FIELD DEPLOYMENT OF A NOVEL APPROACH FOR THE ACQUISITION OF DEEP GROUNDWATER SAMPLES AT NEVADA TEST SITE

P. Nevins, P.A. Murray
AEA Technology Engineering Services, Inc.

C. Russell
Desert Research Institute

ABSTRACT

Groundwater sampling is routinely conducted at hundreds of wells at multiple DOE facilities to monitor changes in groundwater quality as a function of time. Some of these wells are very deep (greater than 600 m) which presents unique problems that must be overcome in order to obtain a representative, undisturbed sample. Current technology consists of the use of submersible pumps, bailed samples, and samples collected using a variety of manufactured systems. Each system or method has its advantages and will be limited to specific applications.

The only types of pumps that can handle deeper wells are those specially designed for the oil industry. They are expensive and were originally designed for continuous operation with high-lubricity liquids. Therefore, these pumps are prone to failure or require extremely frequent maintenance to reduce the risk of failure when functioning as samplers. The pumps have a high power requirement and, for wells not on the power grid, require the setting up of a large amount of support equipment and its associated labor for each sampling event.

A sample of approximately 1 liter is typically required. However, the majority of wells on the DOE complex are stagnant or near-stagnant. It is necessary to purge these wells prior to sampling in order to remove stagnant water. Standard practice requires the purging of three well volumes (typically several thousand gallons). The value of the sampling system will be increased if it can improve on the purge rate of the Bennett pump, which is approximately 1 liter/min in deeper wells.

Pneumatically-driven pumps specifically designed for sampling wells of intermediate depth (200'–1500'), are frequently used but have limited depth capability and become increasingly unreliable as they approach their maximum operating depth. The down-hole location of the pump means that the entire bundle must be retrieved in the event of failure. This is time-consuming and precludes its use for permanent installations. Repeated deployment and retrieval causes progressive damage to the tubing bundle.

AEA Technology has developed a fully-automated pneumatic sampler that employs compressed air to force a polyurethane pig up and down a borehole to retrieve samples. The sampler employs two moving parts and has demonstrated purge rates between 3 to 4 liters per minute. The limited number of moving parts deployed down-hole, improve the system's reliability and cost-effectiveness. In addition, a single sampling trailer can service several wells with significantly reduced labor requirements, further improving the cost benefits.

INTRODUCTION

Deep well sampling of groundwater is routinely conducted at hundreds of wells at the following DOE facilities: Los Alamos National Laboratory, Sandia National Laboratory, Nevada Test Site, Idaho National Environmental Engineering Laboratory and Pantex Processing Facility to monitor potential hazards to the local environment. Sampling water from depths of several thousand feet presents unique problems that must be overcome in order to obtain a representative, undisturbed sample. Conventional mechanical pumps have been routinely deployed to collect the sample. Mechanical pumps deployed under such conditions are subject to extreme pressures (up to 200 atmospheres) and repeated failure due to their intermittent operation.

During FY 02, AEA Technology developed and demonstrated a concept design of a deep well sampler at Sandia National Laboratory. The system was based on a simple tube design, compressed air and a pipe pig. The trials were conducted in conjunction with the Desert Research Institute and Sandia National Laboratory. The work evaluated the performance of the novel design of Deep Well Sampler developed by AEA Technology and compared the technology to the baseline system.

The design of the system tested at Sandia had sufficient promise to further develop the system and deploy it in a deep well at the Nevada Test Site (NTS). Based on the success of the NTS deployment during 2003, the decision was made to further refine the engineering and to deploy a semi-permanent installation in Nye County, adjacent to NTS during 2004.

PRINCIPLES OF AEA TECHNOLOGY SAMPLER

AEA Technology has developed a novel technique for sampling deep boreholes that does away with the need for expensive, unreliable and labor-intensive equipment and operates at low pressures (less than 10 atmospheres) regardless of the depth to the aquifer. Compressed air is used to push a foam 'pig' along the sample tubing. This pig pushes a small volume of water in front of it, requiring much lower pressure than conventional systems where the entire sample line is full of water.

The sampler is initially deployed into the well. This consists of a sampling head attached to a small diameter tubing bundle. At the base of the sampling head is a positive pressure relief valve.

A commercially available foam pipe pig is driven by compressed air from the surface to the sampling head. Water is then allowed to flow into the tubing immediately above the foam pig. Compressed air is applied behind the foam pig driving the pig and the column of water back to the surface as shown in Figure 1. The water is collected in a sample container and the pig is driven back down to the base of the well.

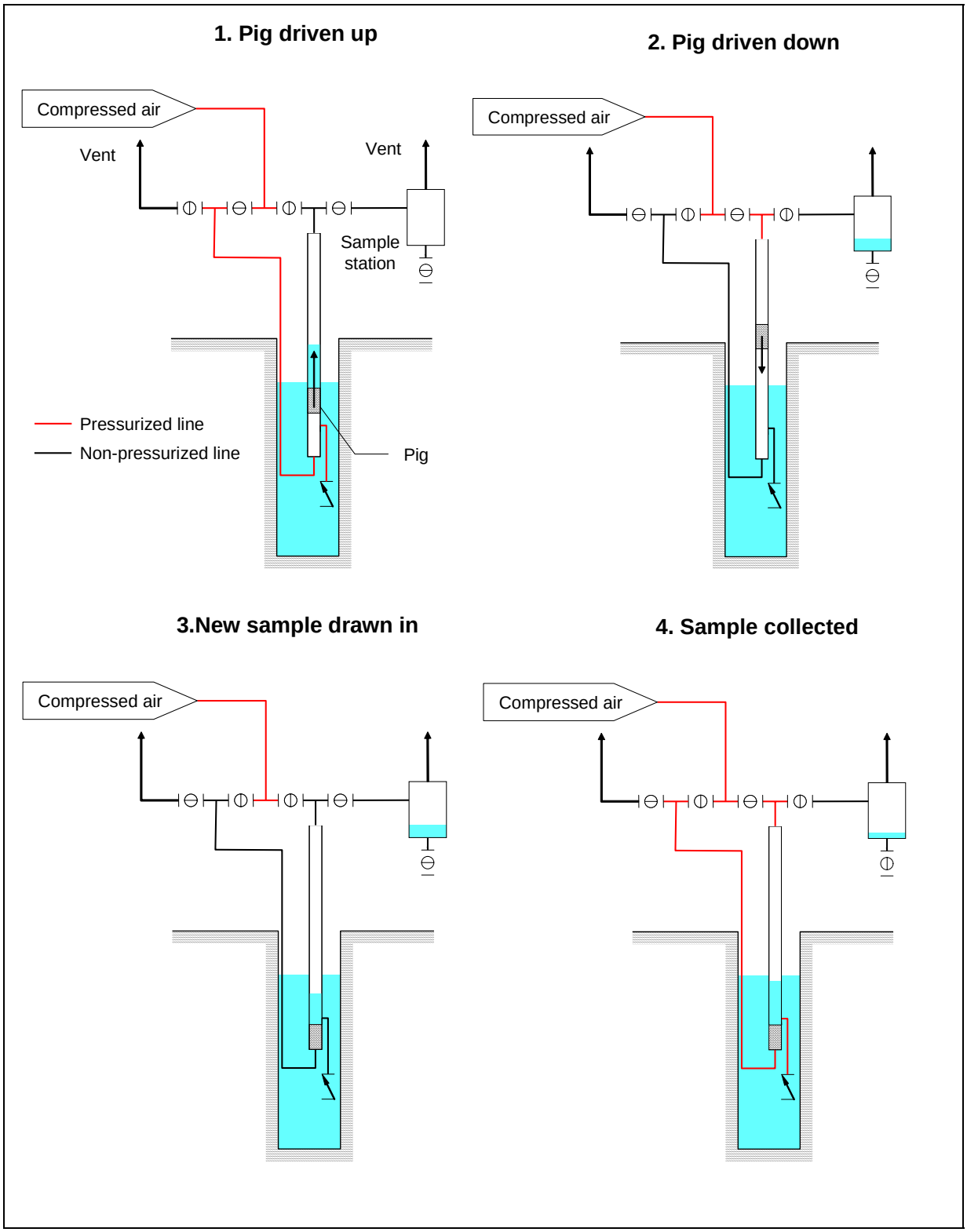

Fig. 1. The operating principle of sampler minimizes moving parts down well and avoids the need for high operating pressures.

DEPLOYMENT RESULTS FOR NEVADA TEST SITE

The objective in deploying the AEA deep-well sampler at Well UE-5n at the Nevada Test Site was two-fold. The primary objective involved evaluating and comparing the results derived from samples collected by the deep-well sampler with results derived from samples collected using standard technology. The secondary objective was to demonstrate the deep-well sampler to potential users.

Samples were collected using two standardized methods: bailing with a discrete bailer and pumping with portable pneumatic pumps. Results of these samples were compared directly to samples collected with the AEA deep-well sampler. The experiment design called for initial samples to be collected at a depth of 222.5 m (730 ft) bgs using the discrete bailer, which consisted of a sealed tube that could be opened and closed at desired depths thereby obtaining water samples that were representative of specific depths within the well. Results from these samples were intended to provide a background level of activity for tritium before subsequent sampling processes occurred. In the intermediate step in the experiment design, the AEA deep-well sampler was installed. The sampler was used to purge the well and collect samples. Results from these samples were compared to the results from the previously bailed samples.

The final step in the deployment involved the installation of a pneumatic pump that was used to purge the well and collect two sets of samples. The first set was a bottoms-up sample that should produce similar results (in terms of sampling depth and extent of purging) to those collected with the AEA deep-well sampler. The pneumatic pump was used to further purge the well, and then samples were collected to determine if the purging method used by the AEA sampler demonstrably affected the quality of samples in comparison to samples collected through more traditional methods.

The sole analytic of concern was tritium. Tritium was selected as it is a fairly common contaminant at U.S. Department of Energy sites; it does not present health hazards at low levels; and it can be affected by air-stripping or slow rates of absorption into plastic (both are potential concerns with the AEA deep-well sampler).

Pre-Operational Bailed Reference Sample

A logging truck and bailer were mobilized to Well UE-5n on February 3, 2004. Three samples were collected from Well UE-5n using the DRI 1-L bailer. The first sample was a field equipment rinsate sample (UE-5n-020304-1450#1). This sample consisted of tritium-free water poured into the top of the bailer and collected through the valve at the bottom. This sample was collected to verify that tritium observed in subsequent samples could not have been derived from inadequate decontamination of the bailer.

The next sample (UE-5n 020304-1520#2) was collected with the discrete bailer at a depth of 222.5 m (730 ft) below land surface. This depth was 7.6 m (25 ft) below the static water level in well UE-5n and represented the original target depth for installing the AEA sampler. A duplicate sample (UE-5n 020304-1555#3) was also collected at this depth to ascertain the variability

inherent in the sample acquisition and analysis process by duplicating, as close as possible, all aspects of the original sample acquisition, handling, and analysis processes.

The AEA deep-well sampler was deployed on February 4, 2004, into Well UE-5n to an initial depth of 222.5 m (730 ft). The sampler ran intermittently during daylight hours over the next seven days. Operations included optimizing cycle times at various depths to improve performance; identifying potential problems with the sample head, valve skid, and current tubing configuration; and demonstrating the viability of the sampler to potential users. By February 11, 2004, a total of 656 L (173 gal) had been purged from the well with the AEA sampler.

Three samples were collected with the AEA deep-well sampler on February 11, 2004. The first sample (UE-5n 021104-1030#1) was a field blank – the intent of a field blank is to expose tritium-free water to the environment surrounding the well head to ensure that tritium vapor in the air is not affecting the results of the sample. Results for the field blank are presented in Table 6-1. An equipment blank was not collected with the AEA deep-well sampler since this was new equipment that had never been exposed previously to tritiated water. The second sample (UE-5n 021104-1125#2) was collected at a depth of 228.6 m (750 ft). Sample results are presented in Table 6-1. The third sample (UE-5n 021104-1130#3) was a duplicate sample also collected at a depth of 228.6 m (750 ft).

Post-Operational Purge and Reference Sample

The deep-well sampler was removed from Well UE-5n immediately after AEA sampling operations were completed. A pneumatic pump, manufactured by Bennet Sample Pumps, Inc., was installed in the well to obtain two sets of samples. The first set was collected as close in time as physically possible and from the identical depth as the samples collected with the AEA deep-well sampler. The Bennet samples, obtained through standard sampling technology, were intended for comparison with the samples collected with the AEA deep-well sampler. The second set was collected following an extended purging cycle with the Bennet pump. The purpose of the second set of samples was to evaluate how representative the AEA deep-well samples were to those collected using standard purging and sampling technology.

The Bennet pump was set at 228.6 m (750 ft) within 2 hours and 50 minutes after the last sample was collected with the AEA deep-well sampler. The initial attempt at pumping the well with the Bennet pump failed (Appendix A). The pump was pulled from the well and reinstalled. On the second attempt, the pump produced 2.2 L/min (0.58 gal/min). The Bennet pump was allowed to pump 5 tubing volumes [one volume equals 28.3 L (7.5 gal)] to purge water remaining in the tubing bundle from previous decontamination operations. After the tubing bundle was purged, two samples were collected. The first sample (UE-5n 021104-1700#4) was collected 5.5 hr following collection of the last AEA deep-well sample. A duplicate sample (UE-5n 021104-1705#5) was collected immediately following the first sample.

Following the initial sampling process, the Bennet pump was used to further purge the well. Multiple problems were encountered. The pump was pulled from the well 4 separate times on February 2, 2004, for various repairs. Following the final repair, the total quantity pumped between 1600 on February 11, 2004 and 1800 on February 12, 2004, was 1500 L (396 gal). The

Bennet pump continued operating at 2.3 L/min (0.61 gal/min) until 1555 on February 23, 2004, when the final set was collected (sample UE-5n 021304-1555#1 and duplicate UE-5n 021304 1555#2). Approximately 3200 L (840 gal) were pumped over the final 23.5 hr before the samples were collected, and a total of 4700 L (1240 gal) were pumped with the Bennet pump from start to finish.

Analysis

All samples were analyzed solely for un-enriched tritium using EPA (1975). Analyses were conducted at the DRI tritium lab in Reno, Nevada, and were accompanied by the requisite method blanks and laboratory standards to ensure accuracy and precision in the results.

Results

The results of all analyses are presented in Table 1. The minimum detection limit for un-enriched tritium samples is approximately 300 pCi/L. The results from sample UE-5n 020304-1450#1 (bailer equipment blank) and sample UE-5n 021104-1030#1 (AEA field blank) indicate that activity falls below the detection limit for the analysis. These results are used as proof that the bailer did not contribute significant quantities of tritium to the samples, and the sampling environment did not contribute significant quantities of tritium to the AEA sample. The remaining samples produced activity results ranging from 146,000–160,000 pCi/L. The variability evidenced between samples and duplicate samples was very low, indicating that a high level of precision can be associated with the results.

Table 1. Results of tritium samples collected at Well UE-5n in Support of Evaluation of AEA Deep-Well Sampler.

Sample Number	Sample Type	Sample Result (pCi/L)	Error (pCi/L)
UE-5n 020304-1450#1	Bailer—equipment blank	39	210
UE-5n 020304-1520#2	Sample from 222.5 m (730 ft) bgs	146,000	960
UE-5n 020304-1555#3	Duplicate from 222.5 m (730 ft) bgs	147,000	910
UE-5n 021104-1030#1	AEA field blank	9	200
UE-5n 021104-1125#2	AEA from 228.6 m (750 ft) bgs	152,000	1,620
UE-5n 021104-1130#3	AEA duplicate from 228.6 m (750 ft) bgs	152,000	1,400
UE-5n 021104-1700#4	Bottoms-up with Bennet pump from 228.6 m (750 ft) bgs	146,000	900
UE-5n 021104-1705#5	Bottoms-up duplicate with Bennet pump from 228.6 m (750 ft) bgs	146,000	1,180
UE-5n 021304-1555#1	Purged Bennet sample from 228.6 m (750 ft) bgs	160,000	860
UE-5n 021304-1555#2	Purged Bennet duplicate from 228.6 m (750 ft) bgs	160.000	1,010

DISCUSSION

Sampling results in Table 1 reveal an interesting trend. The initial bailed samples yielded tritium activities averaging 146,500 ± 935 pCi/L. Tritium activities, following the intermittent purging of the well with the AEA deep-well sampler, increased to 152,000 ± 1510 pCi/L. When the AEA sampler was removed and the Bennet pump installed, tritium activity in the samples declined to 146,000 ± 935 pCi/L. Additional purging of the well with the Bennet pump produced samples yielding tritium activity averaging 160,000 ± 935 pCi/L.

These observations can be explained in terms of the evolving tritium concentrations within Well UE-5n due to natural processes and variations caused by the sampling activities. Following is a discussion regarding the source of tritium in Well UE-5n, a brief reference to previous observations while the well was sampled, and a review of the construction of the well.

The source of the tritium in Well UE-5n is from infiltration of tritiated water that flowed in a ditch located 100 m (328 ft) to the southwest of the well. This ditch transported tritiated water pumped from the cavity of an underground nuclear test for 17 years. The ditch was unlined, allowing for the tritiated water to recharge the groundwater system and slowly migrate laterally toward Well UE-5n.

Previous sampling efforts at Well UE-5n have indicated that the tritium activity in samples was affected by the quantity of water purged from the well. Bailed samples from the well had lower tritium activities than samples that had been extensively purged. The working hypothesis indicates that, under ambient conditions, water within Well UE-5n is relatively static and does not freely exchange with water in the surrounding aquifer. However, tritiated water within Well UE-5n can exchange (via isotopic exchange) with water vapor in the air. This air mass moves in and out of the well bore by barometric pumping. The net result is a decrease in the tritium activity within the well over time. Purging the well draws formation water into the well that contains tritium activities that are greater than the activities within the well bore. This working hypothesis explains why the activities of samples (with the exclusion of the initial Bennet pump samples) increased as more water was purged from the well.

In order to understand the difference between the final samples collected with the AEA deep-well sampler and the initial samples collected with the Bennet pump, one needs to understand the construction of Well UE-5n. The well consists of a 0.381 m (15 in) borehole drilled to a depth of 464 m (1523 ft) entirely in alluvium, having a water level of approximately 214.9 m (705 ft) bgs, and completed with 0.273 m (10 ¾ in) casing. The casing was perforated from 219.4 to 222.5 m (720 to 730 ft) bgs, and the hole volume from the water table to the bottom of the perforations was 0.869 m^3 (30.75 ft^3) or 869 L (229 gal). Bailed samples were collected at the bottom of the perforations and, due to the limited volume obtained during the sampling operations, were representative of water in the well bore and not of water in the surrounding formation. Tritium activities from the bailed samples averaged 146,000 ± 935 pCi/L.

AEA samples were collected from a depth of 228.6 m (750 ft)—6.0 m (20 ft) below the bottom of the perforations. The well volume from the water table to this sample depth was 1.56 m^3 (55.2 ft^3) or 1563 L (413 gal). The well volume from the sample point to the top of the perforations was 1.04 m^3 (36.8 ft^3) or 1040 L (275 gal). The AEA sampler purged a total volume of 656 L (173 gal). This volume was 42 percent of the well volume residing above the sample point to the water table and 63 percent of the well volume residing from the sample point to the top of the perforations. If it is assumed that all water is derived from the perforations and the water above the perforations are not affected by purging, then the 656 L purged by the AEA sampler constituted only 0.63 well volume. The standard for sampling is typically a minimum of three well volumes. Tritium activities collected from the AEA sampler averaged 152,000 ± 1510 pCi/L and were greater than the ambient tritium activities determined from the bailed samples. This indicated that the well was at least partially purged at the time of sampling.

Once the AEA deep-well sampler was removed, it took two attempts to run the Bennet pump in the well before the samples from 228.6 m (750 ft) were collected. The tritium activity in the Bennet samples (including the duplicate) averaged 146,000 ± 935 pCi/L showing that the activity in the Bennet samples was lower than in those acquired with the AEA sampler and statistically

identical with the activity in the bailer samples. It is hypothesized that running the various samplers in and out of the borehole multiple times caused the purged volume to become mixed with the water above the perforations, which had been relatively unaffected by purging. The lower tritium activities reflect this process. Alternatively, there may have been a discrepancy of several feet between the depth meters on the AEA sampler and the Bennet pump. If so, the Bennet pump may have been installed slightly deeper than the AEA sampler. Both conditions would result in lower tritium activities in the Bennet samples than in those collected with the AEA deep-well sampler. The former case should have produced samples with tritium activities that were intermediate in value between the bailed samples and those derived from the AEA deep-well sampler. Thus, the latter case is more likely given this observation

Once mechanical problems were resolved, the Bennet pump was used to purge a total of 4700 L (1242 gal) from the well. This volume of fluid represents 4.5 well volumes (defined as the sample point to the top of the perforations). The highest tritium activities were observed during the experiment (160,000 ± 935 pCi/L) and are assumed to be representative of formation fluids outside of the well bore.

CONCLUSIONS AND RECOMMENDATIONS

Tritium activities were greater in samples collected with the AEA deep-well sampler than in those collected with the bailer. This indicates that the deep-well sampler was able to conduct limited purging of the well without significant loss of tritium due to sampling procedures. The initial set of samples with the Bennet pump were likely affected by either sampling slightly deeper in the well or by mixing the purged section of the well with water above the perforations, which was relatively unaffected by purging. The final Bennet pump samples were collected following the removal of several well volumes, and the activity of these samples was the highest that was observed.

It is evident from the results that the AEA deep-well sampler is capable of purging the well, and the intermediate tritium values reflect that process. It has not been determined if the observed tritium values were significantly altered by the sampling process; i.e., were significant quantities of tritium lost through absorption into the plastic tubing or through air stripping during the sampling and purging processes.

This concern was evaluated through a simple mathematical model of a mixing cell within Well UE-5n. The top of the mixing cell resides at the top of the perforations at 219.4 m (720 ft) below the surface; the bottom of the mixing cell resides at the pump intake at 228.6 m (750 ft). The mixing cell has a volume of 1040 L. The model is presented in Equation 1:

$$dQ/dt = V_i T_i - V_o T_o \quad (1)$$

where Q is the change in total activity of tritium with respect to time (t) in the 1040 L mixing-cell volume; V_i is the volume of water flowing into the mixing cell and T_i is the tritium activity in that water; and V_o is the volume of water flowing out the mixing cell and T_o is the tritium activity of that water. The model was simplified by using a steady-state assumption. Thus, the inflow rate was the total volume (656 L) purged by the AEA deep-well sampler divided by the duration of time (124 hr) that the sampler was used to pump Well UE-5n. This resulted in an average inflow and outflow from the mixing cell of 4L/hr (1.06 gal/hr). In the model $V_i = V_o = 4$ L/hr, T_i is 160,000 pCi/L, and T_o at t_o is 146,500 pCi/L. Radioactive decay of tritium during the model period of 124 hours was assumed to be negligible. The equation was integrated with the results presented below:

$$Q = -1.404 \times 10^{7}\, e^{-(t/260)} + 1.664 \times 10^{8} \qquad (2)$$

The results from Equation 2 were normalized to an activity per unit volume by dividing the results by the volume of the mixing cell. The mixing-cell model was used to predict tritium activities within Well UE-5n for the entire volume of water that was purged using both the AEA deep-well sampler and the Bennet pump. The results of the model were compared to the observed tritium values in Figure 2. Examination of Figure 2 reveals that the sample activity obtained with the AEA deep-well sampler falls reasonably close to the activity predicted by the mixing-cell model after 656 L had been purged from the well. The difference between the predicted results (152,815 pCi/L) versus the observed results is 815 pCi/L. This difference is well within the error associated with the analysis. A comparison of the modeled and observed results reveals, despite the relatively simplistic assumptions of the model, that the samples acquired by the AEA sampler were representative of tritium activities that should have been present in the well as a function of the volume purged. A further conclusion can be made that the impact on the sampling results caused by the method of sampling used by the AEA sampler is indistinguishable from the error associated with the analysis.

Fig. 2. Comparison of mixing model results to observed tritium values from Well UE-5n.

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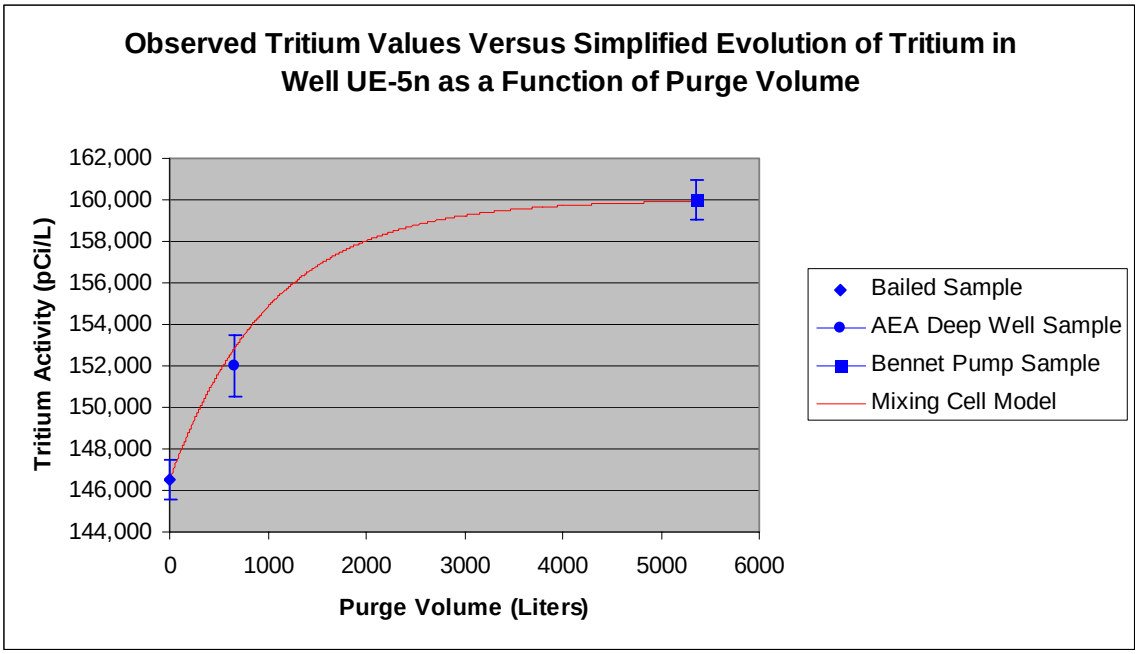

Fig. 2. Comparison of mixing model results to observed tritium values from Well UE-5n.

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