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Lessons Learned In Technology Development for Supplemental Treatment of Low-Activity Waste at Hanford

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ABSTRACT

Hanford needs supplemental technology treatment of low-activity waste (LAW) in addition to the Waste Treatment Plant (WTP). The Washington State Department of Ecology requires that supplemental technology provide the same protection to human health and the environment as WTP LAW glass. In 2002, the U.S. Department of Energy (USDOE) evaluated supplemental treatment technologies for LAW treatment and looked more closely at three: bulk vitrification (BV), steam reforming, and tailored cementitious stabilization. USDOE with Ecology's support chose to design and test BV because it believed BV would offer rapid deployment, low cost, and waste stream versatility.

This paper will describe the path taken in choosing and developing technologies for additional LAW treatment capacity and, more importantly, the lessons learned along the way.

INTRODUCTION

Production of plutonium at Hanford since World War II has left a legacy of 200 million liters (53 million gallons) of nuclear waste. These wastes consist of liquids, saltcake and sludge and are stored in 177 underground tanks. Since these wastes are high-level nuclear waste, they require treatment and disposal in a geologic repository. But the Nuclear Regulatory Commission has allowed that a portion of this mixed waste may be disposed of by shallow land burial after treatment removes major radionuclides [1].

At the WTP, the Pretreatment Facility will process the retrieved tank waste to yield LAW and high-level waste (HLW) streams. The WTP is designed to vitrify the entire HLW stream (excluding water about 10% of the tank waste mass) but only about one-third to one-half of the LAW stream. USDOE needs supplemental treatment capacity for up to two-thirds of the LAW.

The experience gained during the past five years of BV testing can prove valuable. I distill the essence here in the form of lessons learned. I address you not as one who is technically savvy or ripe with wisdom about Hanford, but as a fellow student eager to learn a little more each day. The following sections discuss the method used for developing and testing BV and the issues that arose.

BACKGROUND

USDOE has periodically compared a number of technologies to treat Hanford's LAW since the initial pretreatment module evaluation in the early 1990's. Over the years it has funded various groups of researchers to demonstrate treatment technologies for waste simulant formulations. Testing with simulants rather than actual tank waste saves money.

Sixty-seven of Hanford's single-walled underground tanks are known or assumed to have leaked more than a million gallons of high-level waste. Several groups of tanks have contaminated the groundwater with levels many times the federal drinking water standards. If USDOE does not retrieve and immobilize wastes from the older single-walled tanks, more tanks will leak and more waste will enter the environment. Some of the waste will reach the groundwater and eventually, the Columbia River, the lifeblood of the Northwest.

The need to retrieve and treat wastes in the tanks is urgent. The longer the wastes sit in (or leak from) the tanks, the harder it is to retrieve the wastes. The task is not trivial, because it is complex and immense. The waste in each of Hanford's tanks is unique in both chemical and physical makeup. Within each tank the waste is not uniform and is very difficult to mix. It is very costly to retrieve. Just taking a 5 L tank sample (e.g., multiple 250 mL grabs) for analysis can cost more than $100,000.

Need for Supplemental Technology

USDOE defined an accelerated treatment plan for Hanford in a Performance Management Plan [2] that the Assistant Secretary for Environmental Management approved. USDOE submitted this plan to the Office of Management and Budget in August 2002. This framework document had far-reaching effects and resulted in a major change to WTP's vitrification capabilities.

The original WTP plan had one HLW and three LAW melters. In 2002 USDOE changed its plans and proposed a new configuration. The change is to have two HLW and two LAW melters. The second HLW melter upgraded the WTP capacity to be able to treat the entire HLW stream. The two LAW melters will handle as much waste as the former three melters because the design changes increased capacity from 10 metric ton of glass per day to 15 metric ton per day for each melter.

We have always known we would need more capacity than the WTP to treat all the waste within the WTP's 40-year design life. With a second HLW melter in the WTP, only the LAW stream needs more capacity. The 2002 Performance Management Plan called for that capacity to come on line early or at the same time as the WTP. This would greatly shorten the Hanford mission and decrease the overall cost of cleanup dramatically.

The Method for Developing Supplemental Technology

In early 2002 USDOE convened a panel of experienced stabilization and solidification technology specialists to evaluate several dozen technologies for treating up to two-thirds of the WTP's LAW. The idea was to find a supplemental treatment technology that yielded a product that met the same requirements as vitrification. Ideally, the new process would be faster, cheaper, and more flexible, and could replace a 2nd LAW vitrification plant, our current baseline.

USDOE must prove another technology is technically achievable, will produce as-good-as-glass waste forms, and protect the environment. Our perspective is that we already had a perfectly viable technology and best available treatment technology. So a new technology must be as good as it and offer additional attributes.

Aside from supporting WTP, an important goal was to identify one or more technologies to immobilize waste directly from specific underground storage tanks. USDOE, Environmental Protection Agency, and Ecology formed a team for this study in 2003 and 2004. This team identified 68 tanks that held saltcake, i.e., a thick floating layer of various crystallized salts. The waste would need only simplified pretreatment before treatment for disposal. The team decided that ideally the treatment process would be configured in skid-mounted modules for easy transport between the 68 tanks.

USDOE initially chose three supplemental LAW treatment technologies [3, 4]: bulk vitrification (BV), steam reforming, and tailored cementitious stabilization called "cast stone." USDOE with Ecology's support chose to design and test BV because it believed BV would offer rapid deployment, low cost, and waste stream versatility.

In 2004, Ecology agreed to a plan to perform full-scale tests with Hanford's Tank 241-S-109 waste. USDOE would first install a Demonstration Bulk Vitrification System (DBVS) near this tank. This facility, along with ongoing bench, engineering and full-scale tests, would help determine if the BV process would be acceptable for treating LAW. The DBVS would be a prototype of several future full-scale production plants at Hanford. Tank 241-S-109 waste would separately be retrieved and pretreated to meet waste acceptance criteria for the DBVS. Ecology issued a Research, Development and Demonstration Permit for the DBVS in December 2004 [5]. It conditionally approved all DBVS design packages by June 2005 and issued a permit for construction. But DBVS construction is on hold, in part due to a lack of funding. USDOE has continued BV testing outside Hanford at a contractor's (AMEC) facility at a lower cost (see Fig. 1, courtesy of AMEC).

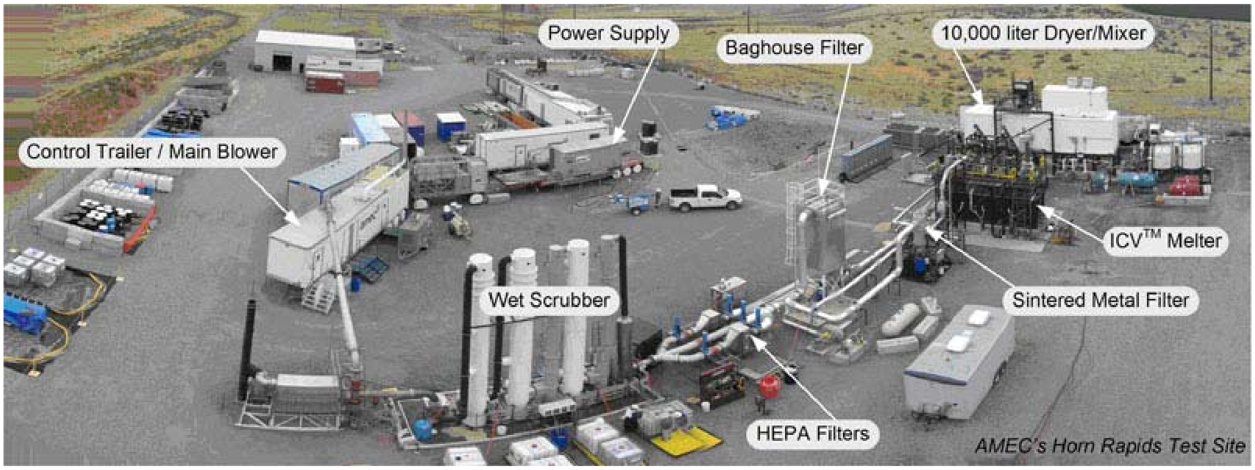

Fig. 1. Test 38D Equipment Layout at AMEC's Horn Rapids Test Site

2006 Mid-Course Correction

The USDOE convened an External Review Panel (ERP) in May 2006 to review [6] the technical basis for the DBVS. In response to the ERP's concerns, USDOE modified the DBVS design in three major areas: dried waste feed, confinement for vitrification box and lid, and offgas treatment.

BULK VITRIFICATION PROCESS

The bulk vitrification process draws upon a large experience base of treating different types of hazardous and mixed wastes in situ. AMEC's BV process for treating LAW has been adapted from AMEC's In-Container Vitrification (ICV™)[1] process. Ten papers on BV by various authors from AMEC, Inc. Geomelt Division; DMJM Technology; RWE NUKEM, Inc.; Pacific Northwest National Laboratory; CH2M Hill Hanford Group, Inc., and USDOE have been published for the annual Waste Management Symposium conferences between 2003 and 2007. A recent paper details the efforts in BV development [7]. In addition, reports are available on various laboratory analyses and many engineering scale and full-scale tests. The papers and reports describe the reasons for the main operational and equipment changes over the past five years of testing. For purposes of this paper, I will briefly outline the main process steps. Fig. 1 displays the equipment layout for the last full-scale test (Test 38D). Fig. 2 gives a block diagram for Test 38D.

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[1] ICV™ is a trademark of AMEC, Inc.

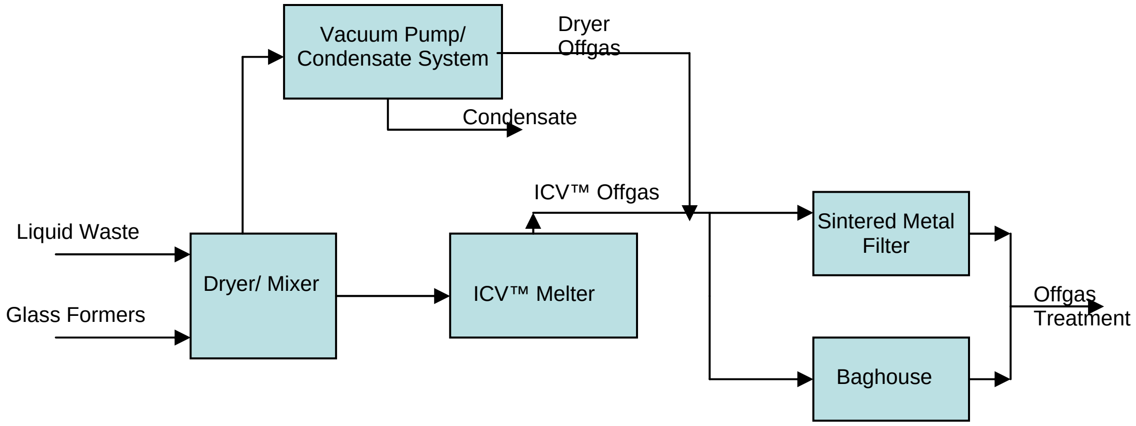

Fig. 2. Block Diagram for Test 38D

At the production BV plant, the incoming liquid tank waste will first be dried while it is mixed with soil and other glass formers in a horizontal cylindrical dryer. A steam jacket heats the dryer and an internal plough provides agitation. A vacuum draws off the moisture and dries the contents to a specified moisture level. The dried mixture then goes to a refractory-lined ICV™ melter that is 2.3 m (tall) x 2.3 m (wide) x 7.32 m (long) (or 7.5' x 7.5' x 24') and the mixture is vitrified by passing an electric current between disposable embedded carbon electrodes. A blower draws away the offgas, which is treated before it is discharged through a stack. After cooling, the vitrified waste will be disposed of along with the container in a near-surface burial facility at Hanford.

At AMEC's Horn Rapids test site, before Test 38D, the dryer was not available for the full-scale vitrification tests. Therefore, USDOE used a blend of reagent-grade dry chemicals as the dried waste simulant. It mixed this simulant with typical Hanford soil. Only one test (Test 38D) dried the liquid simulant in the full-scale dryer. Test 38D took place in August 2007. It was the latest full-scale test and it was the only time USDOE tested waste drying followed by melting together. As such Test 38D is called the Integrated test.

SIGNIFICANT ISSUES AND PRELIMINARY LESSONS

1. *Identify major areas of concern early and address solutions for these areas in parallel. For example, address dryer and offgas issues in conjunction with the vitrification step, not sequentially.*
The initial BV development focused on making the vitrification step viable through testing at the engineering and full scales. Besides vitrification there are two major components of the process-- the precursor waste feed drying step and the post vitrification offgas treatment. Designs of that equipment were partially based on performance expectations in engineering specification sheets. The dryer performance expectations relied on vendor experience and performance claims. Recognition that the dryer is a component of major concern could have helped to speed up its demonstration

for this application. Dryer testing could then have been conducted simultaneously with vitrification testing. The BV development process could have been improved by first identifying and then focusing on primary areas of concern.

2. *Perform bench- and pilot- scale tests for the dryer before proceeding with full-scale operation.*
The test reports [8, 9] summarize the results of early tests done on a 5 L capacity laboratory-scale dryer. The limited testing of this Littleford Day dryer with Hanford wastes (or similar slurries) did not overcome problems of particle agglomeration and stalling of the mixer blade. In bench and pilot testing, dryer walls fouled and dryer contents built up at the ends. These problems may also crop up in full-scale operation. There were scale-up issues and a lack of process control, especially temperature. This drying technology was not ready for full-scale, 10,000 L testing. However, the test log stated time constraints prevented a more thorough evaluation.

The ERP recommended continuing developmental tests on the pilot-scale dryer.

- USDOE resumed lab tests with the 130 L dryer in October 2006.
- The ERP had recommended 1,000 L scale tests [6] as a more logical step to develop operating parameters before integrated testing, but USDOE has not done this.
- USDOE tested full-scale drying in the 10,000 L dryer at AMEC’s Horn Rapids facility from April to August 2007.
  - It has not fully assessed operations and maintenance impacts of dryer wall scaling.
  - Testing to date has not yet shown that the pelletized feed needed will form consistently. The predominantly powdered feed that resulted during this dryer campaign caused many operational problems during the Integrated Test.
  - The ICV™ offgas pipe frequently plugged due to particulate matter carryover.

No other dryer tests are planned before the DBVS startup. The vitrification operation has evolved to the bottom-up mode with multiple small additions of dried waste being made now to fill one box. This mode of operation would be better served by a small continuous dryer instead of the 10,000-L batch dryer [10].

3. *Recognize that even established equipment will require additional testing when used in new environments, e.g. Sintered Metal Filter.*
The application of the sintered metal filter (SMF) in the DBVS offgas line may have problems. The ERP stated that the SMF “will frequently blind” (plug up). In the WTP’s design, the offgas line from the joule-heated melters has an unhindered pipe to the offgas scrubber. This open pipe forms part of an unrestricted film cooler above the WTP melters. It lowers the offgas temperature leading to the formation of particles which the scrubber then captures. USDOE did not apply this design to BV.

The basis for using the SMF for offgas particulate removal in the DBVS remains unclear. The SMF is akin to a high-efficiency particulate air filter. It is designed to remove 99.97% of particles <0.3 microns and cleans itself by backpulsing when the trapped particulates build up. The SMF is intended to capture and recycle contaminants (especially technetium) for which downstream offgas treatment is not effective. The SMF has generally been used for laboratory hood ventilation where the particulates are dry. For the ICV™ offgas application, the SMF manufacturer was unable to guarantee product performance in a stream that will contain mists of condensed sticky salts.

For the BV application there has only been one field test using the offgas SMF, Test 38D. In it the SMF plugged up early in the test due to deposition of salts and could not be cleaned by back pulsing. The test then continued using a parallel bag house filter.

More SMF testing at the Horn Rapids facility could prove useful. If the SMF is installed in the DBVS and does not work, revamping the DBVS offgas system will be difficult. Reworking large lines will take considerable time and money. <u>Continuing integrated tests at AMEC's facility offers a convenient option to test both the dryer and the SMF. But the plan for development of the SMF must be short-term with well-defined success criteria.</u>

4. *Identify the root cause of problems instead of addressing the symptoms. For example, elemental iron precipitation as a pool at the bottom of the melt was caused by eliminating oxidative feed. The subsequent redesign of the floor refractory to allow for metal pool accumulation was likely not required.*
USDOE did full-scale nonradioactive tests using bottom-up and top-down melting at AMEC's facility [7]. AMEC's offgas treatment system was not robust enough to treat the NO_X (nitrogen oxides) resulting from vitrifying the typical high-sodium nitrate waste simulant. So in one full-scale test (Test 38A) in March 2005, AMEC used sodium bicarbonate as a pseudosimulant. The researchers believed that the CO_2 generated in the ICV™ box would provide physical characteristics similar to NO_X, and not tax the offgas system. However, the lack of the oxidant sodium nitrate in the simulant may have caused the reduction of the iron oxide in the soil to a pool of elemental iron, which penetrated the refractory joints. This and the ensuing electrical short circuiting through the box could have caused the hot spot that created a hole in the metal wall of the ICV™ box. Some glass leaked from the hole; an unacceptable failure. The test was prematurely ended.

In the follow-up test (Test 38A-1), AMEC again used bicarbonate and strengthened and recontoured the refractory to contain the iron pool. The expense for a full-scale test and sample analysis is nominally over $1M, but the usefulness of this test remains questionable because a problem was apparently created where one did not exist. USDOE later refurbished the offgas system to treat NO_X properly, and completed a full-scale test (Test 38C) using the sodium nitrate simulant on May 9, 2006.

USDOE is no longer using the soil as the primary glass former. It has replaced soil with a synthetic blend of chemical glass formers. This and other formulation changes have minimized the iron precipitation. But the recesses to accumulate the iron metal pool in bottom refractory panels persist -- an unnecessary design feature.

5. *Do not underestimate the required facility robustness in cost estimates and design development. Lack of contractor experience in radioactive operations probably resulted in underestimating DBVS secondary confinement needs.*
The full-scale vitrification testing at AMEC's facility was very valuable. It highlighted the need for double containment for the melt box. USDOE has upgraded the design of the weather enclosure of the DBVS melt area so that it can stay at a negative pressure. DOE Order 420.1-1 Section 4.1.1.2 requires multiple layers of protection to prevent the release of radioactive materials to the environment. This design change allowed the DBVS design to meet the DOE Order, although at an added cost.

6. *Realistic cost and schedule estimates from the outset will build credibility with regulators and the public.*
USDOE originally set the cost of the BV evaluation, including the DBVS construction, under $50 M. This cost estimate has increased four-fold. Significant underestimation can never aid project success and points to the need to make a careful evaluation of potential uncertainties that multiply costs.

7. *USDOE can and should work with regulators to identify and resolve issues more quickly.*
Cooperation among the permittees, Ecology, and the EPA led to a document outlining the steps to obtain a Determination of Equivalent Treatment for the Bulk Vitrification process. Ecology worked cooperatively with USDOE to develop a Research, Development and Demonstration permit for implementing the DBVS [5]. Also we have been working with USDOE since 2002 on supplemental technology down-select and testing issues.

When requested, Ecology reviews and provides comments on test plans and offers valuable perspectives based on many years of directly applicable experience. USDOE should continue to use this valuable resource.

OTHER FINDINGS

Hanford tank wastes are unique.

Hanford's LAW is not as well defined and straightforward as low-level radioactive wastes from commercial nuclear power plants. Care should be taken to not assume that practices that were successful with other wastes will be successful with Hanford tank waste. Unless qualified, the claim that a process can treat radioactive and hazardous waste can be misleading.

The waste in each of Hanford's177 underground waste tanks is unique and variable. The tanks usually contain a majority of elements from the periodic table, albeit in varying concentrations. To bring in a semblance of conformity, the tank wastes have often been broadly classified into four envelopes. The envelopes are based on the type of chemical and radionuclide constituents and are somewhat linked to the process that generated the waste. However, the envelope definitions do not provide detailed speciation of waste constituents to be processed by the WTP.

Any LAW treatment process must be able to handle a good degree of variation in the waste feed. Simulant recipes for tests must be designed to represent an unknown mix and variety of chemical compositions. Past contractor experience in treating other wastes must be carefully evaluated for its applicability.

Go with what you know -- to a point.

Although LAW treatment will continue for decades, the current multi-pronged approach of testing many different technologies cannot be carried on for too long. Once a reasonable process has been identified, such as the joule-heated melter, there is a strong argument to stay with the tried-and-tested technology. But the difficulties of treating Hanford wastes prompts us to rethink any strategy and not rule out any viable option.

Different waste batches need different solutions.

USDOE is working to improve the waste retrieval/blending/staging plan by continually improving waste characterization. The entire tank farm inventory is being evaluated for processability in the WTP. Instead of four broadly defined envelopes, one approach has 13 groups for the waste [11].

In the 2002 study that ultimately focused USDOE's efforts on BV, the team initially looked at dozens of technologies. While vitrification is a mature technology, we were open to consider other methods to make a waste form "as good as glass." Hanford's wastes are complex. Some of these wastes will be harder to vitrify [11]. This cautions us to reevaluate very carefully the long-term ramifications of today's commitment to vitrification of LAW. And some wastes may be so benign vitrification is overkill. These are more reasons to keep other options open for certain wastes. Therefore USDOE must *retain more tools in its tool bag*. It should close the door on any one option very carefully.

LAW should perhaps be categorized similar to the way tank waste was divided into envelopes and now groups. Instead of bundling everything under one LAW umbrella that calls for vitrification, there may be opportunities for easier and cheaper treatment. It calls for us to ensure that we haven't missed simpler alternatives such as tailored cementitious stabilization (grout) [12] for a specific portion of LAW or secondary liquid wastes. The focus must remain on key product qualities; then one must develop a process to achieve that product quality.

It's hard to fund research when there's real work that needs funding.

There is an apparent inherent conflict between funding for R&D and paying for more real cleanup on large, complex projects like Hanford. Managing this delicate balance is no trivial task for developing supplemental technologies at Hanford.

Funding is finite – objectivity is vital.
While Hanford has a multi-billion dollar budget, there is still not enough. Adequate funding remains a big uncertainty. This problem is very real. For both the laboratory researcher and plant designer, there's comfort in knowing that funds are assured to continue work on the same project with little interruption. In some instances care must be taken to uphold objectivity in reporting results.

Know when to stop
When developing a process, researchers can conceive engineering solutions for nearly any problem encountered. But unending persistence in finding technical solutions or new alternatives may not be noble. USDOE must curb the temptation to keep on testing; it must respect schedule constraints. It must scrutinize, with upper management input, the real value of each key step.

Because of the tremendous cost to resolve technical challenges at Hanford, it is important to consider the cost versus benefits of any technical approach. The benefits evaluation for continuing research must demonstrate judicious use of taxpayer funds for Hanford cleanup. It is a challenge to both USDOE and its regulators to define appropriate decision criteria (including cost, performance, schedule, risk, versatility, etc.) when weighing a promising new technology against an existing one.

Draw on experts and previous experience.
USDOE uses an effective method of periodic external reviews for evaluating technical progress on important projects. In 2002 it used a process of numerical grading to select immobilization technologies during a three-day workshop [3]. There was not enough time to examine the data for the different technologies in this narrow period. In contrast, the ERP that reviewed the progress of BV studied the process and documentation for four months before publishing its final report. The process of selecting technologies could have benefited from a similar sustained evaluation. A similar early time investment in careful evaluation would be the more appropriate path for a status check today. We must look around and perhaps draw lessons from worldwide experiences and successes elsewhere within the USDOE complex.

CONCLUSIONS

- Contractors' off-the-shelf vitrification technology that worked elsewhere may not apply easily to Hanford's waste challenges.
- The BV development process could have been improved by first identifying and then focusing on primary areas of concern.
- Continuing integrated tests at the Horn Rapids facility offers a convenient option to test both the dryer and the SMF. But the plan for development of the SMF must be short term with well defined success criteria.

USDOE has the responsibility to carefully evaluate each proposal and make critical decisions that will make optimum use of limited funds. The ERP provided valuable technical guidance on improving BV's design. This must be complemented by a similar study of cost effectiveness of a process. We must have a better understanding of life-cycle costs before a path for supplemental treatment is chosen.

USDOE has now gained five years of experience in developing BV. It is time for USDOE to make defensible economic evaluations before further funding towards developing supplemental treatment. It must reevaluate if the projected advantages of rapid deployment, low cost, and waste stream versatility are still valid.

The decision-making methodology USDOE uses to approve designs as part of its Critical Decision Process appears rigorous and useful. Looking ahead, Ecology expects USDOE will use lessons learned from BV and other testing in a concerted manner as part of their decision-making process. The success of Hanford's cleanup depends on it.

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