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Improved Ex-Tank Leak Detection and Monitoring Technology Demonstrations in Support of Single-Shell Tank Waste Retrieval at the Hanford Site in Richland, Washington

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Abstract- *Led by the United States Department of Energy Office of River Protection (DOE-ORP) and CH2M HILL Hanford Group, Inc. (CHG), a team of experts from Pacific Northwest National Laboratory (PNNL), Lawrence Livermore National Laboratory (LLNL), Lawrence Berkley National Laboratory (LBNL), University of Texas at Austin, Duke Engineering Services, Vista Engineering Technologies, L.L.C., and HydroGEOPHYSICS, Inc. have been working together to narrow the field of new external tank leak detection technologies. The ability to detect and assess potential leaks more quickly will help reduce potential risks to public health and the environment during efforts to retrieve millions of gallons of waste from Hanford's older single-shell tanks (SST's). A method for early and reliable detection of leaks around and below the entire 75-foot diameter bottom of a SST is needed.*

"Proof-of-concept" testing of six ex-tank leak detection and monitoring technologies was conducted at Hanford's 105-A Mock Tank Site in August 2001. A workshop was conducted in January, 2002 to review the results and select the best of the methods tested for further testing and demonstration in support of an SST retrieval. Three methods were selected: High Resolution Resistivity; Electrical Resistance Tomography – Long Electrodes; and Electrical Resistance Tomography – Point Electrode Arrays.

Planned development activity includes performance evaluation tests to determine probability of detection and the probability of false alarm for each technology and deployability tests in an actual Hanford tank farm environment.

I. INTRODUCTION

The mission of the Department of Energy Office of River Protection (DOE-ORP) and its Tank Farm Contractor, CH2M Hill Hanford Group (CHG), is to safely store, retrieve, immobilize, and dispose of roughly 53 million gallons of high-level radioactive wastes stored in 177 underground storage tanks (USTs) at the Hanford Site in Richland, Washington. The 177 USTs are comprised of 149 single-shell tanks (SSTs), constructed between 1943 and 1964, and 28 newer double-shell tanks (DSTs), constructed between 1968 and 1986.

Sixty-seven of Hanford's 149 SSTs are known or suspected to have leaked a total of less than 1,000,000 gallons of high-level radioactive wastes.[1,2] The SSTs have exceeded their design lives and are of questionable leak integrity. No new wastes have been added to the SSTs since November of 1980. Furthermore, interim stabilization operations are underway to remove pumpable liquids from the SSTs for transfer to the DSTs. Finally, CHG is conducting SST retrieval technology demonstrations in accordance with the Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement). The Tri-Party Agreement requires integration of retrieval system designs with leak detection, monitoring, and mitigation (LDMM) technologies.[3,4,5] A Retrieval Performance Evaluation (RPE) methodology is used to make risk-based decisions regarding LDMM system functions and requirements.[4,5] One method of meeting these functions and requirements involves using systems and equipment that measure soil conditions surrounding, or external to, the tank. The ability to quickly and accurately detect and quantify the volume of potential leaks will reduce risks to human health and the environment during SST waste retrieval operations and support ongoing tank closure initiatives. This paper discusses ongoing efforts to demonstrate improved ex-tank leak detection and monitoring technologies in support of SST waste retrieval activities and LDMM strategies. These ex-tank leak detection and monitoring technologies may also have application to SST post-closure monitoring requirements.

Unique challenges are encountered in the effort to apply ex-tank leak detection and monitoring methods on

Hanford's SSTs. The tanks were built from 1943 to 1964. Some spills and leaks have occurred resulting in radiological contamination of soils near the surface and around some tanks. The tanks are reinforced concrete structures, 75 feet in diameter, with a single carbon steel liner. They are buried in the soil with the tank bottoms from 37 to 50 feet below grade and 6 to 10 feet of backfill over the tank dome. Tank contents are comprised of numerous radioactive elements including long-lived isotopes of Technetium, Selenium, Iodine, Carbon, and Uranium and shorter-lived isotopes of Strontium and Cesium.[6] Total curie content of some tanks is over 1 million curies. Total estimated curie content in DSTs and SSTs is 228 million curies. The SSTs contain roughly 120 million curies with the remainder in the DST system. Chemical constituents include sodium nitrites, nitrates, phosphates, aluminates, carbonates, and sulphates in saltcake and liquid, and various metal hydroxides, oxides and phosphates in sludge. In addition to the obvious radiological and chemical hazards, flammable gasses are present in the waste of some tanks. The tanks are located in closely spaced groups of from 4 to 18 tanks. The near-surface infrastructure includes pipes called risers for tank access, fill and transfer piping, cathodic protection systems, numerous pumps, ventilation systems, and associated cables and conduit with significant differences among tanks. Access around the tanks also varies considerably. Some tanks with known leak history are in close proximity to non-leaking tanks. Figure 1 shows a typical SST group, or farm, under construction. Figure 2 depicts a typical SST.

II. EX-TANK TECHNOLOGY SELECTION

In January 2000, six ex-tank leak detection and monitoring technologies were selected for "proof-of concept" tests. The tests were conducted at Hanford's 105-A Mock Tank Site.[7,8,9] A 36% solution of sodium thiosulfate pentahydrate was selected as a tank leak simulant. The technologies included electrical resistivity tomography (ERT), high-resolution resistivity (HRR), cross-borehole electromagnetic induction (CEMI), cross-borehole seismic (XBS), and cross-borehole radar (XBR), and a suite of methods called subsurface airflow and extraction (SAFE), which included partitioning interwell tracer tests (PITT).

A unique feature of all six technologies is that they are able to "look" across the tank bottom and integrate the materials underneath the tank as opposed to point source measurements around the perimeter of the tank. This significantly enhances the leak detection capabilities over the capabilities of the spectral gamma-ray drywell monitoring system that only senses leaks once the leak reaches within aproximately1 m of the drywells placed around the perimeter of the tank. The volume integration capability of these newer technologies is expected to significantly reduce the minimum detected leak volume and the time to detect a leak and implement appropriate leak mitigation measures.

III. SUMMARY OF METHODS AND PROOF OF CONCEPT TEST RESULTS

Electrical Resistivity Tomography (ERT) determines the resistivity of the soil by passing current between two adjacent electrodes. The electrical potential due to the presence of the resulting dipole is measured at various distances and positions. The values of the measured potentials indicate the distribution of current density within the soil and hence the electrical resistivity. ERT has typically been conducted using a cross-borehole geometry with multiple electrically isolated electrodes placed in vertical arrays. At the mock tank, data was also analyzed using a long electrode configuration to simulate using steel cased wells that exist around many tanks. The results show that a "triggering" system detecting a change in soil resistivity can be provided with nominal changes to existing tank farm dry well infrastructure. Test results also show that a low-resolution imaging system can be constructed using the existing infrastructure of steel-cased dry wells that surround Hanford's SSTs. A more enhanced electrical resistivity network would be capable of generating higher resolution tomographic images for defining tank leak plume geometry, as well as establishing liquid travel times and directions. The test results indicate a lower limit of leak detection of approximately 1,135 L (300 gallons) using an optimum electrode array.

The High Resolution Resistivity (HRR) method was developed and deployed by researchers from HydroGEOPHYSICS, Incorporated. At the mock tank site, sixty-one surface electrodes were installed and used in conjunction with three steel-cased wells. The existing ERT arrays were also used to increase the sampling density and improve electrical measurement resolution. The term High Resolution Resistivity-Steel Casing Resistivity Technology (SCRT) refers to an adaptation of HRR using existing steel casings in combination with surface electrodes and the tank itself in contact with the waste stream. Results of the HRR-SCRT method show that simple plume geometry and volume estimates can be readily obtained. The HRR method detection limit is conservatively estimated at 1,893 L (500 gallons).

Cross Borehole Electromagnetic Induction (CEMI) uses the principle of induction to measure the electrical

Figure 1
Hanford S-Tank Farm Construction

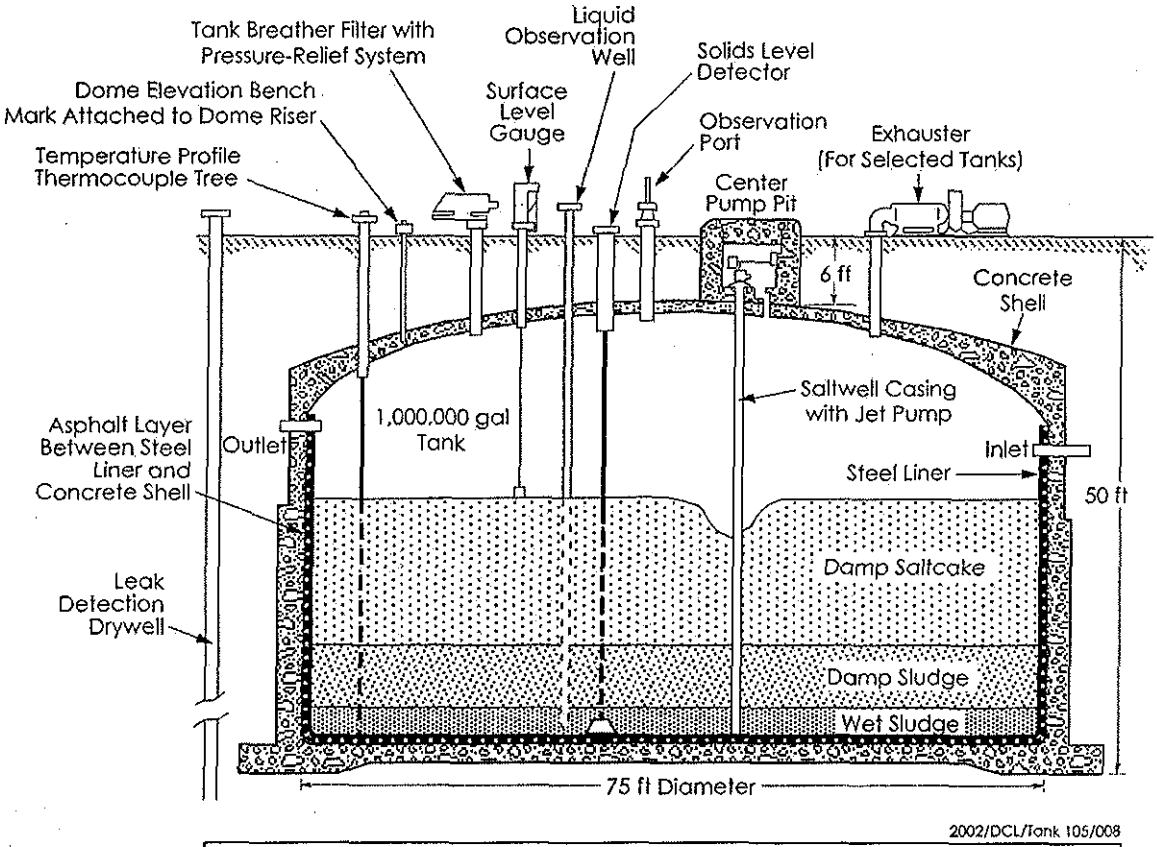

Figure 2
Representation of a 100 Series SST, Showing ancillary Instrumentation and Construction Features

conductivity of the subsurface between two boreholes. The CEMI system consists of a source in one well and a receiver in a second well. The source generates a time-varying electromagnetic field that induces electric currents to flow in the surrounding earth. At the receiver borehole, a custom-designed magnetic induction coil detects the total magnetic field, consisting of the magnetic fields from the induced currents in the earth, as well as the primary magnetic field generated by the transmitter. The magnitude and phase of the received fields are a function of the earth's conductivity. By positioning both the transmitter and receiver tools at various levels above, below, and within the zone of interest, images of the conductivity distribution between the wells can be generated. The data are interpreted by inverse modeling to produce a tomogram. The mock tank test was the first deployment in Hanford type (high resistivity) environment for CEMI. The steel tank was found to have a significant effect due to the large EM induction in the tank itself. The results showed that for Hanford type soil with the presence of a large steel tank detection of a leak in the range of 1000 gallons is impractical. CEMI also requires the installation of PVC or fiberglass cased wells as steel casings block the electromagnetic signal.

Four Cross-Borehole Seismic (XBS) measurements were made at the mock tank site by researchers from LBNL. The XBS method requires liquid-filled boreholes, or other means of coupling to the soil, to conduct the measurements. Changes in soil moisture content were detectable but not to the accuracy or resolution of radar. Seismic is very sensitive to detecting the difference between near and fully saturated sediments (95% to 100% saturation) and less sensitive to lower moisture levels, which a leaking plume would stabilize at. Tests indicated that seismic pulse first arrival information provided the best indication of moisture content changes. The XBS effort was plagued by well seal failures and the necessity of preventing leakage of water from the boreholes (used for seismic signal coupling) that could hamper measurements made with the electrical and electromagnetic methods. Poor coupling due to the newly installed wells may also have affected the XBS results.

Six Cross-Borehole Radar (XBR) measurements were made during the testing at the mock tank site by researchers from LBNL. Preliminary plots of "first arrivals" show a more pronounced sensitivity to changes in soil moisture content when compared to the seismic data. Test data indicate that changes in "first arrival" amplitude show the greatest change within 2 to 3 hours after the start of liquid injections. All subsequent changes in amplitude indicate that the XBR "first arrivals" were tracking a horizontal spread of the sodium thiosulfate pentahydrate solution without obvious vertical migration. The researchers reported that the radar method might be capable of detecting a leak volume as low as 100 to 150 gallons under the right conditions. The XBR method can only be used in polyvinyl chloride (PVC) well casings or open holes; steel casings cannot be used.

Subsurface Air Flow and Extraction (SAFE) refers to a suite of LDMM technologies intended to support SST retrieval operations. The technologies are very distinct in concept, but share a common subsurface flowfield and analytical infrastructure. Three of the leak detection technologies (In-Tank Tracers, flowfield disturbance, and Partitioning Interwell Tracers) were demonstrated during the FY01 Mock Tank Site LDMM program. In-tank tracers employ gases or volatile liquids having appropriate partitioning coefficients with water and brine to allow transport with the tank waste and the ability to be readily stripped from leaked tank waste by a subsurface air flowfield. The tracers must be added to the tank during waste-dissolution operations. Detection in the advective flow stream provides detection of a leak. During in-tank tracer testing, chlorodifluoromethane was used as a soluble tracer and was easily detected using in-field gas chromatography equipment. Test results show that leaks on the order of 378.5 L (100 gallons) can be detected using in-tank tracer methods. However, significant uncertainty exists regarding the ability to mix a tracer sufficiently with actual tank waste so that it can be present at the point of a leak. Flowfield disturbance is a leak detection technology based on changes in subsurface airflow behavior due to changes in pneumatic conductivity resulting from liquid infiltrating into the subsurface. Conservative tracer elution curves are analyzed for perturbations resulting from leak-induced porosity changes in the swept pore volume under a tank. Slower arrival times or multiple-peaked curves relative to baseline conditions are indicative of a leak. The flow-field disturbance method appears to be an excellent tool for confirmation of larger leaks, however, the in-tank tracer methods are much more sensitive to small volume leaks. Partitioning Interwell Tracer Tests (PITTs) use the principle of chromatographic separation through partitioning-induced flow retardation of tracers to quantify substances of interest in the swept zone. Four tests were completed using a combination of partitioning and conservative tracers. Large decreases in partitioning coefficients associated with the high ionic strength of the sodium thiosulfate pentahydrate solution were observed which resulted in a corresponding decrease in the sensitivity of the PITT method. Analyses of the PITT data were inconclusive.

IV. DOWN SELECTION WORKSHOP

A workshop was conducted in January, 2002 to select the best of the tested methods for further testing and demonstration in support of an SST retrieval.[10] Wide participation was encouraged with representation by Washington State Department of Ecology (WDOE), DOE-ORP, CHI Geosciences, Bechtel Idaho, as well as CHG, Numatec Hanford Corporation (NHC), and the National Laboratories and private firms involved in the tests. Seven criteria were considered in the selection: safety, performance for detecting a leak, performance for monitoring or quantifying a leak, performance in mitigating a leak, technical maturity, cost, and schedule. A paired comparison analysis was used to weight the criteria. The members of the selection board considered the test results, presentations by representatives of each technology, and their unique perspectives on the technology and practical deployment issues to evaluate the methods with respect to the weighted criteria and select three methods. The three methods selected by the decision board were: 1) High Resolution Resistivity-Steel Casing Resistivity Technology (HRR-SCRT), 2) Electrical Resistance Tomography – Long Electrodes; and 3) Electrical Resistance Tomography – Point Electrode Arrays.

Although all three of these methods are based upon electrical techniques, there are some significant differences between them. HRR-SCRT was rated first for two main reasons. First the performance was very good both in terms of ability to detect small leaks as well as quantify the release results. HRR-SCRT typically quantified the release volumes with errors less than ten percent. The other key factor in the HRR-SCRT success was the fact that the system could be deployed using existing drywells and not require any additional drilling to implant electrodes in the tank farms. The major concern with the technique is that to operate in the tank farms, the tank waste needs to be excited with the electrical source. This could represent a safety issue related to the possible presence of flammable gas in the waste.

The second ranked technology was the ERT long electrode arrays. Like the HRR-SCRT the installation of this approach uses existing equipment and may only require the installation of a few more electrode arrays to provide sufficient coverage. Although the method is inexpensive to install and does not face any significant safety issues, it also has the lowest performance of the three selected technologies. Based upon the preliminary results, the detection limit of the ERT long electrode method at the mock tank scale is likely to be approximately 1,500 and 2,000 gallons, which is significantly higher than the other two approaches which detect leaks on the order of 300 gallons at the mock tank scale. Because of the higher detection limit, a significantly higher detection threshold (i.e. 4,000 gallons) will have to be used to produce a comparable probability of false alarm when compared to the other two methods which will use thresholds around 600 to 1,000 gallons. The effect of this increased threshold on the performance of the ERT long electrode method will have to be considered in design of the performance evaluation test program.

The point electrode array version of ERT represents the most mature and also possibly the best performance of the selected technologies. This technology has been demonstrated at the mock tank site both in 1995 and 1996 and then again under this program in 2001 with excellent results. In all cases, detection in the low hundreds of gallons were documented and three dimensional images of the fluid were produced with high resolution. This technology is robust and the only drawback is the difficulty in installation of the arrays. The installation of the arrays is straight forward, but requires drilling, or possibly direct push technologies if the soils will permit, to install the equipment. The depth of electrodes below the bottom of a tank is an issue that will be evaluated in more detail during the evaluation testing.

V. PLANNED DEVELOPMENT EFFORTS AND STRATEGY

Future development efforts have the objective of providing tank leak detection systems that meet the leak detection and monitoring requirements for tank retrieval and that are economically deployable and can be operated in a tank farm. The first step in planned development efforts is a performance evaluation test conducted at a surrogate for an actual SST. The Mock Tank used for the earlier "proof-of-concept" tests is again the planned test site with minor modifications. Second, a deployment test on an actual SST in conjunction with one of the SST Retrieval Demonstrations will be used to confirm, as much as possible, assumptions made regarding deployability and effects of tank farm infrastructure on leak detection capability.

VI. PERFORMANCE EVALUATION TEST

The performance testing is specifically aimed at determining the probability of detection and the probability of false alarm for each technology for a specified leak volume. The test must also provide data for modeling and a protocol that can be used in a Deployment Test on an actual SST. A critical part of this

testing is selection of a test site. The test site should be similar to the actual tank environment where these LDMM methods will be used. The 105A Mock Tank Site on the Hanford Site has several key differences from an actual SST but was selected as most representative of a typical SST. The testing will include determining the impact of differences between the test site and a typical SST and the gathering of data to scale results to a typical SST. For instance, the mock tank is 50 feet in diameter compared to an SST diameter of 75 feet. Other key questions include the effect of other neighboring tanks and piping, and the effect of the proximity of the long electrodes to the tank wall. The test will also evaluate various sources of noise including existing plumes in the tank farm and natural precipitation events.

Each of the methods will be evaluated under several different scenarios to provide data that can be used in evaluating performance at various leak threshold levels (i.e., what is the probability of detecting a 500 gallon leak versus a 1500 gallon leak). This range of testing will allow several key factors potentially affecting leak detection performance to be addressed including the impacts of leak location, leak rate, and existing soil contamination.

The probability of detection is determined by conducting a series of injections and calculating the percentage of injections that are detected by the leak detection system using a specified leak threshold volume. The goal is 95%. Selecting different threshold volumes will produce different probabilities of detections. The probability of false alarms is more difficult to determine as it involves understanding the various noise sources that can influence the leak detection system. The probability of false alarms will be determined from the series of "non-injections" included in the test sequence. The goal is less than 5%. Again, selecting different threshold volumes will produce different probabilities of false alarm.

VII. SST DEPLOYMENT DEMONSTRATION

Further evaluation of these leak detection and monitoring methods will include a deployment test at an actual SST. The first opportunity for this is the retrieval demonstration planned for Tank 241-S-112 in accordance with the Tri-Party Agreement M-45 series milestones. The dome of S-112 is buried about 10 ft below grade, as illustrated in Figure 2. The subsurface also contains electrical wiring in conduit, cathodic protection wiring, and piping. In addition, S-112 is the final tank in a cascade of three tanks and has large below grade interconnecting piping. A deployment demonstration on S-112 would address these unique physical properties and other factors that could have an impact on leak detection performance. The first deployment demonstration is currently in the planning stage.

VIII. CONCLUSION

Results from the "proof-of-concept" testing of the ex-tank leak detection and monitoring technologies are very encouraging with respect to improving leak detection and monitoring sensitivity during tank waste retrieval operations. Current limitations associated with baseline leak detection and monitoring techniques involving in-tank material balance and ex-tank spectral gamma logging in dry wells appear to be addressed by the "volume integrating" and "tomographic imaging" capabilities of the improved methods. Detection capability on the order of a few hundred to a thousand gallons appears achievable under optimum conditions. Capability under actual Tank farm conditions has yet to be determined. Despite the uncertainty caused by effects of nearby tanks and piping, electrical noise, and contamination from historical leaks, the results indicate that an improvement over current methods can be achieved.

A technology down-selection workshop was convened to narrow the field of potentially improved leak detection and monitoring technologies to three preferred methods. This selection was based on "expert panel" evaluations against selected performance criteria. These criteria addressed safety, performance, technical maturity, cost, and schedule. The three methods selected for further evaluation and testing are: High Resolution Resistivity-Steel Casing Resistivity Technology; Electrical Resistance Tomography – Long Electrodes; and Electrical Resistance Tomography – Point Electrode Arrays. These will be subjected to more rigorous performance testing similar to Environmental Protection Agency (EPA) or other suitable guidelines to demonstrate a minimum 95% probability of detection with no more than a 5% probability of false alarms. Deployability tests are also planned in an actual Hanford tank farm environment. Finally, leak detection and monitoring technologies being demonstrated in support of Hanford tank waste retrieval operations are being considered for possible application in meeting SST post-closure monitoring requirements.

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