge lies in developing cleaning mechanisms to remove waste from between the cooling coils, where the steam jets cannot reach. Perhaps such a jet could be mounted on a crawler that moves across the tank floor and stirs and sucks up all the waste, and maybe also cleans the then exposed tank bottom.

Even if this is a difficult task, it is certainly well within our technical possibilities. Robots for all different kind of tasks have been developed, sometimes of greater complexity than cleaning a metal structure. Cleaning the tanks with robots might also create less new waste than repeated flushing cycles or chemical cleaning.

In its technical review of the planned Tank Farm closure at INEEL, the Tanks Focus Area recommends repeated sampling and evaluation of the wastes remaining after flushing and cleaning. If the wastes are more difficult to remove than anticipated by DOE, other, more aggressive methods already tested at other sites are available. Such additional cleanup devices include the Hanford Tank C-106 sluicer, borehole-miner extendible nozzle, waste-retrieval end effector, and Flygt mixers[136]. For a detailed description of these devices, we refer to the cited document. Basically, they are all designed to stir up and remove hard-to-remove radioactive waste, and they have been tested at other DOE sites.

In order to use cleanup technologies that do not yet exist, the waste would have to remain accessible, which would not be the case if it were grouted. Therefore, the Performance-based Closure / Closure to Landfill Standards alternatives would effectively prevent a future cleanup of the present contamination.

The decision not to remove as much high-level waste as is possible does not seem to depend on technological feasibility, but on political will and cost effectiveness. Well-planned cleanup systems should be applicable at several DOE sites and therefore should be well worth the investment.

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[135] US DOE, Stereo Viewing System, Tanks Focus Area, May 2000.
[136] Bamberger et al, 2001, p. 2.2.

Chapter 8. Discussion

DOE seems to have decided to close INEEL's HLW tanks as soon as possible and at the lowest cost achievable. The object is clearly not to identify the best way to clean up the contamination, but to prove that backfilling the tanks with concrete poses no threat to anybody.

As described in the previous chapters, we question the assumptions used for the risk assessment. We are not sure that the tanks, filled with concrete and abandoned after 100 years, will remain in perfect shape for 500 years.

Water has been known to infiltrate the tank vaults, and infiltration may increase in the future when the membrane is more and more perforated, which could leach the contaminants much faster than projected with an annual infiltration rate of 1.6 inches. Since the capacity of the diversion dam is well below the upper limit of a 100-year flood, let alone that of a 1000-year flood, flooding of INTEC would have to be included as a possibility. This could dramatically increase the amount of water that infiltrates the waste, and large amounts of water could also "flush" contaminants through the vadose zone into the groundwater. Further, perched water bodies directly underneath the Tank Farm could accelerate the transport of radionuclides through the vadose zone down to the aquifer.

This possibly faster transport to the aquifer would not only increase the amount of contamination that can be taken up by a receptor, but would increase the number of contaminants of potential concern. As seen in the risk assessment at WVDP, with a higher release rate the importance of the contaminants shifts from long-lived radionuclides, such as I-129 and Tc-99, to shorter-lived ones, such as SR-90, Cs-137 and Am-241.

In addition to the limited cleanup process of flushing, spray-washing, and grouting, existing robotic technologies could be applied, and others developed, if needed. Economic rather than technical considerations may be impeding development and use of such cleanup robots. But INEEL, SRS, Hanford and WVDP, have a total of 241 HLW tanks. The danger these pose justifies the development of special cleaning equipment. In fact, an efficient, safe cleanup technology would generally be useful in dealing with many nuclear waste problems, including the use and closure of temporary storage sites and the cleaning of transportation casks.

We also question the declaration of the wastes as waste incidental to reprocessing (WIR). Whereas HLW has to be disposed of at a safe geologic storage facility, WIR would be abandoned on-site. The declaration process for WIR by evaluation and the risk assessment undertaken by DOE are linked; that is, the EIS most coincidentally shows that relabeling waste as WIR is less costly, and the health effects are magically reduced by this redefinition.

At INEEL, the re-labeling process started with the declaration of the HLW remaining in the tanks as SBW. SBW is considered transuranic waste and therefore by definition not HLW. HLW is the only waste that by law has to be disposed of in a geologic repository. Even though DOE-INEEL agrees that the tanks used to contain HLW, and that the tank heels cannot be retrieved, they conclude that, as of now, all of the waste is SBW. It is highly questionable if the dilution of HLW heels with (concentrated) SBW really leads to SBW, or actually to more HLW. If, as DOE states, all of the wastes now are SBW, we could simply dilute all HLW with some other wastes and solve the planet-wide HLW problem. We would not even need a geologic repository. However, it is NRC practice and common sense that HLW may not be diluted on-site but must be removed.

In order to declare HLW to be WIR using the evaluation process from DOE Order 435.1, DOE has to prove that 1.) key radionuclides are removed as much as technologically and economically practicable, 2.) the radioactivity of the waste does not exceed low-level waste Class C or alternative standards, and 3.) the maximum annual dose to the public is below 25 mrem/y.

The phrase "as much as economically practicable" can be interpreted in many ways. At INEEL and SRS, it seems to have been understood as "to the extent that any alternative or additional cleanup process would be much more expensive". We are doubtful that the first term in criterion 1 (as much as technologically achievable) is fulfilled. It depends on how seriously DOE takes the recommendations of sampling and evaluating the residual tank waste, and whether it is willing to carry out additional cleaning operations if needed. Flushing and spraying the tanks with water and filling them with grout is certainly not the best DOE could do to remove key radionuclides, but it seems to be the most that DOE is willing to do.

The risk assessment is set to prove the fulfillment of criterion 3.). As discussed above, we doubt the outcome of this assessment in the light of the much higher doses calculated for other sites. Criterion 2.) is reached with the "dilution method" described as follows:

The NRC[137] proposes that the volume of the waste, the grout and the covering soil are combined together for the calculation of the waste concentration per m^3, even though the waste is not expected to mix with either concrete or the soil above the tanks. This brings the nuclide concentration within standards for low-level waste class C. With this method, we could simply "dilute" all existing HLW with enough surrounding solid material -be it concrete, dirt, or even other waste- until either standards for low-level waste C, or alternative standards as constructed by DOE are met, and then declare it to be WIR. Criterion 2.) therefore depends on the "rules" —and who sets them—about how to calculate a radionuclide concentration in waste.

Conclusion

While the definition of HLW has been quite clear for at least 30 years, the NRC and DOE understanding has changed as the price of waste disposal has risen. The radioactivity present in HLW is greater than that that in low-level waste, and therefore, it is not suitable for near-surface disposal, but has to be stored in a safe place. At INEEL, there is a certain amount of HLW left in the tanks, and DOE wants to leave it in place. For an intruder, this would lead to a far greater radiation dose than calculated for a low-level landfill. In order not to violate the law, DOE intents to change the name of the waste from HLW to WIR, and in order to do so, it had to prove that the three criteria of the evaluation process are fulfilled. Even if just one of the criteria is not met, the HLW cannot be declared WIR, and the grouting of the tanks would be illegal. Indeed, the WIR designation itself is illegal for disposal purposes.

In our view, none of the three criteria are fulfilled for INEEL HLW in tanks. 1.) The waste could be cleaned up further than proposed by INEEL; 2.) the remaining radioactivity exceeds that of low-level waste C; and 3.) the potential risk to the population is far higher than calculated in the EIS.

As a result, to leave the waste in the tanks and carry out the Performance-based Closure would be irresponsible and could lead to a contamination of the Snake River Plain Aquifer, from which an large population draws its potable water.

[137] Davis 2001.

We propose that the tanks be sampled, analyzed after the proposed cleaning operations, and the results of the analysis used for the deployment of further cleaning processes, until the tank is clean enough to be removed and safely stored above-ground. This would amount to a mixture of the Clean Closure and Performance-based Closure Alternatives, with the low worker doses from the latter, and the eliminated long-term doses from the former. In order to apply future cleanup technologies, the tanks will have to be maintained and monitored until such technology becomes available.

Tables

Table 1. Reported volumes and activities (decayed to 2016) of waste at INTEC. Volume numbers are from 1998.

Waste	Volume (gal)	Radioactivity (Ci)
Calcine inventory in 1998 (a)	1.10E+06	1.83E+07
Total HLW ever produced (b)	8.30E+06	
Tank inventory in 1998 (c)	1.42E+06	3.21E+05
SBW ever produced (lower bound) (c)	1.40E+06	
SBW ever produced (upper bound) (c)	3.60E+06	

a: D-EIS 1999
b: ERDA 1977
c: LMITCO 1998

Table 2. Historical (measured) tank heel volumes, tank heel estimates from LMITCO[138], and content of each tank at INEEL.

Tank	Time of Construction	Historical heel (gallons)	Heel estimate[a] (gallons)	Cooling coils	Contained HLW	Now filled with SBW
WM-180	1951-52	9,500	10,000	X	X	X
WM-181	1951-52	7,500	10,000			X
WM-182	1955-57	3,600	5,000	X	X	
WM-183	1955-57	never emptied	5,000	X	X	X
WM-184	1955-57	never emptied	5,000			X
WM-185	1955-57	4,600	5,000	X	X	X
WM-186	1955-57	never emptied	5,000		X	X
WM-187	1958-64	13,700	12,000	X	X	
WM-188	1958-64	13,700	12,000	X	X	
WM-189	1958-64	5,000	5,000	X	X	
WM-190	1958-64	never filled	5,000	X		
Total			79,000	8 of 11	8 of 11	6 of 11

a: Beck 1999a

[138] Beck 1999a.

Table 3. Tank volume and radioactivity in 1998 (decayed to 2016) for each 300,000-gal tank.

Tank	Waste volume[a] (gal)	Conc.[a] (Ci/gal)	Dec. to 2016 (Ci/gal)	Total activity (Ci)	Act.decayed to 2016 (Ci)
WM-180	2.80E+05	1.95E-01	1.28E-01	5.45E+04	3.60E+04
WM-181	2.80E+05	2.18E-01	1.44E-01	6.10E+04	4.02E+04
WM-182	1.00E+04	4.23E+00	2.79E+00	4.23E+04	2.79E+04
WM-183	2.00E+04	1.52E+00	1.01E+00	3.05E+04	2.01E+04
WM-184	2.60E+05	1.35E-01	8.93E-02	3.52E+04	2.32E+04
WM-185	1.20E+05	7.71E-01	5.09E-01	9.25E+04	6.10E+04
WM-186	2.80E+05	2.37E-01	1.57E-01	6.65E+04	4.39E+04
WM-187	5.00E+04	2.80E-01	1.85E-01	1.40E+04	9.23E+03
WM-188	1.20E+04	2.49E+00	1.64E+00	2.98E+04	1.97E+04
WM-189	1.00E+05	6.09E-01	4.02E-01	6.09E+04	4.02E+04
WM-190	5.00E+03	4.01E-02	2.64E-02	2.00E+02	1.32E+02
Total	1.42E+06	3.44E-01	2.27E-01	4.87E+05	3.21E+05

a: LMITCO 1998

Table 4. Amount and concentration of the most important residual contaminants in HLW-tank heels before and after closure, compared to radionuclide concentration in SBW.

Radionuclide (decayed to 2016)	Post closure[a] (Ci)	Post closure[b] (Ci/gal)	Model-SBW[c] (Ci/gal)	1998 waste[d] (Ci/gal)	Post cl. DEIS[e] Ci
Sr-90	6.20E+05	1.14E+01	1.78E-01	2.96E+00	9.26E+04
Tc-99	7.62E+02	1.41E-02	4.54E-05	not given	2.31E+01
I-129	4.02E-01	7.41E-06	3.79E-05	1.70E-04	1.22E-01
Cs-137	2.81E+05	5.18E+00	1.74E-01	4.05E+00	9.29E+04
Np-237	5.10E-01	9.41E-06	1.36E-05	1.21E-04	6.74E+00
Pu-238	1.14E+03	2.10E-02	1.59E-03	4.75E-02	7.90E+02
Pu-239	7.57E+01	1.40E-03	2.54E-04	4.19E-03	1.29E+02
Pu-240	7.92E+01	1.46E-03	4.92E-05	6.08E-04	2.44E+01
Pu-241	1.99E+03	3.67E-02	1.70E-04	1.22E-02	3.18E+02
Am-241	3.59E+01	6.62E-04	2.50E-04	2.13E-02	1.20E+02
Total	9.05E+05	1.67E+01	3.55E-01	2.27E-01	1.87E+05

a: NUS Tetra Tech 2001
b: Residual volume of 4,929 gallons per tank (4-inch-layer in 25-ft-radius tank)
c: Wenzel 1997
d: LMITCO 1998
e: Beck 1999a

Table 5. Radioactivity due to the most important radionuclides in HLW-Tank Farm decayed to 2016, under the No Action Alternative[139].

Radionuclide	Total D-EIS[a] (Ci)	Total F-EIS[b] (Ci)
Sr-90	2.39E+05	7.68E+05
Tc-99	6.04E+01	8.48E+02
I-129	3.41E-01	7.27E-01
Cs-137	2.37E+05	4.67E+05
Np-237	1.79E+01	1.27E+01
Pu-238	2.09E+03	4.34E+03
Pu-239	3.35E+02	8.75E+02
Pu-240	6.45E+01	1.34E+02
Pu-241	8.44E+02	3.17E+03
Am-241	3.89E-01	8.03E+02
Total	4.79E+05	1.25E+06

a: Beck 1999a
b: NUS Tetra Tech 2001, Table 4-1

[139] Beck 1999c.

Table 6. Radionuclide concentrations in post-closure Tank Farm inventory in relation to LLW class C limits as given by NRC. Limit of 100 nCi/g is for sum of α-emitting TRU.

Radionuclide	Total (Ci)	Concentration[a] (nCi/g)	Limit 1[b] (Ci/m^3)	Limit 1[b] (nCi/g)	Limit 2[c] (Ci/m^3)
Sr-90	6.20E+05	2.36E+06			7.00E+03
Tc-99	7.62E+02	2.90E+03	3.00E+00		
I-129	4.02E-01	1.53E+00	8.00E-02		
Cs-137	2.81E+05	1.07E+06			4.60E+03
Np-237	5.10E-01	1.94E+00			
Pu-238	1.14E+03	4.35E+03			
Pu-239	7.57E+01	2.89E+02			
Pu-240	7.92E+01	3.02E+02			
Pu-241	1.99E+03	7.59E+03		3.50E+03	
Am-241	3.59E+01	1.37E+02			
Total a-TRU	1.33E+03	5.07E+03		1.00E+02	

a: Volume of 4,929 gallons with density of 1.28
b: 10 CFR Part 61.55, Table 1: long-lived radionuclides
c: 10 CFR Part 61.55, Table 2: short-lived radionuclides

Table 7. Dose (in mrem) calculated by DOE for the maximally exposed resident farmer for the performance-based closure alternative[140]

Receptor	No Action		Perf.-based Closure/ Closure to Landfill St.		Perf.-based Closure with Grout A disposal		Perf.-based Closure with Grout C disposal	
	Tank Farm	All facilities[a]	Tank Farm	All fac.[a]	Tank Farm	All fac.[a]	Tank Farm	All fac.[a]
Resident farmer	84	574	4.4	5.8	5.0	7.2	4.6	6.7
Industrial worker	4.4	29.4	0.4	0.4	0.4	0.6	0.4	0.5
Recreational user	0.6	4.3	0.1	0.1	0.1	0.1	0.1	0.1
Intruder	51,000	51,000	19,000	19,000	20,000	20,000	25,000	25,000
Resident with basement[b]	10,284	10,774	3,804	3,806	4,005	4,007	5,005	5,007

a: Other facilities include Bin Sets, New Waste Calcining Facility and Process Equipment Evaporator

b: Assumption: Resident spends total of 100 days in basement during construction and subsequent use of basement for 30 years; shielded by 45 cm of concrete (dose reduced by factor of 500)

[140] F-EIS 2002, Table C.9-6.

Table 8. Total residual activity in Tank Farms WVDP[141] compared to INEEL

Radionuclide	Half-life y	All tanks INEEL Ci (in 2016)	All tanks WVDP Ci (in 2000)	All tanks WVDP Ci (in 2016)
Sr-90	2.91E+01	6.20E+05	2.01E+05	1.38E+05
Tc-99	2.13E+05	7.62E+02	5.03E+01	5.03E+01
I-129	1.57E+07	4.02E-01	1.00E-02	1.00E-02
Cs-137	3.00E+01	2.81E+05	4.01E+05	2.77E+05
Np-237	2.14E+06	5.10E-01	7.04E-01	7.04E-01
Pu-238	8.78E+01	1.14E+03	2.81E+02	2.48E+02
Pu-239	2.41E+04	7.57E+01	7.03E+01	7.03E+01
Pu-240	6.57E+03	7.92E+01	4.00E+01	4.00E+01
Pu-241	1.44E+01	1.99E+03	8.10E+02	3.75E+02
Am-241	4.32E+02	3.59E+01	2.01E+03	1.96E+03
Total		9.05E+05	6.06E+05	4.17E+05

[141] DOE 1996a, Appendix C, p. C-24.

Table 9. WVDP Maximum annual dose under the unexpected conditions scenario (loss of institutional control in 2108), from the HLW Tank Farm under Alternative III.

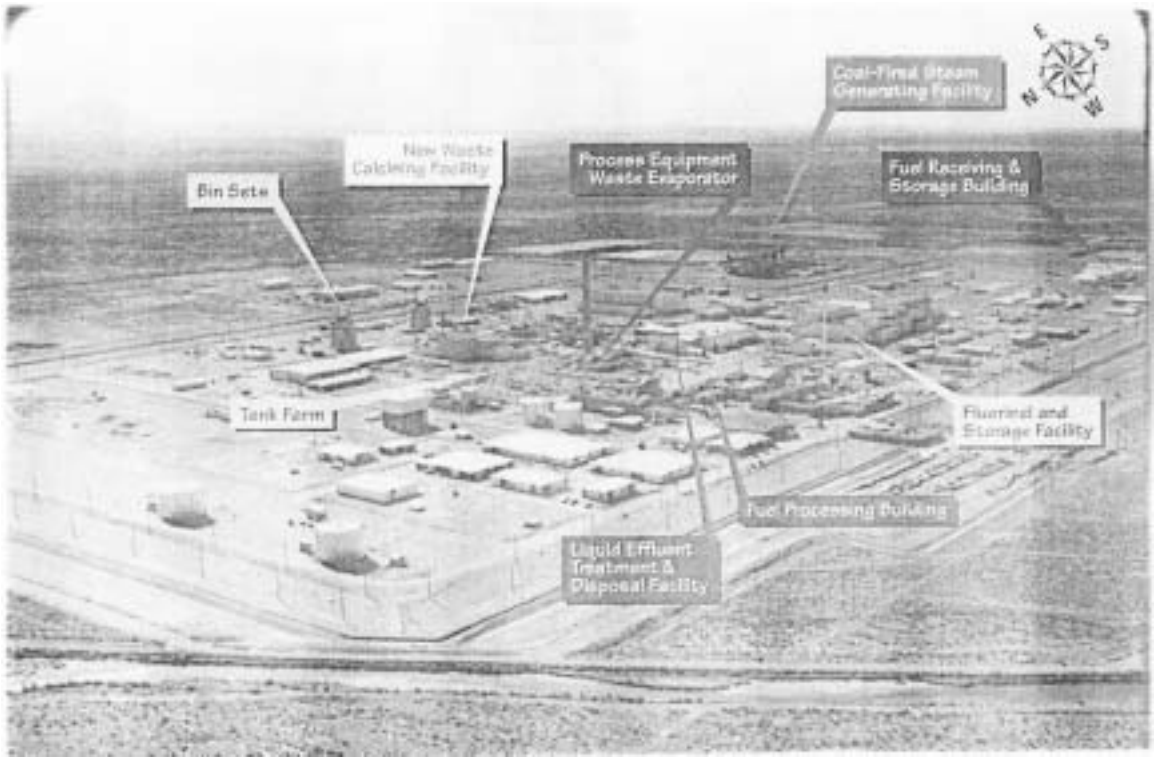
Receptor	Unit	Year of occurrence	Dose
Resident farmer	mrem/y	2108	8.90E+07
Off-site resident	mrem/y	2181	5.41E+02
Off-site population	person-rem/y	2181	4.31E+01

Table 10. Dose calculated by DOE for the public from the two HLW Tank Farms at SRS, under the Clean and Fill with Grout Option.

Source	Receptor	Type of dose	Unit	Dose
F-area Tank Farm total	Adult resident	max. lifetime dose	mrem	1.90E+00
F-area Tank Farm, groundwater well at 1 m	water consumer	max. annual dose	mrem/y	1.30E+02
F-area Tank Farm, groundwater well at 100 m	water consumer	max. annual dose	mrem/y	5.10E+01
H-area Tank Farm total	Adult resident	max. lifetime dose	mrem	7.00E-01
H-area Tank Farm, groundwater well at 1 m	water consumer	max. annual dose	mrem/y	1.00E+05
H-area Tank Farm, groundwater well at 100 m	water consumer	max. annual dose	mrem/y	3.00E+02

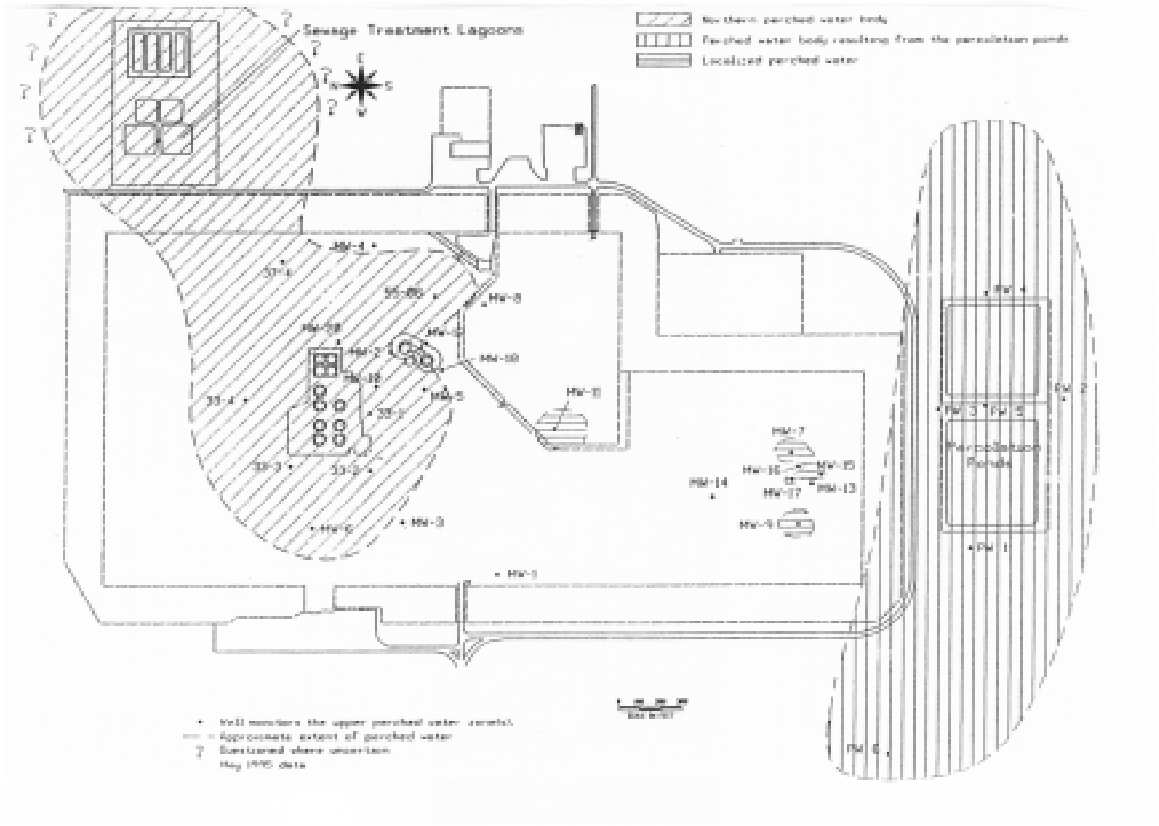
Figures

Figure 1. View of INTEC with the most important facilities. Picture from D-EIS[142].



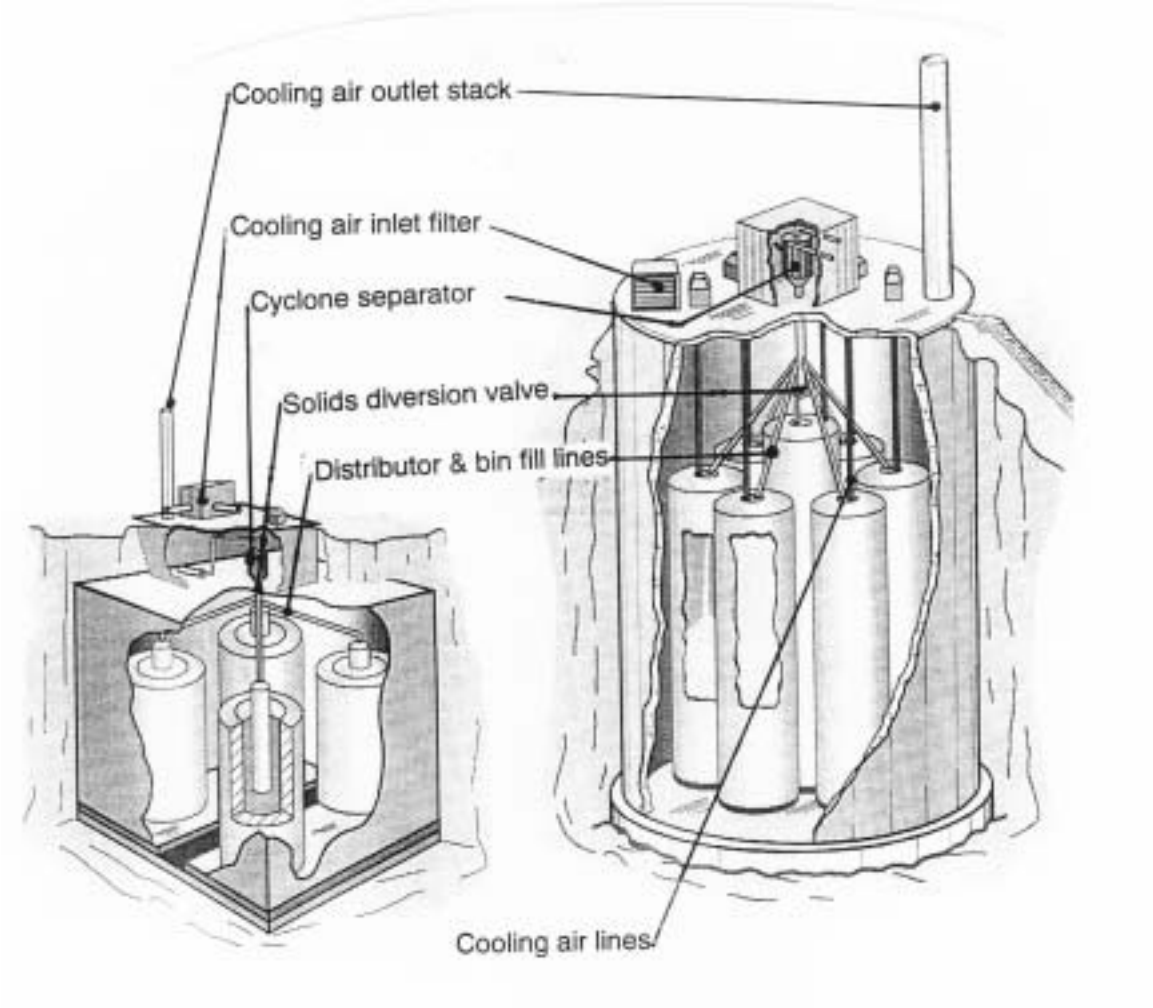
[142] US DOE, D-EIS 1999, p. 1-8.

Figure 2. Approximate extent from the upper basalt perched water bodies at INTEC[143].



[143] DOE 1997, Figure 2-19, p. 2-65.

Figure 3. Two different types of bin sets (set # 1 and # 2-3, respectively) used to store calcined HLW at INEEL. [144]



[144] Source: D-EIS 1999, p. 1-14.

Figure 4. Tank WM-180, one of 11 tanks at the INEEL Tank Farm, with cooling coils on bottom and along walls.

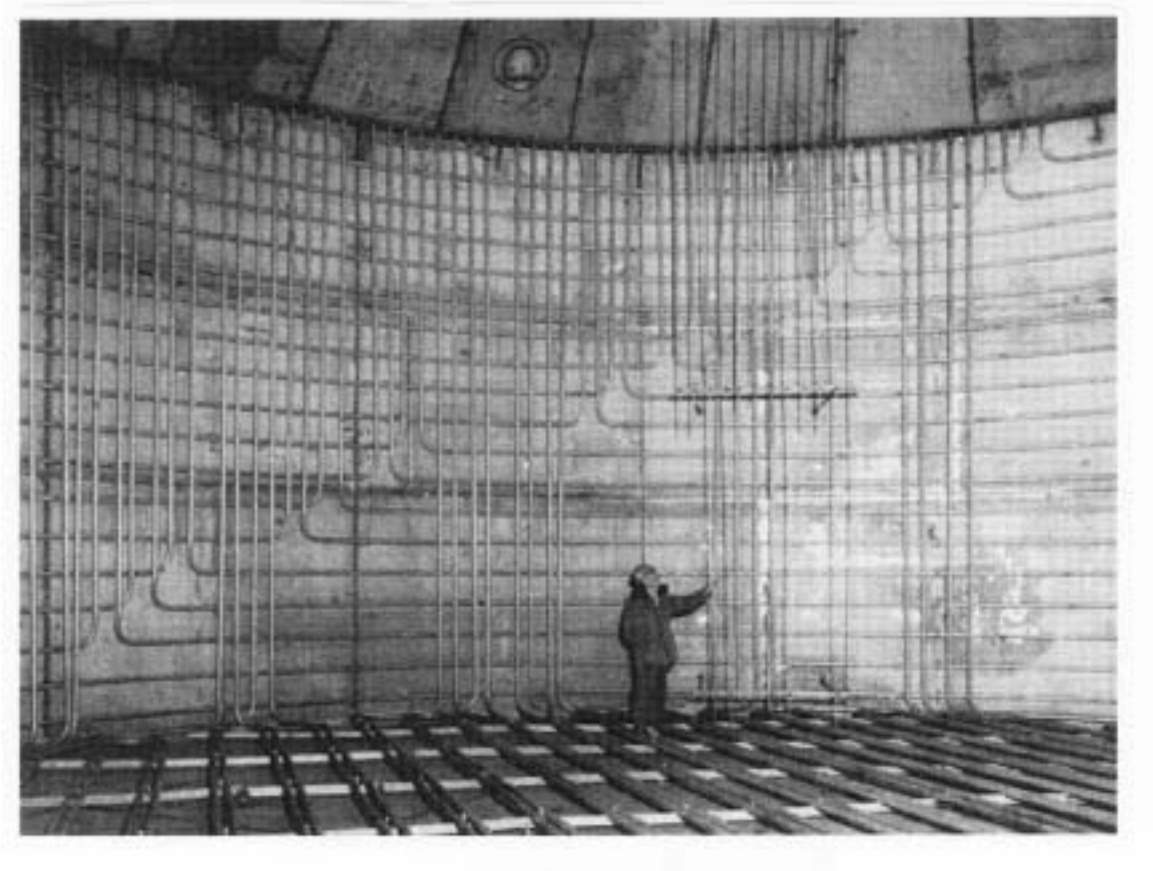
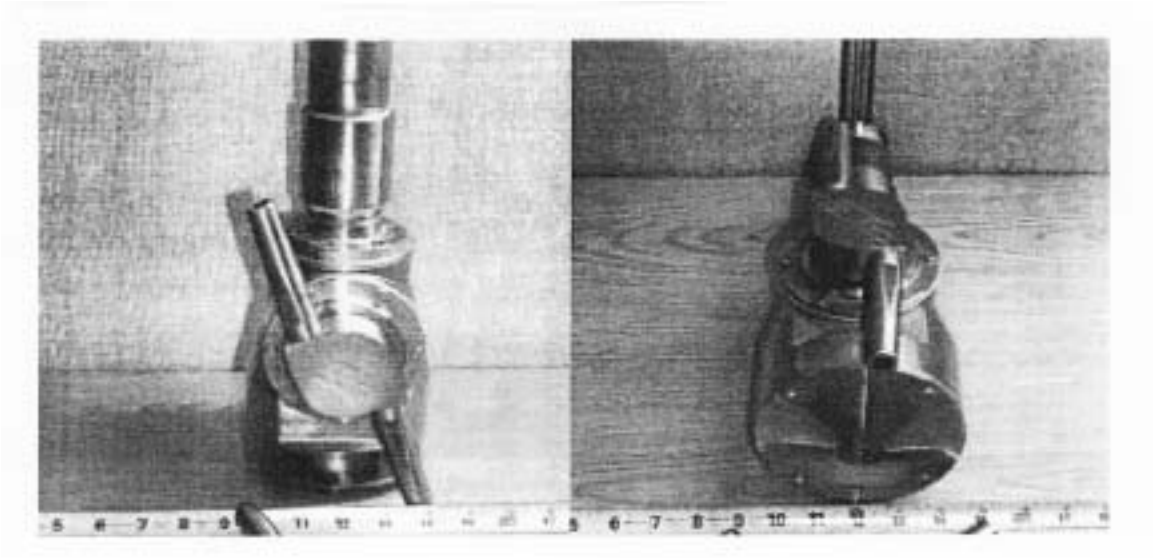
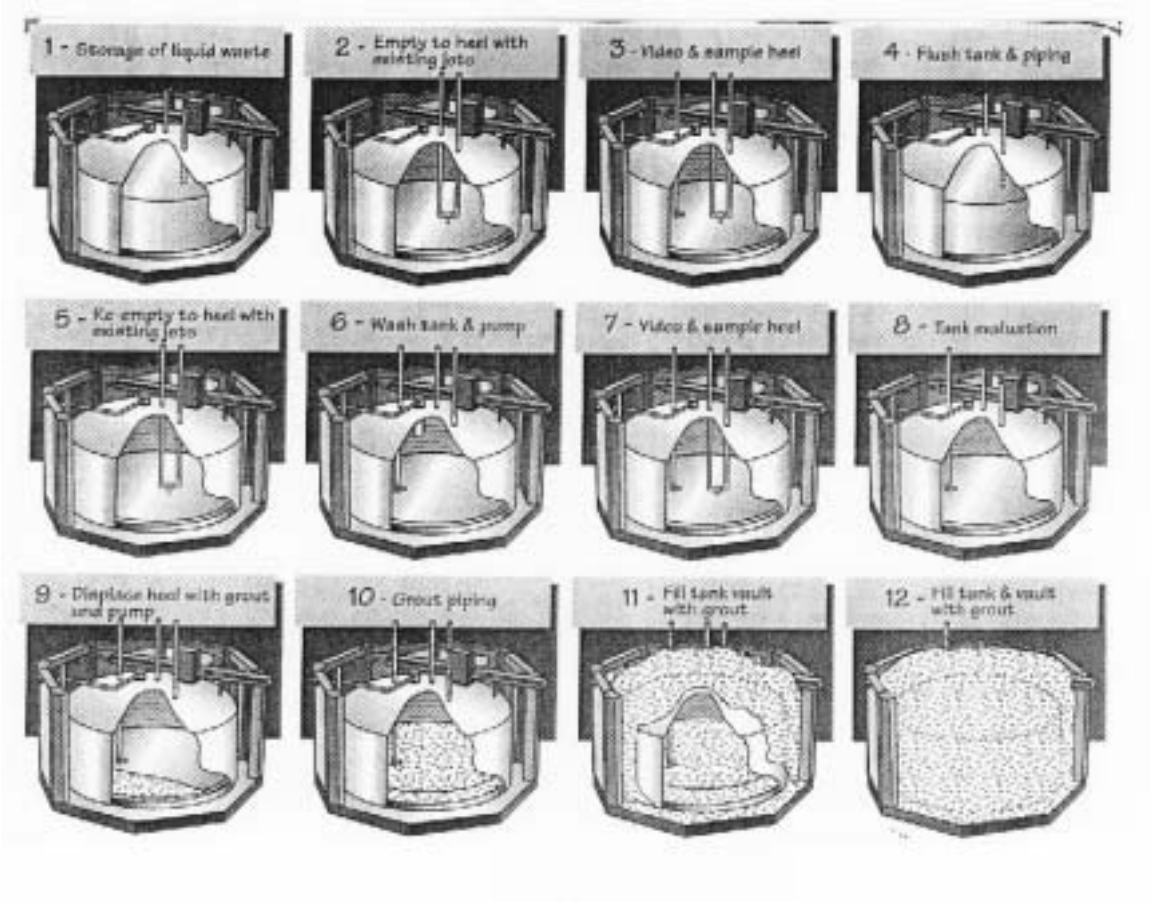


Figure 5. Wash ball used for internal tank cleaning[145]



[145] Bamberger et al, 2001

Figure 6. DOE-diagram that shows the proposed tank closure for the Performance-based Closure Alternative[146].



[146] US DOE, D-EIS 1999, p. 1-19.

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