RETHINKING THE HANFORD TANK WASTE PROGRAM

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ABSTRACT

The program to treat and dispose of the highly radioactive wastes stored in underground tanks at the U.S. Department of Energy's Hanford site has been studied. A strategy/management approach to achieve an acceptable (technically sound) end state for these wastes has been developed in this study. This approach is based on assessment of the actual risks and costs to the public, workers, and the environment associated with the wastes and storage tanks. Close attention should be given to the technical merits of available waste treatment and stabilization methodologies, and application of realistic risk reduction goals and methodologies to establish appropriate tank farm cleanup milestones. Increased research and development to reduce the mass of non-radioactive materials in the tanks requiring sophisticated treatment is highly desirable. The actual cleanup activities and milestones, while maintaining acceptable safety standards, could be more focused on a risk-to-benefit cost effectiveness, as agreed to by the involved stakeholders and in accordance with existing regulatory requirements. If existing safety standards can be maintained at significant cost savings under alternative plans but with a change in the Tri-Party Agreement (a regulatory requirement), those plans should be carried out. The proposed strategy would also take advantage of the lessons learned from the activities and efforts in the first phase of the two-phased cleanup of the Hanford waste tank farms.

Compared with current planning in the Hanford tank waste program, which encompasses the construction of vitrification facilities for low-activity as well as for high-level wastes, it may be possible to significantly reduce the costs and cleanup schedule by adopting an alternative strategy/management approach. Some changes in DOE's strategy for this program are already being made, such as the initiation of optimization studies with focus on the first phase of the program, and issuance of a fairly comprehensive Integrated Technology Plan with focus on the second phase ("balance of mission"). Suggestions are offered herein for additional options that are promising and could be considered.

INTRODUCTION

The Hanford Site in Washington remains one of the foremost challenges to the U.S. Department of Energy's program to remediate and restore land areas that were previously dedicated to nuclear defense activities. Residuals from such activities could pose significant radiological risks to man and the environment. Defense work at Hanford began in the early 1940s with construction of plutonium production reactors and continued for over four decades. This paper addresses some of the radioactive waste and environmental problems associated with this program and presents technical and management options that might usefully be applied.

BACKGROUND

The chemical processes used to dissolve the irradiated fuel elements and to recover the plutonium evolved from the initial bismuth phosphate process, to the Redox process, and finally to the Purex process, which remains the worldwide standard for plutonium recovery from spent reactor fuel. In all of these processes, the irradiated fuel elements are dissolved in an aqueous solution of boiling nitric acid. The resultant highly radioactive wastes were then stored underground (ca. 10 feet below the surface), in large (~1 million gallon) reinforced concrete tanks lined with steel on the bottoms and on the sidewalls. Ordinary carbon steel was used because of the scarceness and cost of stainless steel in that wartime period. Because of their highly acidic nature, the wastes were neutralized before being stored in the tanks. One hundred forty nine single shell tanks (SSTs) with design lifetimes of 20 years were constructed between 1943 and 1964. All of these SSTs have now exceeded their design lifetimes, and at least 67 of them have leaked. The easily extractable water from these tanks has been pumped out to preclude further leakage into the environment.

Between 1968 and 1986, twenty-eight double shell tanks (DSTs) were constructed. The DSTs consist of a freestanding steel interior tank surrounded by a carbon steel-lined reinforced concrete tank. The DSTs have design lifetimes of 40 years. To date, no confirmed leakers have been identified.

Continued reprocessing produced wastes that had to be sent to the tanks in order to make room for the new wastes. Additives (e.g., ferrocyanides) were added to the existing wastes in the tanks to precipitate much of the radioactive materials and the supernatant was decanted into other tanks until the resulting liquid was safe to discharge to the soil. Eventually, heterogeneous mixtures of highly concentrated wastes and additives (sludge), crystalline mixtures of salts (saltcake), liquid mixtures of the solubilized and crystalline particles of the wastes, and a crust of the agglomerated floating particles that have adhered to each other, all of which can serve to trap the gases generated by chemical processes and radiolysis, were accumulated in the tanks. Furthermore, the radiolytically generated heat promoted the evaporation of the liquid and aqueous portions of the wastes.

Recent publications provide a good description of technical problems related to remediation of the tank wastes (1, 2). There are about 220,000 m^3 of highly heterogeneous High-Level Wastes (HLW) with complex and unknown chemistry and sometimes non-compatible chemical properties stored in the tanks. An estimated 100 million curies and 75 million curies are located in the SSTs and DSTs, respectively, and over 1 million curies are in the surrounding soils and vadose and saturated zones. It should also be recognized that continuing chemical reactions and radiolysis are constantly changing the chemical and physical composition of the wastes.

Responsibility for the cleanup and disposition of the Hanford tank wastes, including construction and operation of the vitrification facility, is now assigned to the Department of Energy's (DOE) Office of River Protection (ORP) (3).

Currently, the cleanup plans, as formalized in the Tri-Party Agreement (TPA, reference 4), call for remediation of the tanks to be performed in two phases. In the first phase, the contents that represent 25% of the risk to human health and 10% of the tank waste volume shall be immobilized by the year 2018 in compliance with the State of Washington's risk level of 10^{-5}. In the second phase, immobilization of 41% of the waste volume representing 54% of the risk to humans will be accomplished by the year 2028. The date for the mandated retrieval of 99% of the tank waste volume has not yet been established. The difficulties of this cleanup task and this time table are exemplified by considering that the first attempts to vitrify the highly radioactive wastes in the Hanford tanks began in the 1950s and the present plans call for immobilization to begin within 10 years using, as yet, unproven systems.

Since at least as early as 1966, there have been numerous reviews of the conditions at the Hanford site, most of which have focused on a single aspect of the problem. Only a few of the investigations have addressed the problem holistically. The same has been true for the on-site operations, with separate contractors responsible for different missions that address individual parts of the problem. This fragmented problem-solving approach has resulted in sub-optimal problem resolution with no equalization of risks or costs of risk reduction. The only holistic reviews readily available in the open literature (5-10) are those of the National Research Council (NRC) published by the National Academy Press and earlier publications by the National Academy of Sciences (NAS).

A recent NAS/NRC study has concluded that current plans to treat and dispose of HLW are fraught with technical uncertainties, and many of the planned treatment activities are a first-of-a-kind effort presenting enormous technical challenges (8). While the study recommended a wide variety of research, there is no comprehensive plan as yet that addresses how all of this might be integrated. The current interest in DOE with roadmaps for planning how to achieve a satisfactory cleanup has recently been extended to the tank program through the ORP's integrated technology planning.

The DOE has taken a more systematic look in the past decade at the Hanford tanks in the context of other wastes on the Hanford Site. Perhaps the first holistic look at even one segment of the problem was a 1991 report by K.D. Boomer *et al.* (11). The second series of studies by K.D. Boomer *et al.* (12) was published in 1993. Subsequently, a report on the Tank Waste Remediation System (TWRS, reference 13) was published in 1994, followed by a Final Environmental Impact Statement (FEIS, reference 14) for the Hanford Tank Waste Remediation System in 1996. The FEIS examined eight alternatives representing four categories of waste removal levels from the storage tanks: None, Minimal (liquid waste only), Partial (only tanks having highest potential long-term groundwater impacts), and Extensive (99 volume-% of all of the wastes).

Recently, Bechtel National Inc. (BNI), a prime contractor for the ORP, has proposed a number of optimization studies to "… improve life-cycle performance (such as, improved radiochemical separations), facility design (such as, improved space utilization), and technologies (such as, second generation treatment and immobilization technologies that are ready for demonstration and application), and affect the Contract requirements." as required in their prime contract for designing, building and commissioning the Waste Treatment Plant (WTP) in a "cost-effective manner."(15) The current list of optimization studies, as initiated by BNI or CH2Hill Hanford Group (also a prime contractor for the ORP), is as follows:

a) ILAW (Immobilized Low-Activity Waste) Product Specification Recommendations
b) Impacts of De-listing ILAW
c) LDR (Land Disposal Restrictions) Compliance Strategies for Melter Disposal
d) LDR Compliance Strategies for Solid Waste Disposal
e) Alternative Melter Technologies for Future Replacement and Facility Upgrades
f) Alternative Laboratory Configuration Analysis
g) Impacts on WTP from Incorporation of Ignitability and Reactivity Standards
h) Thin-Walled IHLW Canister Design
i) Relaxation of Maximum Solids Content Requirements for LAW Feed

The initiation of these tradeoff or optimization studies is a positive development that should lead to steady improvements in reduction of risks and costs, along with improved efficiencies for the Hanford tank waste program.

Another very positive development has occurred with issuance of a fairly comprehensive Integrated Techology Plan (ITP) that outlines the Science and Technology (S&T) advances needed to ensure successful completion of the ORP mission (16). A roadmapping process is also being used to complement the existing S&T planning process. Roadmapping provides a useful framework for integrating near-term S&T issues with life-cycle technical challenges that have no readily available solutions or whose existing solutions are unduly expensive or pose unacceptable risks.

The ITP addresses the five major technical functions of the Hanford tank waste program: store the wastes; retrieve the wastes; treat the wastes; dispose of the products; and close the tanks and other facilities. The principal focus of the ITP is the second phase of the program, referred to as the "balance of mission," for which there is still flexibility in choice of options and strategic planning. Thus, authors are encouraged that the ORP is aware of many of the technical and programmatic needs that must be satisfied for successful completion of the mission.

The identification and assessment of potentially advantageous technologies and treatment options must be regularly conducted throughout the Hanford tank waste program. For example, we are aware of at least two technologies that have the potential for very substantial savings to the program: temperature change induced precipitation and removal of nitrite and nitrate non-radioactive compounds, and sulfate removal by Burkeite evaporative crystallization (17), but both processes require further development.

STRATEGY

Since September 11th, we tend to look at risks in a different light. In addition, prior to the terrorist attacks on that date, the economy was already receding and that process has accelerated since then. Consequently, it is important to review what risks are now tolerable and, in a recessionary economy, how best to spend the far fewer available funds. Safety is a social choice and our society has been profoundly affected by events of the last several months, and so, it is vital to re-examine our highest expenditures and to decide whether to make changes in the way these funds are spent.

It should be noted that the Hanford tank waste program is a first-of-a-kind undertaking. Because of its earlier development of reprocessing technologies, a more exotic mix of wastes must be dealt with at the Hanford Site than at Savannah River and Idaho. Furthermore, because of a long history of unsuccessful attempts to bring it to closure, it is now clear that a different, more flexible approach is necessary to resolve the waste management issues. In particular, DOE must exert stronger leadership in its management and integration role to ensure that the work of the different contractors is closely coordinated to successfully complete this extremely complex program.

Although such a flexible approach may initially seem more expensive, the costs avoided by not conducting a never-ending search for the "best solution" for the variety of stored wastes will result in a cheaper problem resolution. It would certainly be more acceptable to the public, because it acknowledges the uncertainties and unknowns, and to the scientific community because it takes the standard scientific approach to handle this gigantic research problem. To learn as we proceed and to modify our approach to accommodate reality rather than forcibly attempt to reach an idealistic but unattainable goal is the reasonable method to solve a complex problem.

RETRIEVAL AND TREATMENT OF HANFORD'S TANK WASTES

A number of technologies are currently available, and enhanced or needed new methods are under development for removing (prior to processing) the contents of Hanford's waste tanks (e.g., development of crawler technology as an option for removal of solids near the bottom of the waste tanks), as described in References 1, 2, 18, 19, and 20. It is anticipated that the acquisition of additional knowledge and experience concerning retrieval of wastes from the tanks will reveal technology gaps that should be addressed in the future. It also needs to be shown that the emphasis on complete removal of wastes from the tanks is still justified and if not, what is a reasonable amount.

Targeting specific tank(s) for full-scale demonstration of waste transfer and disposal techniques, such as 3-dimensional characterization, wall cleaning, grouting, etc., is essential. These demonstrations should be implemented on specific waste tanks judiciously selected to achieve desired waste end-states. Waste treatment demonstrations should consider 100% waste removal from the tank or partial removal and in-place immobilization of the waste balance. These demonstrations could increase confidence that the tank contents could be safely eliminated from consideration for further treatment. Otherwise, available stabilization technologies must be proven effective to allow these wastes to remain in the tanks and be safely stored on site. These decisions should be made in a holistic manner. In addition, the risks due to waste remaining in the storage tanks, together with the risks imposed by waste that has leaked from the tanks or buried nearby should be factored in the overall risk assessments and decision-making process.

In its entirety, the tank waste treatment plan consists of tank waste retrieval and final cleaning/stabilization of the tanks; transfer of waste materials to the waste pre-treatment facility; application of a multitude of methodologies for materials transport, treatment, separation and stabilization/immobilization/storage; and the transfer of radioactive wastes to the vitrification facility for further treatment and disposition. A variety of pre-treatment technologies may be applied, for example, to tailor the waste feed to the vitrification plant for optimization purposes (e.g., to increase waste loading) and to decrease solubility by reduction-oxidation (redox) adjustments such that improved glass/waste product properties are obtained. Thus, the quantities, characteristics, and final disposition of the end products of the Hanford Waste Treatment Plant (WTP) will be determined by optimization-based operations.

Design, construction, and initial operation of the vitrification plant are complex and massive undertakings, requiring the careful coordination of many parties, e.g. the prime and sub-contractors and their workers. Clearly, the Hanford tank waste program must make real progress in timely remediation of the Hanford Site. This path forward must be expeditious and smooth, even though it may necessarily be based on incomplete or uncertain information (e.g., a lack of precise and comprehensive data about the contents of Hanford waste tanks; the unknown efficiencies and compatibility of the projected technologies and methodologies; and an incomplete determination of final waste streams from the pre-treatment facility). To accomplish this, the plant and all of its component parts must be designed to accommodate the uncertainties indicated above. The components must be capable of handling what would in other cases be "off specification" materials. The plant must have the capability to characterize the waste stream from the tanks. The treatment system must be flexible enough to handle the waste streams coming from the tanks, and the glass composition must be amenable to adjustment to handle the waste streams from the treatment system. There must be sufficient space in the building that additional pieces of equipment, if needed, can be accommodated.

During the years remaining until the vitrification plant becomes operational and begins to process radioactive waste streams, a significant amount of research and development is strongly recommended. As noted above, the ITP can serve to link strategies, as well as technologies and treatment options, between the first phase and the remaining "balance of mission." Particular emphasis should be placed on producing waste streams that can be safely accommodated by the final treatment processes and meeting the necessary regulatory criteria, while keeping the costs within reasonable bounds.

Though the final end states will be affected by the experience in the first and second phases, an initial end state must be selected for design and initial operational purposes. Present plans indicate that the final waste streams going to the WTP may consist of at least three (3) separate forms:

1) high-level waste (HLW) that will be vitrified into glass logs destined for disposal in a geological repository,

2) intermediate and low-level waste (LLW) that will be vitrified or otherwise immobilized for disposal as radioactive waste, and

3) very low activity waste (LAW), non-radioactive, and potentially hazardous waste that will be otherwise disposed of.

The pre-treatment facility can serve to process initial tank waste streams using classical chemical and physical processes (e.g., phase separation based on solubility considerations; etc.). A significant amount of practical experience with the various separation and treatment technologies applied on various scales has accrued in the industrial (e.g., chemical processing) world (e.g., redox adjustment; precipitation and phase separation; etc.). This experience should be transferable to the Hanford tank waste program.

Where shown to be viable (through an accelerated research and development program) and desirable (e.g., from optimization studies), the separation of radioactive constituents from large quantities of non-radioactive solids, including inorganic salts, should be achievable using industrial scale technologies such as evaporation, hydrocloning/centrifuging, precipitation, crystallization, and settling.

New approaches that may have particular application to the Hanford tank wastes should be thoroughly researched (e.g., evaporative crystallization), as well as the achievement of enhanced yields through innovative techniques (e.g. solubility controls based on phase equilibria). It is important that the vitrification facility be designed with considerable flexibility (e.g., to accommodate potential changes in design – that is, use of alternative melters) in order to accommodate changes in actual waste streams resulting from the pre-treatment processes that are selected after testing and optimization trials. A significant savings in the overall remedial costs would result from significantly reducing the quantity of material requiring vitrification and other relatively costly immobilization technologies.

Thus, it is envisioned that the pre-treatment facility will serve an important function - to separate and produce consistent waste streams that are be vitrified or otherwise treated to produce final waste forms. This may result in a lower volume of radioactive wastes while producing relatively large volumes of non-radioactive wastes or

LAW for which much less costly disposal options exist. Over the entire Hanford waste tank remediationprogram, this could result in significant cost savings, as well as a reduction in the schedule.

RECOMMENDED PATH FORWARD

The authors recommend that the DOE incorporate or continue to implement the following strategies in its planning:

DOE needs to reduce the cost and length of time of the tank remediation program. The program is currently scheduled to run for more than 40 years and is estimated to cost more than 40 billion dollars. An accelerated research and development program to remove the non-radioactive bulk chemicals (e.g., sodium salts – nitrates, sulfates, and iron compounds) from the feed to the vitrification plant should be initiated. This would significantly reduce the cost and the time to vitrify the remaining wastes.

DOE needs to ensure that operational flexibility is maintained. This is already occurring with the Bechtel National, Inc. (BNI) approach that deploys a more flexible architecture for the change out of technologies (i.e., use of a canyon design as has been proven in chemical separations such as Purex) than was the case in the previous design by British Nuclear Fuels Ltd. (BNFL). The architecture must provide space and infrastructure for a variety of processes to treat the heterogeneous waste streams.

The department needs to maintain flexibility with respect to the final end state. While defining an end state is necessary to design and operate the process, the lessons learned in operations and the new processes produced by a vigorous research and development program, as well as the cultural changes that will occur over time, mandate that the end state can be changed for the proper reasons. Stakeholders must be involved at every stage of the process.

To accomplish all of this, the DOE needs to institute modern administrative practices. With the severance of the BNFL contract and the end of the privatization concept for the Hanford tank waste project, DOE finds itself in the unexpected position of serving as the general manager and integrator for the project. This is a role that DOE normally relegates to a contractor. However, most governmental agencies usually reserve this role to themselves and DOE should learn from the more successful departments how they accomplish this. For private sector businesses to achieve their objectives, they must be leaders in the science and technology of the business sector they are engaged in, forward thinking, agile, and results oriented. The ORP must adopt this approach.

Other management initiatives, such as (a) promotion of system-wide optimization studies and (b) the application of advanced relative risk assessment methodologies to improve operational safety and to reduce radiological/environmental and programmatic risks, should continue to be encouraged. Also, ongoing re-assessment of the ITP and aggressive research and development should remain important activities in this program.

Recent events at ORP involving management and contractual changes leading to greater emphasis on holistic solutions to reduce risks, costs and time to complete the program are encouraging. It appears that new momentum is underway to ultimately solve these problems, and a continued nurturing of this approach is hoped for.

REFERENCES

1. R.E. Gephart and R.E. Lundgren "Hanford Tank Cleanup: A Guide to Understanding the Technical Issues," Battelle Press, 1998.

2. DOE/EM-0564 "Tanks Focus Area Annual Report FY2000," U.S. Department of Energy, November 2000.

3. Public Law 105-261, Section 3139, "Hanford Waste Tank Cleanup Program Reforms," U.S. Congress, October 15, 1998.

4. Hanford Federal Facility Agreement and Consent Order, "Tri-Party Agreement of the Washington State Department of Ecology, U.S. Department of Energy, and U.S. Environmental Protection Agency, and the Washington State Department of Ecology," 89-10 Rev. 5, as amended through December 31, 1998.

5. NAS/NRC Report "Radioactive Wastes at the Hanford Reservation - A Technical Review," National Research Council, National Academy Press, 1978.

6. NAS/NRC Report "Rethinking High-Level Radioactive Waste Disposal," National Research Council, National Academy Press, 1990.

7. NAS/NRC Report "The Hanford Tanks - Environmental Impacts and Policy Choices," National Research Council, National Academy Press, 1996.

8. NAS/NRC Report "Systems Analysis and Systems Engineering in Environmental Remediation Programs at the Department of Energy Hanford Site," National Research Council, National Academy Press, 1998.

9. NAS/NRC Report "An End State Methodology for Identifying Technology Needs for Environmental Management, with an Example from the Hanford Site Waste Tanks", National Research Council, National Academy Press, 1999.

10. NAS/NRC Report "Research Needs for the High-Level Waste Stored in Tanks and Bins at U.S. Department of Energy Sites-Environmental Management Science Program," National Research Council, National Academy Press, 2001.

11. WHC-EP-0405-1, Draft, K. D. Boomer *et al.*, "Systems Engineering Study for the Closure of Single-Shell Tanks," Westinghouse Hanford Company, June 1991.

12. WHC-EP-0616, Rev. 0, K. D. Boomer *et al.*, "Tank Waste Technical Options Report," Westinghouse Hanford Company, March 1993.

13. DOE/RL-92-61, Rev. 1, "Tank Waste Remediation System Integrated Technology Plan," U.S. Department of Energy, 1994.

14. DOE/EIS-0189, "Tank Waste Remediation System, Hanford Site, Richland Washington, Final Environmental Impact Statement," U.S. Department of Energy and Washington State Department of Ecology, August 1996.

15. Alderman, C., M. Crippen, C. Cejka, R. Webb, "Waste Treatment Optimization Studies Plan" BNI, PL-W375-EG00011, Rev C, 2 April 2001

16. DOE-ORP-2001-17, Rev. 0, P.A. Guaglitz *et al*., "Preliminary Integrated Technology Plan for the River Protection Project," U.S. Department of Energy, August 15, 2001.

17. Provisional U.S. Patent, Don Geniesse, "Sulfate Removal in Hanford Aqueous Waste by Burkeite Evaporative Crystallization," 2001.

18. RPP-7188, Rev. 0, "Decision Document for Single-Shell Tank 241-C-104 Preferred Waste Retrieval Technology," April 2001.

19. SAND99-3015, "Decision Analysis for the Selection of Tank Waste Retrieval Technology," March 2000.

20. DOE/RL-89-16, "Single-Shell Tank Closure Work Plan," Jacobs Engineering Group, Inc., Draft Report, March 2001.