Subject: Groundwater Evaluation of the Shirley Basin South, Wyoming, Disposal Site

To Whom It May Concern:

This letter is in response to a letter from Mr. Dominick Orlando dated August 16, 2012. The letter indicated that U.S. Nuclear Regulatory Commission (NRC) staff had accepted the U.S. Department of Energy's (DOE) plan to conduct the following assessments and evaluations for the Shirley Basin South, Wyoming, Uranium Mill Tailings Radiation Control Act (UMTRCA) Title II Disposal Site:

- Develop an assessment of the attenuation of the constituents of concern (COCs)
- Evaluate the conceptual model for the site
- Assess the potential risk from the COCs
- Reevaluate the alternate concentration limits (ACLs) based on the assessment of potential risk and recommend a revision to the monitoring program, if appropriate

The enclosed report *Groundwater Evaluation and Recommended Monitoring for the Shirley Basin South, Wyoming, UMTRCA Title II Disposal Site* (August 2013), addresses these assessments and evaluations, which are in response to exceedances of ACLs for radium-226 and radium-228 in site monitoring wells. Of particular concern is elevated radium-226 in a downgradient well located at the site boundary.

Previous evaluations by DOE have led to the conclusions that the disposal cell is functioning as designed, a contaminant plume is not leaving the site, and that the elevated radium is due to localized mineralization (the monitoring wells are completed in the same formation that contains the uranium ore). DOE also recommended longer monitoring for several COCs because of their low concentrations or their insignificance as cell performance indicators.

The evaluations presented in the enclosed report support DOE's previous conclusions. A review of the former licensee's (Petrotomics) documents suggests that the assumptions for their aquifer modeling remain valid. Also, monitoring results from DOE's expanded well network indicate the site aquifers are behaving better than Petrotomics' groundwater modeling predicted, and verify that there is no evidence a plume is leaving the site. Furthermore, potential site-related contamination due to tailings seepage would not present any unacceptable risks at concentrations that are likely to be observed at the site boundary. Therefore, DOE proposes the following monitoring recommendations:
• Continue monitoring all site wells annually
• Continue monitoring uranium and thorium-230 according to the approved ACLs
• Continue monitoring radium-226 and radium-228, but without application of ACLs or other standards
• Continue monitoring cell performance and plume migration indicator constituents and parameters (chloride, nitrate, sulfate, pH, and total dissolved solids)
• Discontinue monitoring several COCs (cadmium, chromium, lead, nickel, and selenium).
• Evaluate monitoring program after 5 years and revise as warranted

Upon agreement with these recommendations by NRC, DOE will revise the site Long-Term Surveillance Plan (LTSP) accordingly. Implementation of the recommendations would commence following NRC concurrence of the revised LTSP.

Please call me at (720) 377-9682 if you have any questions. Please send any correspondence to:

U.S. Department of Energy
Office of Legacy Management
2597 Legacy Way
Grand Junction, CO 81503

Sincerely,

Scott R. Surovchak
Site Manager

cc w/enclosure:
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K. Frederick, WDEQ
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Groundwater Evaluation and Recommended Monitoring for the Shirley Basin South, Wyoming, UMTRCA Title II Disposal Site

August 2013
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Groundwater Evaluation and Recommended Monitoring
for the Shirley Basin South, Wyoming,
UMTRCA Title II Disposal Site

August 2013
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### Abbreviations

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<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ACL</td>
<td>alternate concentration limit</td>
</tr>
<tr>
<td>COC</td>
<td>constituent of concern</td>
</tr>
<tr>
<td>DOE</td>
<td>U.S. Department of Energy</td>
</tr>
<tr>
<td>EPA</td>
<td>U.S. Environmental Protection Agency</td>
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<tr>
<td>HEL</td>
<td>health effects level</td>
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<tr>
<td>KM</td>
<td>Kaplan-Meier</td>
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<tr>
<td>mg/L</td>
<td>milligrams per liter</td>
</tr>
<tr>
<td>MTL</td>
<td>maximum tolerance level</td>
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<tr>
<td>NRC</td>
<td>U.S. Nuclear Regulatory Commission</td>
</tr>
<tr>
<td>pCi/L</td>
<td>picocuries per liter</td>
</tr>
<tr>
<td>Petrotomics</td>
<td>Petrotomics Company</td>
</tr>
<tr>
<td>POC</td>
<td>point of compliance</td>
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<tr>
<td>POE</td>
<td>point of exposure</td>
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<tr>
<td>TDS</td>
<td>total dissolved solids</td>
</tr>
<tr>
<td>UCL&lt;sub&gt;95&lt;/sub&gt;</td>
<td>95 percent upper confidence limit on the mean</td>
</tr>
<tr>
<td>UMTRCA</td>
<td>Uranium Mill Tailings Radiation Control Act</td>
</tr>
<tr>
<td>UPL&lt;sub&gt;95&lt;/sub&gt;</td>
<td>95 percent upper prediction limit</td>
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Executive Summary

The Shirley Basin South, Wyoming, Uranium Mill Tailings Radiation Control Act Title II Disposal Site was transferred to the U.S. Department of Energy (DOE) under the U.S. Nuclear Regulatory Commission general license in 2005 from the former licensee Petrotomics Company (Petrotomics). The site's Long-Term Surveillance Plan required monitoring eight site wells to confirm groundwater compliance. The wells are completed in two aquifers within the uranium-ore-bearing formation that was mined at the site.

DOE’s first sampling event in 2005 indicated that cadmium and radium-228 concentrations exceeded approved alternate concentration limits (ACLs) in some of the wells. A review of historical data showed that concentrations of these constituents had exceeded ACLs in those wells prior to site transfer. Cadmium concentrations have been below the ACL since 2005. However, radium-228 has remained above the ACL in two wells.

The response to these exceedances included installing six new downgradient monitoring wells in 2008 to determine if a contaminant plume was leaving the site. Concentrations of all groundwater constituents of concern in the new wells were within the required standards except for elevated radium-226 in one well near the site boundary. Subsequent evaluations by DOE concluded that the elevated radium concentrations at the site were due to localized mineralization in the formation being monitored and did not represent offsite movement of a contaminant plume. After review of those evaluations, the U.S. Nuclear Regulatory Commission requested additional information to support DOE’s conclusions.

The subsequent evaluation provided in this report supports DOE's original conclusions. A further review of Petrotomics' ACL application and groundwater modeling, combined with an evaluation of groundwater monitoring data collected by Petrotomics and DOE, indicate that elevated radium concentrations at the site represent localized ore mineralization. There is no evidence to suggest that the disposal cell is not functioning as designed, and the attenuation capacity of the formation is sufficient to prevent offsite plume migration of the legacy groundwater contamination. Furthermore, potential site-related contamination due to tailings seepage will not present any unacceptable risks at concentrations that are likely to be observed at the site boundary. Therefore, DOE proposes the following monitoring recommendations.

- Continue monitoring all site wells annually.
- Continue monitoring uranium and thorium-230 according to the approved ACLs.
- Continue monitoring radium-226 and radium-228, but without application of ACLs or other standards.
- Continue monitoring cell performance and plume migration indicator constituents and parameters (chloride, nitrate, sulfate, pH, and total dissolved solids).
- Discontinue monitoring several constituents of concern (cadmium, chromium, lead, nickel, and selenium).
- Evaluate monitoring program after 5 years and revise as warranted.
1.0 Purpose and Scope

Groundwater at the Shirley Basin South Uranium Mill Tailings Radiation Control Act (UMTRCA) Title II disposal site (the site) is being monitored by the U.S. Department of Energy (DOE) Office of Legacy Management in accordance with the approved Long-Term Surveillance Plan (DOE 2004). DOE acquired the site under the U.S. Nuclear Regulatory Commission (NRC) general license in 2005 and began annual groundwater monitoring that year. The monitoring well network for the site is shown in Figure 1. Aquifers in the Upper Sand (wells have the suffix “SC”) and Main Sand (wells have the suffix “DC”) units of the Wind River Formation are being monitored. Monitoring well K.G.S.#3, a former potable water supply well for milling operations, is completed in the Lower Sand unit of the Wind River Formation.

DOE’s first sampling event in 2005 indicated that cadmium concentrations in point-of-compliance (POC) well 5-SC and radium-228 concentrations in POC well 5-DC and downgradient well 54-SC exceeded approved alternate concentration limits (ACLs). A review of historical data showed that these constituents had exceeded ACL concentrations in those wells prior to site transfer. Cadmium concentrations have been below the ACL since 2005. However, radium-228 has remained above the ACL in wells 5-DC and 54-SC.

The response to these exceedances included installing six new downgradient monitoring wells in 2008 (shown in Figure 1) to determine if a contaminant plume was leaving the site. Concentrations of all constituents of concern (COCs) in the new wells have been within the required standards except for elevated radium-226 in well 110-DC near the site boundary. Subsequent evaluations by DOE (March and June 2011) concluded that the elevated radium concentrations at the site were due to localized mineralization in the formation being monitored and did not represent movement of a contaminant plume. Consequently, DOE recommended a revised monitoring program that eliminated sampling for several COCs, including radium-226 and radium-228. After review of those evaluations and recommendations, NRC requested additional information to support DOE’s conclusions (NRC 2012).

In response to NRC’s request, this evaluation consists of three main topics: (1) review of the conceptual site model developed by Petrotomics, particularly with respect to attenuation of COCs; (2) assessment of the potential risk from the COCs; and (3) a reevaluation of the appropriateness of the ACL values based on this review. This review relied on historical data collected by Petrotomics in support of their ACL application, which was subsequently accepted by NRC, as well as additional data collected by DOE since the time the site was transferred to DOE.

2.0 Site History

The Petrotomics uranium mill began operation at the site in 1962 with a production capacity of 500 tons per day. In 1968, the capacity was expanded to 1,000 tons per day by the addition of thickeners, leach tanks, and another solvent extraction circuit. The mill was expanded again in 1970 to a capacity of 1,500 tons per day (Getty 1981).
Figure 1. Monitoring Well Network at the Shirley Basin South, Wyoming, Disposal Site
The ore being processed through the mill came from open pit mines in the immediate vicinity of the mill. The mill was a conventional acid leach uranium-ore processing plant (Getty 1981). Chemical reagents used in the milling and solvent extraction process included ammonia, sodium chlorate and chloride, and sulfuric acid.

The tailings from milling operations were placed in the tailings pond from the beginning of operation in 1962. In 1985, due to the depressed uranium market, the mining and milling operations were shut down and mill decommissioning commenced. Mill components that were not salvaged and sold were buried or placed in the disposal cell (Petrotomics 2001).

NRC approved Petrotomics' corrective action plan in 1989. Corrective action included remediation of the contaminated aquifer underlying the impounded tailings. Groundwater was pumped from numerous extraction wells until the tailings and the aquifer were essentially dewatered. The pumped water was evaporated in lined ponds. Further remediation was determined to be impractical; therefore, Petrotomics applied for ACLs in 1996 and was granted NRC concurrence in 1998. The cell cover was completed in 2000, and final site reclamation was completed in 2001 (Petrotomics 2001).

### 3.0 Review of the Conceptual Site Model

#### 3.1 Hydrogeology

The main aquifers of concern at the site are in the Upper Sand and Main Sand units of the Tertiary Wind River Formation. Prior to mining at the site, the groundwater flow generally followed the dip of these units, which is to the northeast. Both sand units crop out upgradient (south) of the site and are recharged by meteoric water in those areas; however, the surface expression of the Upper Sand unit south of the site is minimal.

The disposal cell was constructed in place (i.e., the mill tailings were not relocated). Although a shale layer is present over much of the Upper Sand unit in the area, it is absent under portions of the disposal cell. Consequently, leachate in the mill tailings drained into the Upper Sand unit during milling operations, followed by transient drainage from the disposal cell.

The Main Sand is discontinuously separated from the Upper Sand by an intervening shale. This shale unit pinches out to the northeast of the disposal cell in the vicinity of Pit 4 where the Main Sand and Upper Sand units coalesce, resulting in a combined thickness of approximately 140 feet (Figure 2). The Main Sand is the unit that contained the uranium ore body that was open-pit mined at the site. Petrotomics also noted that the shale aquitard unit is locally absent under the north portion of the disposal cell as evidenced by high concentrations of mill-related constituents in former well 12-DC in the Main Sand aquifer. It is suspected that contaminants in the Upper Sand aquifer migrated to the Main Sand aquifer in this area of hydraulic connection.

Interbedded claystones, siltstones, and thinly bedded sandstones totaling more than 50 feet thick separate the Main Sand unit from the underlying Lower Sand unit. The Lower Sand unit is approximately 100 feet thick at the site and was unaffected by uranium mineralization. Monitoring results from well K.G.S.#3, completed in the Lower Sand unit, continue to verify that mill-related contaminants are not present in the Lower Sand aquifer.
Figure 2. Cross Section A-A' of the Shirley Basin South, Wyoming, Disposal Site
Groundwater was removed from the Upper Sand and Main Sand units in the disposal cell area during corrective action to remediate the contaminated groundwater. The aquifers in this area were essentially dewatered. During mining operations and prior to groundwater remediation, the aquifers were dewatered in the mine pit area northeast of the disposal cell.

The ACL application noted that the Upper Sand unit should eventually dry up near the disposal cell as transient drainage ceases. Decreasing water levels observed in this aquifer near the disposal cell suggests that transient drainage from the encapsulated mill tailings continues to decline or has stopped, and that upgradient natural recharge is minimal (Figure 3). Monitoring well 51-SC, located immediately downgradient of the disposal cell, was dry at the time of the 2011 and 2012 sampling events. Water level measurements in the other wells indicate that the groundwater flow is to the northeast as expected.

While water levels continue to decline in the Upper Sand aquifer near the disposal cell, the Main Sand water table is rising, indicating a recovery from dewatering activities (Figure 4). However, recovery is not occurring as fast as predicted in the ACL application. Natural recharge to the Main Sand aquifer occurs at the outcrop area south of the site and may be occurring at the partially reclaimed mine pit area. Assuming transient drainage from the disposal cell continues to decline or has ceased, recharge to the aquifer is mainly by uncontaminated meteoric water. The potentiometric surface of the Main Sand aquifer at the site is essentially flat, so there is no discernible flow direction at this time. Although it has not been investigated, recovery of both aquifers may be controlled by the surface elevation of Ur Energy’s (formerly Pathfinder Mining Company) pit lake located north of the site boundary.

The point of exposure (POE) for site groundwater is considered to be the site boundary. However, the nearest practical POE is the Ur Energy pit lake because the Upper and Main Sand aquifers have no surface expression and are not used as a groundwater source between the site and the pit lake. The Ur Energy mine pit intersects the same Upper Sand and Main Sand aquifers, so it is assumed that these aquifers discharge water to the lake. In Petrotomics’ ACL application, the contribution of these aquifers to the pit lake was estimated at 2 percent of the lake volume.

3.2 Geochemistry

Sulfate and pH relationships. Geochemical modeling was conducted as part of the ACL application to determine the likely speciation of constituents in the groundwater under the varied conditions observed at and downgradient of the disposal cell. In particular, changes in pH and redox state were accounted for in the model to evaluate potential attenuation between the former impoundment (area of the current disposal cell) and the restricted area boundary (the area licensed by NRC for the containment and disposal of mill byproduct material). Calcite in the aquifer matrix reacts with the acidic tailings fluids, raising the pH of the groundwater. These reactions cause concentrations of dissolved metals to attenuate through sorption, precipitation, or coprecipitation mechanisms.
Figure 3. Hydrographs of the Upper Sand Aquifer Monitoring Wells

Figure 4. Hydrographs of the Main Sand Aquifer Monitoring Wells
The modeling and site-specific observations led to the conclusion that groundwater pH and sulfate provide the best predictors of water quality. It was concluded that at pH higher than 4 and sulfate levels less than 6,000 milligrams per liter (mg/L), metals would be attenuated to very low levels that are considered to be acceptable at the POE (site boundary). Flow and transport modeling indicated that these conditions would be met and maintained at the site boundary even after steady-state conditions at the site are achieved (estimated to occur by 2050). A statistical analysis of all data with pH greater than 4 and sulfate less than 6,000 mg/L was conducted to estimate predicted concentrations for POE locations. Some inconsistencies were noted for radium data (i.e., concentrations were elevated even at high pH and low sulfate); these were attributed to the presence of naturally mineralized zones.

To evaluate whether the geochemical relationships (and therefore the geochemical model) described in the ACL application still hold, post-1997 data were examined. Data after 1997 were evaluated because groundwater remediation activities were completed, and the decline of water levels in the Main Sand aquifer monitoring wells had stopped or reversed (see Figure 4).

Concentrations of metals versus pH for this data set are shown in Appendix A Figures A-1 through A-11. One striking feature of these data is a pronounced gap between pH values of approximately 5 and 6. Metals concentrations for the high-pH samples are relatively low; low-pH samples tend to have higher and more variable metals concentrations. Sulfate concentrations for all but a few low-pH samples are higher than for high-pH samples.

Based on the post-1997 data set, it appears that the general model of acidic plume neutralization and metals attenuation with groundwater migration through the aquifer still holds. However, data for the site show that a better cutoff in terms of pH is probably 5 rather than 4, as assumed in the ACL application (Figure 5). This is consistent with observations reported in the literature for other milling and mining sites with acidic plumes (Zhu et al. 2002, Brown et al. 1999, Kjoller et al. 2004). At those sites, reactions between acidic fluids and the aquifer matrix result in sharp pH, redox, and precipitation-dissolution reaction fronts that produce distinct geochemical zones in the aquifer. The interface between the zones tends to be sharp and narrow as opposed to gradual.

Several studies report the occurrence of an initial geochemical divide at a pH of about 5 where surface reactions between groundwater and aquifer solids become significant (Zhu et al. 2002). Other divides at higher pH levels are attributed to other reactions such as calcite dissolution. It has been suggested that the low-pH portion of a plume can persist for quite some time, even after flushing of many pore volumes of water, due to acidity retained on surfaces of aquifer solids.

With continued seepage of tailings fluids, the reaction zones can shift downgradient. The time-concentration plot for pH shows that pH was more variable during corrective action for both the high- and low-pH groups. No discernible trends are observed. Graphs of the newer wells (Figure 5) near the site boundary (100-SC, 102-SC, 112-DC, 113-DC) have distinctly higher pH values than the rest of the high-pH wells. These wells, which also have the lowest concentrations of sulfate and total dissolved solids (TDS) (along with well 110-DC), as shown on Figure 6 and Figure 7, may represent another distinct geochemical zone in the aquifer.
Petrotomics estimated POE concentrations for groundwater based on a data set with pH > 4 and sulfate < 6,000 mg/L. Modeling indicated that these conditions would be met at the site boundary. A 95 percent upper confidence limit on the mean \( (UCL_{95}) \) was calculated for each constituent in this data set to provide a reasonable maximum estimate of groundwater concentrations at the site boundary (the POE); this approach is consistent with standard U.S. Environmental Protection Agency (EPA) guidance for developing exposure point concentrations for risk assessments (EPA 2002). The more recent evaluation reported here suggests that the use of a data set with a pH > 5 is more likely to represent concentrations beyond the initial acid front. The high-pH data set was used to calculate \( UCL_{95} \) values to serve as potential exposure point concentrations for POE locations. All of the COC concentrations using the post-1997 data set with pH > 5 are lower than Petrotomics POE estimates (Table 1). Those results are discussed further in Section 3.3.
Figure 6. Post-1997 Sulfate Time-Concentration Plots for All Site Wells

Figure 7. Total Dissolved Solids Time-Concentration Plots for All Site Wells
Table 1. Comparison of Constituent Concentration Predictions at the POE

<table>
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<tr>
<th>Constituent</th>
<th>Petrotomics POE Predictions (all data as of 1997)</th>
<th>Current Evaluation POE Predictions (post-1997 data)</th>
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<tr>
<td>Cadmium (mg/L)</td>
<td>0.038</td>
<td>0.00081</td>
</tr>
<tr>
<td>Chromium (mg/L)</td>
<td>0.077</td>
<td>0.00164</td>
</tr>
<tr>
<td>Lead (mg/L)</td>
<td>0.18</td>
<td>0.00177</td>
</tr>
<tr>
<td>Nickel (mg/L)</td>
<td>1.32</td>
<td>0.0864</td>
</tr>
<tr>
<td>Radium-226 (pCi/L)</td>
<td>148</td>
<td>35.92</td>
</tr>
<tr>
<td>Radium-228 (pCi/L)</td>
<td>39.9</td>
<td>3.67</td>
</tr>
<tr>
<td>Selenium (mg/L)</td>
<td>0.038</td>
<td>0.00497</td>
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<tr>
<td>Thorium-230 (pCi/L)</td>
<td>20.7</td>
<td>0.322</td>
</tr>
<tr>
<td>Uranium (mg/L)</td>
<td>1.25</td>
<td>0.0288</td>
</tr>
</tbody>
</table>

Key: mg/L = milligrams per liter; pCi/L = picocuries per liter

Effects of natural mineralization. As noted in the ACL application (Petrotomics 1997), radium-226 concentrations for some high-pH samples were inconsistent with the observations for other constituents. That is, unlike other constituents that indicated lower concentrations in groundwater with higher pH, radium-226 concentrations were less predictable (Figure A-6). Petrotomics observed that the distribution of radium in the groundwater system was dissimilar to that of other seepage-related constituents. Additionally, concentrations of radium in site background wells were observed at more than three times the UMTRCA standard. This observation of anomalous radium behavior was attributed to naturally mineralized zones.

Figure 8 shows results of uranium analyses (0.001–0.101 mg/L) from three boreholes located in an unmined portion of the site (from Petrotomics 1997). Concentrations up to 0.5 percent U₃O₈ were reported for the borehole cores. The boreholes, completed as wells 14-DC, 15-DC, and 16-DC—which are no longer present at the site (Figure 1)—were sampled nine times between March 1994 and February 1996. Groundwater samples from these wells also had elevated concentrations of total radium (radium-226 plus radium-228), ranging from 166 to 1,241 picocuries per liter (pCi/L) (Figure 9), despite having relatively high pH (5.4–7.0). These elevated concentrations were not the result of attenuation of disposal cell–contaminated groundwater, as demonstrated by substantially lower concentrations in wells 10-DC and 19-DC, which are upgradient from former wells 14-DC, 15-DC, and 16-DC but downgradient of the disposal cell. For the full period of sampling from April 1992 through June 2012, uranium concentrations in well 10-DC have ranged from 0.005 to 0.029 mg/L, with an average of 0.013 mg/L; concentrations in POC well 19-DC, sampled from September 1998 through June 2012, have averaged 0.0019 mg/L. During the same sampling periods, the highest total radium concentrations were 49.3 pCi/L in August 1995 for well 10-DC and 18.3 pCi/L in July 2009 for well 19-DC. Therefore, the elevated uranium and radium concentrations in the three decommissioned wells are attributed to a localized ore zone.

This correlation between ore mineralization and elevated uranium and radium is characteristic of the Wind River Formation regionally. Harshman (1972) reported groundwater data from samples from a spring and 30 wells and boreholes in the vicinity of the site (Table 2 of that report). Sixteen of the samples had radium concentrations that exceeded the current EPA drinking water standard of 5 pCi/L, with concentrations ranging up to 100 pCi/L. Uranium concentrations in six of the samples exceeded the current EPA drinking water standard of 0.030 mg/L, with
Figure 8. Uranium Time-Concentration Plots for Petrotomics Wells 14-DC, 15-DC, and 16-DC

Figure 9. Radium Time-Concentration Plots for Petrotomics Wells 14-DC, 15-DC, and 16-DC
concentrations as high as 0.42 mg/L. Sulfate concentrations for these samples were low (<800 mg/L), and pH was high (averaged 7.7). These occurrences were attributed to the natural mineralization of the formation. Lowry (1973) cited naturally occurring total radium concentrations up to 1,700 pCi/L in the region.

The observation that radium concentrations are not well correlated with pH and sulfate reinforces the conclusion that natural sources of uranium and radium are likely to be present across the site and surrounding portions of the Wind River Formation. Groundwater concentrations in these source areas will likely not be uniform, but will be influenced by localized concentrations of ore minerals.

DOE is seeing the same inconsistency with well 110-DC. High radium-226 concentrations (>120 pCi/L) are associated with high pH (>6.4) and relatively low sulfate (<1,900 mg/L). As in the ACL application and the other sources referenced in this section, DOE attributes these aberrant concentrations to the presence of natural mineralization as opposed to the downgradient migration of a contaminant plume from the disposal cell. This conclusion is supported by the fact that if concentrations observed at well 110-DC were the result of downgradient plume migration, much higher concentrations of radium-226 should be observed in wells upgradient of well 110-DC (e.g., POC wells); no such observations have been made.

**Attenuation Capacity.** Conservative calculations by Petrotomics estimated the attenuation capacity of the aquifers at an order of magnitude higher than required to completely neutralize the tailings fluid inventory. Their calculations were based on an estimated volume of tailings fluids from discharge records; a conservative tailings fluid pH of 2.6; a calculated aquifer volume capacity (top of the Upper Sand unit to the base of Main Sand unit within the site boundary); and a calculated available calcite concentration of 4.74 moles per liter (mol/L) (0.142 mol/L is needed to neutralize to pH of 6.8). Petrotomics concluded that the attenuation capacity of the formation is more than adequate to prevent offsite plume migration.

Harshman (1972) noted that calcite is not evenly distributed throughout the Wind River Formation and is present as both matrix cement and as large concretions (which would have less surface area for reaction). Variations in the percentage of calcite would result in variable buffering capacity. However, observations seem to indicate a system that is fairly stable with respect to pH. The low-pH wells (wells close to the disposal cell) continue to have low pH, and the high-pH wells (wells closer to the site boundary) continue to have high pH (Figure 5). The high-pH wells are not showing any indication of decreasing pH. Therefore, there is no evidence to date that the acidic front has migrated downgradient since the termination of corrective action.

### 3.3 Relationship Between POC and POE Concentrations

The POC wells (particularly 5-SC) have shown considerable variability over time for most constituents. This is likely due to the nature of the acidic water in this part of the Upper Sand aquifer. Fluctuating pH levels may explain the fluctuation of other metals concentrations as well with the possible exception of uranium; uranium behavior tends to be more dependent on redox conditions. Even if concentrations of constituents in POC wells appeared to show an increasing trend, this would not necessarily signal excessive cell leakage, especially since water levels in the Upper Sand aquifer are declining.
Declines in water levels in the Upper Sand aquifer could mean that dissolved constituents are concentrated in a lesser quantity of aquifer water, thereby resulting in increases of contaminant concentrations. At an UMTRCA Title I site where dewatering was occurring in an area containing remnant subsurface contamination, increased concentrations were observed in groundwater during a time of lowered water levels (DOE 2010) and were attributed to the lower volume of water. At another Title I site, increases in uranium concentration were observed after a major flood event in a distal portion of a groundwater plume (DOE 2013). It has been hypothesized that the raised water levels resulted in mobilization of uranium that was sorbed to shallow aquifer materials. Similarly, rising water levels in the Main Sand unit could mean renewed interaction of groundwater with aquifer materials containing sorbed and precipitated constituents; this interaction could remobilize these constituents.

While it may never be possible to fully explain specific increases and decreases of particular constituents at a given well location, it is evident that the low-pH groundwater present in the vicinity of the POC wells represents a highly reactive zone. It would not be unrealistic to see future concentrations of COCs within the range of historical concentrations.

The unpredictability of contaminant behavior in POC wells does not, however, affect the ability to ensure the protectiveness of the site. As long as Upper Sand aquifer water levels decline or eventually level off, it can be assumed that no unacceptable cell leakage is occurring. Monitoring water levels in the Upper Sand aquifer may be a more reliable indicator of cell cover performance than groundwater chemistry, assuming that limiting infiltration of water through the cell cover equates to adequate performance. Additionally, unlike at some other Title II sites, estimated POE concentrations are not dependent on maintaining certain concentrations at the POC (e.g., where attenuation is accomplished largely through dispersion and dilution during contaminant transport). Rather, the POE levels are contingent only on the geochemistry and attenuation capacity of the aquifers and the ability to maintain a pH greater than 5 in the vicinity of the site boundary. As long as the acid front (pH areas less than 5) is maintained within the site boundary, fluctuations of contaminant concentrations in POC wells have no bearing on POE concentrations.

3.4 Comparison Between Model Predictions and Actual Results

In their ACL application, Petrotomics predicted groundwater elevations for both aquifers for the year 2010 and for ultimate steady-state conditions, and sulfate and uranium concentrations for both aquifers for the years 2000, 2010, 2020, 2050, 2100, 2200, 2500, and 3000. The following subsections compare Petrotomics' 2010 predictions with results from DOE's June 2010 sampling event. The comparisons add further evidence that a contaminant plume is not causing the elevated radium concentrations and that the predicted attenuation capacity of the aquifers is conservative.

Groundwater Elevations. Figure 10 and Figure 11 show the predicted groundwater potentiometric surface and corresponding elevations measured by DOE for the Upper Sand and Main Sand aquifers, respectively. Actual groundwater elevations in the Upper Sand aquifer range from approximately 31 to 48 feet below the predicted elevations in the northeast (downgradient) portion of the site (Figure 10). As shown in Figure 3, groundwater elevations in this aquifer continue to decline in wells near the disposal cell while elevations in wells near the site boundary are increasing slightly. POC well 51-SC has dried up, suggesting that the disposal cell has essentially eliminated surface recharge upgradient of the well. This also suggests that if the cell
Figure 10. 2010 Groundwater Elevations in the Upper Sand Aquifer
Figure 11. 2010 Groundwater Elevations in the Main Sand Aquifer
continues to leak, then leakage is minimal. This aquifer response was predicted by Petrotomics, but dewatering of the Upper Sand aquifer near the disposal cell has occurred faster than predicted. Several factors are likely contributing the present conditions: recharge has been significantly reduced by the presence of the disposal cell; Pit 4 excavation removed the confining layer in that area, so groundwater recharge and/or evaporation may be occurring at the bottom of Pit 4; and the Ur Energy pit lake north of the site may be controlling the downgradient elevation.

Figure 4 shows that groundwater elevations are increasing in the Main Sand aquifer, which was predicted, but actual measurements indicate that recharge is occurring much slower than the predicted rate. The 2010 measurements were approximately 19–33 feet below the predicted elevations (Figure 11). The reasons for this difference are likely similar to the reasons for the lower-than-predicted elevations in the Upper Sand aquifer. With probably minimal or no recharge from cell leakage, the water recharging the aquifer is likely from precipitation in a recharge area southwest of the disposal cell and through the bottom of Pit 4.

**Sulfate Concentrations.** Predicted and actual sulfate concentrations for the Upper Sand aquifer are shown in Figure 12. The actual concentrations are substantially below predicted concentrations except for those at well 5-SC, which is upgradient of the boundary at which the Petrotomics model predicted no saturation in the Upper Sand aquifer (shown as the model zero saturation limit in Figure 10). Groundwater in the area of this well, located close to the north edge of the cell, is minimal and may not be flowing; contaminant concentrations are expected to be high under these conditions. Sulfate concentrations in the Main Sand aquifer on the east side of the site (10-DC, 112-DC, and 113-DC) are essentially as predicted, while concentrations in the other wells are substantially below predicted values (Figure 13).

**Uranium Concentrations.** Except at well 5-SC, the 2010 uranium concentrations in the Upper Sand aquifer are very low (Figure 14). The value of 3.4 mg/L for well 5-SC is most likely elevated for the same reason as sulfate. It is concluded that uranium in this aquifer is responding as well as, or better than, predicted. Uranium concentrations for the Main Sand aquifer are shown on Figure 15. Unlike in the Upper Sand aquifer, actual uranium concentrations in the Main Sand aquifer are at least an order of magnitude below predicted concentrations.

### 4.0 Potential Risk from the COCs

The Petrotomics ACL application identified livestock and other terrestrial receptors (e.g., antelope) as the most probable users of groundwater at the POE. To ensure protection of this use, they identified health effects levels (HELs) for comparison with predicted POE concentrations. They considered and rejected State of Wyoming livestock standards as appropriate HELs. Instead, maximum tolerance levels (MTLs) (NAS 1980) were determined to be more appropriate for establishing HELs for nonradiological constituents. Radiological benchmarks used for wildlife at the Rocky Flats, Colorado, Environmental Technology Site (Higley 1996) were adopted for radionuclides. An updated version of the MTLs (NAS 2005) was consulted to determine if any of those values had changed. While some values have been adjusted slightly higher or lower, none had changed significantly. Therefore, the HELs from Petrotomics’ ACL application are retained for this evaluation.
Figure 12. 2010 Sulfate Concentrations in the Upper Sand Aquifer
Figure 13. 2010 Sulfate Concentrations in the Main Sand Aquifer
Figure 14. 2010 Uranium Concentrations in the Upper Sand Aquifer
Figure 15. 2010 Uranium Concentrations in the Main Sand Aquifer
As previously noted, revised predicted POE values for this evaluation were based on a data set with pH > 5. Table 2 provides Petrotomics' HELs, Wyoming livestock watering standards, predicted POE concentrations, and maximum background concentrations for comparison. All current predicted POE concentrations are lower than both Petrotomics' POE predictions and the HELs that NRC concurred with in the ACL application. With the exception of radium, predicted POE values are also below State of Wyoming livestock standards.

Table 2. Comparison of Predicted Concentrations to Health Effects Levels and Livestock Standards

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Approved HEL in Petrotomics' ACL Application</th>
<th>Wyoming Standard for Livestock Watering</th>
<th>POE Predictions in Current Evaluation</th>
<th>Maximum Background from ACL Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cadmium (mg/L)</td>
<td>5.0</td>
<td>0.05</td>
<td>0.0081</td>
<td>0.05</td>
</tr>
<tr>
<td>Chromium (mg/L)</td>
<td>1,000</td>
<td>0.05</td>
<td>0.00164</td>
<td>0.06</td>
</tr>
<tr>
<td>Lead (mg/L)</td>
<td>30</td>
<td>0.1</td>
<td>0.00177</td>
<td>0.024</td>
</tr>
<tr>
<td>Nickel (mg/L)</td>
<td>50</td>
<td>NA</td>
<td>0.0864</td>
<td>0.28</td>
</tr>
<tr>
<td>Radium-226 (pCi/L)</td>
<td>400</td>
<td>5 pCi/L total</td>
<td>35.92</td>
<td>18.8</td>
</tr>
<tr>
<td>Radium-228 (pCi/L)</td>
<td>300</td>
<td></td>
<td>3.67</td>
<td></td>
</tr>
<tr>
<td>Selenium (mg/L)</td>
<td>2</td>
<td>0.05</td>
<td>0.00497</td>
<td>0.009</td>
</tr>
<tr>
<td>Thorium-230 (pCi/L)</td>
<td>400</td>
<td>NA</td>
<td>0.322</td>
<td>13.70</td>
</tr>
<tr>
<td>Uranium (mg/L)</td>
<td>40</td>
<td>NA</td>
<td>0.0288</td>
<td>3.24</td>
</tr>
</tbody>
</table>

Key: ACL = alternate concentration limit; HEL = health effects level; mg/L = milligrams per liter; pCi/L = picocuries per liter; POE = point of exposure

It was not readily apparent from this review how Petrotomics developed their HELs for water. The MTLs are predominantly for feed and are reported in units of milligrams per kilogram. It appears that Petrotomics assumed an equivalent parts per million concentration (i.e., milligrams per liter) would be appropriate for water. While this assumption may not be appropriate, it is of little practical consequence because all constituents except radium are predicted to be below corresponding livestock standards.

Although no standards have been established for nickel, uranium, and thorium, those concentrations are predicted to be less than the maximum background. As previously discussed, elevated radium concentrations represent local mineralized zones in the ore body. It can therefore be concluded that any contamination due to tailings seepage will not present any unacceptable risks at concentrations that are likely to be observed at the POE.

5.0 Appropriateness of ACL Values

Development of Petrotomics' approved ACLs assumed that groundwater concentrations observed in POC wells after taking corrective action would be representative of future concentrations (i.e., these data represent the new "baseline" conditions for the site). Conceptually this approach is valid, but there were two questionable assumptions associated with its implementation. First, data used in calculating the ACLs were collected while the corrective action system was in operation and thus did not account for the rebound in concentrations that commonly occurs when a groundwater remediation system is shut down. Second, the statistical measure that was used to estimate ACLs was a UCL95 of the data set. This statistic is not used to predict future concentrations, but to estimate a population mean based on past observations.
To correct for the first condition, only post-remediation (after 1997) data were used in the current ACL calculation. For the second, instead of a UCL\(_{95}\), a 95 percent upper prediction limit (UPL\(_{95}\)) was the statistic used to estimate the ACLs. A UPL\(_{95}\) is an estimate of a maximum future concentration that is likely to be observed based on the current data set. This estimator of a future maximum value represents a more reasonable “not to exceed” value for an ACL than an estimator of the population mean (EPA 2010).

The low-pH post-1997 data set (January 1998 through June 2012) was analyzed with EPA’s ProUCL statistical software (http://www.epa.gov/osp/hstl/tsc/software.htm). Nonparametric techniques were selected to account for the non-normality of the data and to accommodate nondetects. UPL\(_{95}\) values were determined using several methods. The software recommended the use of a Kaplan-Meier (KM) method. Results for the 95 percent KM Chebyshev UPL yielded the highest predictions. Table 3 presents these results for each constituent; current ACLs are provided for comparison. Some values based on the post-1997 data set are higher than current ACLs, including radium and uranium, while others are lower.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Current ACLs</th>
<th>95% KM Chebyshev UPL for post-1997 Low-pH Data Set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cadmium (mg/L)</td>
<td>0.079</td>
<td>0.139</td>
</tr>
<tr>
<td>Chromium (mg/L)</td>
<td>1.83</td>
<td>1.734</td>
</tr>
<tr>
<td>Lead (mg/L)</td>
<td>0.05</td>
<td>0.0326</td>
</tr>
<tr>
<td>Nickel (mg/L)</td>
<td>6.15</td>
<td>6.715</td>
</tr>
<tr>
<td>Radium-226 (pCi/L)</td>
<td>91.3</td>
<td>98.49</td>
</tr>
<tr>
<td>Radium-228 (pCi/L)</td>
<td>25.7</td>
<td>157.7</td>
</tr>
<tr>
<td>Selenium (mg/L)</td>
<td>0.12</td>
<td>0.109</td>
</tr>
<tr>
<td>Thorium-230 (pCi/L)</td>
<td>2,409</td>
<td>1,110</td>
</tr>
<tr>
<td>Uranium (mg/L)</td>
<td>9.2</td>
<td>11.99</td>
</tr>
</tbody>
</table>

Key: ACL = alternate concentration limit; mg/L = milligrams per liter; pCi/L = picocuries per liter

Cadmium, chromium, lead, nickel, and selenium, which are COCs with current ACLs, were previously evaluated by DOE (2011a and 2011b). Based on factors including consistently low monitoring results, being poor indicators of cell leakage, being readily attenuated, and not posing a hazard at the site boundary, DOE concluded that continued monitoring of these constituents is not necessary or beneficial. Time versus concentration plots for all COCs in the Long-Term Surveillance Plan are provided in Appendix B.

### 6.0 Recommended Compliance Monitoring

#### 6.1 Well Network

DOE recommends continuing to monitor all of the site wells (Figure 1). Upper Sand aquifer wells 5-SC and 51-SC and Main Sand aquifer wells 5-DC and 19-DC would continue to be monitored as POC wells. New Upper Sand aquifer wells 100-SC and 102-SC and Main Sand aquifer wells 110-DC and 113-DC would be monitored as POE wells.
6.2 Constituents and Limits

It is recommended that two hazardous constituents—uranium and thorium-230—be retained for long-term disposal cell compliance monitoring. Although the basis for the establishment of ACLs for uranium and thorium-230 may be questionable, they have already received NRC approval and appear to be reasonable for long-term monitoring needs. It is not likely, based on post-remediation observations, that use of these values would trigger unwarranted evaluations, especially using the monitoring approach outlined below. It is recommended, therefore, that the ACLs for those two constituents remain as they are.

As demonstrated in this evaluation, ACLs for radium-226 and radium-228 are inappropriate because of naturally occurring radium in the ore body being monitored. Continuing to monitor for these constituents is considered useful in verifying this conclusion and to observe how concentrations fluctuate as the aquifers continue to stabilize to steady-state conditions. Therefore, DOE recommends to continue monitoring for radium-226 and radium-228, but without application of ACLs or other groundwater protection limits.

Chloride, nitrate, sulfate, TDS, and pH should also be monitored as cell-performance and plume migration indicator constituents and parameters without ACLs. Proposed monitoring constituents and concentration limits are provided in Table 4. Monitoring data for hazardous and indicator constituents will be qualitatively evaluated for the presence of trends even if an ACL or other standard is not exceeded.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>ACL</th>
<th>Groundwater Protection at the POE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thorium-230</td>
<td>2,409 pCi/L&lt;sup&gt;a&lt;/sup&gt;</td>
<td>NA</td>
</tr>
<tr>
<td>Uranium</td>
<td>9.2 mg/L&lt;sup&gt;a&lt;/sup&gt;</td>
<td>NA</td>
</tr>
<tr>
<td>Radium-226</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Radium-228</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Chloride</td>
<td>NA</td>
<td>2,000 mg/L&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Nitrate + Nitrite as N</td>
<td>NA</td>
<td>100 mg/L&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Sulfate</td>
<td>NA</td>
<td>3,000 mg/L&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>TDS</td>
<td>NA</td>
<td>5,000 mg/L&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>pH</td>
<td>NA</td>
<td>&gt;5&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Key: ACL = alternate concentration limit; mg/L = milligrams per liter; NA = not applicable; pCi/L = picocuries per liter; POE = point of exposure; TDS = total dissolved solids
<sup>a</sup> Final ACL approved in License Amendment (NRC 2002)
<sup>b</sup> Wyoming Class III (livestock) groundwater protection standard
<sup>c</sup> Concentration to ensure that concentrations of metals meet protective HELs for livestock watering

Sulfate and pH will be tracked for wells downgradient of POC wells to ensure that attenuation criteria are maintained. If trends suggest that a groundwater standard or criterion may be exceeded at the site boundary, a statistical analysis may be performed to quantify these predictions and consider the need for an evaluative monitoring program. Currently, sulfate concentrations at the proposed POE wells are well below the 3,000 mg/L groundwater protection standard, and pH levels are well above the 5 threshold.

If an ACL for a hazardous constituent is exceeded at a POC well, DOE will inform NRC and the Wyoming Department of Environmental Quality of the results. If results from the next two
annual sampling events confirm that concentrations remain above an ACL (i.e., an exceedance is observed for 3 consecutive years), DOE will develop an evaluative monitoring work plan and submit it to NRC for review before implementing it. Results of evaluative monitoring will be used, in consultation with NRC and the Wyoming Department of Environmental Quality, to determine if any action is necessary.

### 6.3 Monitoring Frequency

Annual sampling of all site monitoring wells would continue for a minimum of 5 years after NRC approval of the revised compliance monitoring program. After the fifth sampling event, the groundwater monitoring program will be evaluated to determine if the disposal cell is performing as designed (i.e., no evidence of unexpected leakage) and if changes to the monitoring program are appropriate. Recommendations drawn from the evaluation will be submitted to NRC for concurrence and could include continuation of the monitoring program or revision of the program (i.e., changes to the analyte list or sampling frequency).

### 7.0 References


Appendix A

Groundwater Constituent Concentration Versus pH Plots for Post-1997 Data
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Figure A-1. Cadmium Concentrations Versus pH for Post-1997 Data.

Figure A-2. Chloride Concentrations Versus pH for Post-1997 Data.
Figure A-3. Chromium Concentrations Versus pH for Post-1997 Data.

Figure A-4. Lead Concentrations Versus pH for Post-1997 Data.
Figure A-5. Nickel Concentrations Versus pH for Post-1997 Data.

Figure A-6. Radium-226 Concentrations Versus pH for Post-1997 Data.
Figure A-7. Radium-228 Concentrations Versus pH for Post-1997 Data.

Figure A-8. Selenium Concentrations Versus pH for Post-1997 Data.
Figure A-9. Sulfate Concentrations Versus pH for Post-1997 Data.

Figure A-10. Thorium-230 Concentrations Versus pH for Post-1997 Data.
Figure A-11. Uranium Concentrations Versus pH for Post-1997 Data.
Appendix B

Groundwater Constituent Time-Concentration Plots for All Data
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Figure B-1. Cadmium Time-Concentration Plots for All Data

Note: A hollow symbol denotes an analytical result below the detection limit.
Figure B-2. Chloride Time-Concentration Plots for All Data
Figure B-3. Chromium Time-Concentration Plots for All Data

Note: A hollow symbol denotes an analytical result below the detection limit.
Note: A hollow symbol denotes an analytical result below the detection limit.

Figure B-4. Lead Time-Concentration Plots for All Data
Figure B-5. Nickel Time-Concentration Plots for All Data

Note: A hollow symbol denotes an analytical result below the detection limit.
Figure B.6. Nitrate as Nitrogen Time-Concentration Plots for All Data

Note: A hollow symbol denotes an analytical result below the detection limit.
Figure B-7. Nitrate + Nitrite as Nitrogen Time-Concentration Plots for All Data

Note: A hollow symbol denotes an analytical result below the detection limit.
Note: A hollow symbol denotes an analytical result below the detection limit.

Figure B-8. Radium-226 Time-Concentration Plots for All Data
Figure B-9. Radium-228 Time-Concentration Plots for All Data

Note: A hollow symbol denotes an analytical result below the detection limit.
Figure B-10. Selenium Time-Concentration Plots for All Data

Note: A hollow symbol denotes an analytical result below the detection limit.
Figure B-11. Sulfate Time-Concentration Plots for All Data
Note: A hollow symbol denotes an analytical result below the detection limit.

Figure B-12. Thorium-230 Time-Concentration Plots for All Data
Figure B-13. Total Dissolved Solids Time-Concentration Plots for All Data
Note: A hollow symbol denotes an analytical result below the detection limit.

Figure B-14. Uranium Time-Concentration Plots for All Data