UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

September 6, 2016

Mr. Steve Hatten
President
Lost Creek ISR, LLC.
5880 Enterprise Drive, Suite 200
Casper, WY 82609

SUBJECT: AMENDMENT NO. 5, SOURCE MATERIAL LICENSE NO. SUA-1598, LOST CREEK IN-SITU RECOVERY PROJECT, SWEETWATER COUNTY, WY, UNDERGROUND INJECTION CONTROL CLASS V FACILITY AND 2016 SURETY UPDATE (TAC NOS. L00782 AND L00805)

Dear Mr. Hatten:

By letter dated March 3, 2015, (U.S. Nuclear Regulatory Commission's (NRC's) Agencywide Documents Access and Management System (ADAMS) Accession No. ML15076A400), Lost Creek In-Situ Recovery (ISR), LLC (LCI) submitted a request for amendment to its license for the Lost Creek facility for the on-site disposal of treated liquid waste through injection into on-site shallow well(s). In addition, by letter dated December 7, 2015 (ADAMS Accession No. ML16021A490), LCI submitted a revision to the 2016 annual financial assurance amount.

The NRC staff has completed its review of the Class V amendment request and the 2016 surety update calculations and approves both requests. Enclosed, please find the NRC staff's "*Safety Evaluation Report, Review of the Request for On-site Disposal of Liquid Waste to Shallow, Underground Injection Control Class V Well(s) and the 2016 Annual Surety Update*" and Source Material License No. SUA-1598, Amendment 5. For the 2016 surety update, the NRC staff has approved the amount of $14,996,900 to cover a third party cost for reclamation of the facility (Enclosure 1). Amendment No. 5 to LCI's Source Material License reflecting changes to the appropriate license conditions by approving the amendment requests is attached (Enclosure 2).

Pursuant to requirements under the National Environmental Policy Act, staff has prepared an Environmental Assessment for this action (ML16216A273). The Finding of No Significant Impact (FONSI) for this action has been published in the Federal Register on September 6, 2016 (81 FR 61257).

In accordance with 10 CFR 2.390 of the NRC's "Agency Rules of Practice and Procedure," a copy of this letter will be available electronically for public inspection in the NRC Public Document Room or from the Publicly Available Records component of ADAMS. ADAMS is accessible from the NRC Web site at http://www.nrc.gov/reading-rm/adams.html.

If you have any questions regarding this action, please contact Mr. John Saxton, the Project Manager for Source Material License No. SUA-1598, at 301-415-0697 or, by e-mail, at John.Saxton@nrc.gov.

Sincerely,

***/RA/***

Andrea Kock, Deputy Director
Division of Decommissioning, Uranium Recovery
and Waste Programs
Office of Nuclear Material Safety
and Safeguards

Docket No.: 040-09068
License No.: SUA-1598

Closes TAC Nos.: L00782 and L00805

Enclosures:
1. Safety Evaluation Report: Review of the Request for On-site Disposal of Liquid Waste to Shallow, Underground Injection Control Class V Well(s) and the 2016 Annual Surety Update
2. Amendment No. 5, Source Material License No. SUA-1598

cc: B. Wood, WDEQ
M. Newman, BLM

If you have any questions regarding this action, please contact Mr. John Saxton, the Project Manager for Source Material License No. SUA-1598, at 301-415-0697 or, by e-mail, at John.Saxton@nrc.gov.

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M. Newman, BLM

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**SAFETY EVALUATION REPORT**
**REVIEW OF THE REQUEST FOR ON-SITE DISPOSAL OF LIQUID WASTE TO SHALLOW UNDERGROUND INJECTION CONTROL CLASS V WELL(S) AND THE 2016 ANNUAL SURETY UPDATE**
**LOST CREEK ISR, LLC LOST CREEK PROJECT**
**SWEETWATER COUNTY, WYOMING**

| | |
|---|---|
| **Docket No.:** | 040-09068 |
| **License No.:** | SUA-1598 |
| **Date:** | May 19, 2016 |
| **Facility:** | Lost Creek Project |
| **Technical Reviewers:** | John Saxton<br>David Brown<br>Reginald Augustus |
| **Project Manager:** | John Saxton |

## 1.0 Summary and Conclusions

### 1.1 <u>Request for On-site Disposal through a Underground Injection Control Class V Well</u>

By letter dated March 3, 2015, Lost Creek ISR, LLC (LCI) submitted a request for disposal of treated liquid byproduct material waste through injection into on-site shallow well(s) (LCI, 2015a). The request consists of a Technical Report (TR) and Environmental Report (ER), which was supplemented with additional information in response to staff's request for additional information (NRC, 2015; LCI, 2015b). In addition, in April 2015, LCI revised its technical report in response to comments by Wyoming Department of Environmental Quality (WDEQ); LCI submitted a copy of the revised report to the NRC on February 8, 2016, (LCI, 2016a).

LCI proposes to inject treated byproduct material waste into UIC Class V injection wells that is located near the existing central processing plant and approximately 450 meters (m) (1500 feet [ft]) from the nearest wellfield, (i.e., Mine Unit 1). LCI proposed to use M-FG7 as its primary injection well with M-FG6 designated as a backup injection well should the need arise. The injection wells will be screened at an approximately 60-m (200-ft) interval within the shallowest saturated formation, which LCI has designated as the DE and FG horizons of the Battle Spring Formation. The depth to the water table in the area of the proposed injection is approximately 60-m (200-ft). The proposed maximum injection rate is 760 liters per minute (L/min) (200 gallons per minute [gpm]) and the requested maximum permissible injection pressure is $3.15 \times 10^5$ pascals (Pa) (45.7 pounds per square inch, [psi]). Based on a continuous injection rate of 225 L/min (60 gpm) for the first 5 years and 760 L/min (200 gpm) during the remainder of an assumed operational period of 14 years, LCI estimates the total injected volume to be $4.2 \times 10^9$ L ($1.480 \times 10^8$ cubic feet (1.1 billion gallons)). These values are independent of the number of wells, or which well performs the injection.

Enclosure

LCI proposes to treat the liquid byproduct material through ion exchange (IX) to remove uranium; reverse osmosis (RO) to remove total dissolved solids, radionuclides and metals; and an additional IX with specialty resins containing barium sulfate salts to remove radium. The LCI proposes to add: (1) low concentrations of sulfate prior to the final treatment to minimize dissolution of barium sulfate from the resins; and (2) pH neutralizing caustic soda (sodium hydroxide) to increase the pH levels to at least 6.0 standard units. LCI stated the treated fluids will meet the effluent concentrations in Appendix B to 10 CFR Part 20 and proposed a monitoring program to ensure those levels are maintained throughout the life of the operations.

In addition to NRC approval, use of the wells will require permitting by the State of Wyoming as a Class V facility through the Underground Injection Control (UIC) program. Wyoming Water Quality Rules and Regulations Chapter 27, Section 2(l), provide that a Class V facility means any property that contains an injection well, which is not defined as a Class I, II, III or IV well. In general, Class V wells are permitted to inject specified treated wastewater into the shallow subsurface. WDEQ granted permit number 15-081 by letter dated November 27, 2015 (WDEQ, 2016).

This Class V request complements the existing approved disposal alternative consisting of injecting concentrated liquid byproduct material waste into UIC Class I deep disposal well(s). The UIC Class I wells are designed to inject brine from the RO treatment (i.e., concentrated byproduct material stream) into the deep subsurface and that remains unchanged by this request, which is for disposal of RO treatment permeate. Prior to this amendment, the existing uses for permeate include makeup water for the plant process water, makeup water for the barren lixiviant, evaporation during its residence in the storage ponds, and disposal in the Class I deep disposal well.

The NRC staff evaluated whether LCI's proposed disposal procedure meets the requirements of 10 CFR 20.2002. In brief, the requirements of 10 CFR 20.2002 require an analysis and procedures to ensure that the resultant doses are As Low As is Reasonably Achievable (ALARA) and meet the dose limits. As discussed in this Safety Evaluation Report (SER), the current NRC staff practice is to approve on-site disposal of radioactive materials based on a dose criterion of a few millirem per year.

The Class V injection zone is the same overlying aquifer designated for the ISR operations (i.e., FG horizon); however, as documented in this SER, the NRC staff agrees with LCI's calculations that the proposed injection is sufficiently far from the nearest ISR wellfield to have negligible impacts on its operation; specifically the required monitoring to ensure LCI confines its possession and use of source material to the wellfield. The licensee proposes adequate monitoring to ensure the levels in the injected fluid are ALARA and meet the effluent concentrations in Appendix B to 10 CFR Part 20. In addition, the proposed action will reduce consumptive use of the aquifer by injecting water back into the aquifer.

As documented in this SER, the NRC staff finds that the proposed disposal procedures satisfy those requirements. Therefore, staff recommends approval of the amendment request as Amendment No. 5 to Source Material License No. SUA-1598 with the recommended revised and additional License Conditions, the bases for which are discussed in detail in this SER.

## 1.2 *2016 Annual Surety Update*

By letter dated December 17, 2015, LCI submitted to the NRC for review and approval of its 2015-2016 annual surety update (LCI, 2015d). The itemized costs were included in a submittal dated December 7, 2015 (LCI, 2015c). The LCI's estimated costs for reclamation by a third party for activities to be performed during the reporting period is $14,996,900.

As discussed in this SER, staff reviewed the estimated costs and finds the update is based on current dollars and consists of reasonable costs for the required reclamation activities. Therefore, staff recommends approval of this update and amending LC 9.5 to include the revised total reclamation cost of $14,996,900.

# 2.0 Background

## 2.1 *Request for On-site Disposal through a UIC Class V Well*

In the approved license application for the Lost Creek facility, as amended (LCI, 2008), Lost Creek ISR, LLC (LCI) states that the waste disposal system, consisting of at least two UIC Class I deep disposal wells, adequately supports the liquid effluent needs for the Lost Creek Project. The LCI had anticipated that the permeate, or the clean water portion of the liquid waste after treatment through a Reverse Osmosis (RO) system, would be re-injected into the wellfield(s), sent to storage for use in the ISR process or disposed of through the wastewater disposal system. Shortly after beginning operations in October 2013, LCI realized that uses for large volumes of permeate during the initial operations were limited and often required disposal to the wastewater disposal system. However, the disposal capacity for the wastewater disposal system was less than originally anticipated due to actual lower formation injection rates for the installed wells. The additional disposal of permeate stressed the wastewater-disposal-system capacity. Consequently, in discussion with NRC staff, LCI has been evaluating alternative disposal methods (e.g., land application, enhanced evaporation, and UIC Class V well injection).

By letter dated March 3, 2015, LCI submitted a request for disposal of treated liquid byproduct material waste through injection into on-site shallow wells (LCI, 2015a). The amendment request consists of a TR and ER, which were supplemented by additional information submitted in response to staff's request for additional information (LCI, 2015b). In addition, LCI revised the TR on April 15, 2015, in response to comments by the WDEQ and provided the revised report to NRC on February 8, 2016 (LCI, 2016a).

## 2.2 *2016 Annual Surety Update*

Pursuant to LC 9.5 of License SUA-1598, LCI is required: (1) to maintain an NRC-approved surety arrangement to adequately cover decommissioning and decontamination costs if performed by a third party; and (2) to submit annual updates to the financial surety amount.

By letter dated December 17, 2015, LCI submitted to NRC for review and approval of its 2015-2016 annual surety update (LCI, 2015d). The itemized costs were included in a submittal dated December 7, 2015 (LCI, 2015c). LCI's estimated costs for reclamation by a third party for activities to be performed during the reporting period is $14,996,900.

This safety evaluation report (SER) documents staff's review of the Class V amendment request and the 2015-2016 annual surety update.

## 3.0 Regulatory Basis

### 3.1 *Request for Waste Disposal through a UIC Class V Well*

LCI proposed to inject treated liquid waste into a single Class V well. LCI proposed to inject waste into well M-FG7, and retain well M-FG6 as a backup injection well. Class V is defined by the Underground Injection Control (UIC) program administered by the Wyoming Department of Environmental Quality, Water Quality Division (WDEQ/WQD). The applicable state regulations are found in Wyoming's Water Quality Rules and Regulations (WQRR): the Quality Standards for Wyoming Groundwaters, Chapter 8; Well Construction Standards, Chapter 26; and Underground Injection Control Program Class I and V Wells, Chapter 27. Class V wells are injection wells not included in Class I, II, III or IV. In general, Class V wells inject non-hazardous fluids (i.e., commercial, industrial or municipal waste) directly into or above formations that contain underground sources of drinking water. In the amendment request (LCI, 2015a), LCI identified the proposed request as Subclass 5C3, which, in Appendix C of WQRR Chapter 27, is defined as:

> Industrial Process Water and Waste Disposal Facilities - Receive wastes generated by industrial and commercial processes. Examples include but are not limited to wastes from car washing, taxidermy, metal plating, printing, silk screening, refining, slaughter houses, and chemical manufacturing companies.

For an individual Class V permit under WQRR Chapter 27, the facility shall include a pre-treatment plan to insure toxic materials/substances are not discharged to the groundwater at concentrations higher than the class-of-use standards (WQRR Chapter 8) or the Maximum Contaminant Level (MCL) in the National Primary Drinking Water Regulations (40 CFR Part 141), whichever is more stringent.

For purposes of NRC, the proposed action is on-site disposal of treated liquid byproduct material waste. The applicable sections of NRC regulation are as follows:

10 CFR Part 20
- Subpart B Radiation Protection Programs
  - 10 CFR 20.1101 Radiation protection programs
- Subpart D Radiation Dose Limits to Individual Members of the Public
  - 10 CFR 20.1301 Dose limits for individual members of the public
  - 10 CFR 20.1302 Compliance with dose limits for individual members of the public
- Subpart K Waste Disposal
  - 10 CFR 20.2001 General requirements
  - 10 CFR 20.2002 Method for obtaining approval of proposed disposal procedures

At the present time, LCI is authorized for storage of liquid byproduct material in the storage ponds and disposal by injection into deep disposal wells.

The NRC staff's evaluation consists of LCI's proposed revisions to its Radiation Protection Program to ensure adequate protection of occupational health and safety, LCI's compliance with dose limits to ensure adequate protection of the public's health and safety, and, LCI's methods and procedures to meet NRC's alternative disposal requirements in 10 CFR 20.2002.

### 3.2 *2016 Annual Surety Update*

LC 9.5 of LCI's License SUA-1598 requires submittal of annual updates to the financial assurance amount. Along with the amount, LCI is required to submit supporting documentation:

- "*showing a breakdown of the costs and the basis for the cost estimates with adjustments for inflation, maintenance of a minimum 15-percent contingency of the financial assurance estimate, changes in engineering plans, activities performed, and any other conditions affecting the estimated costs for site closure.*"

This LC is based on 10 CFR Part 40, Appendix A, Criterion 9, which states in part the following:

- *The licensees's surety mechanism will be reviewed annually by the Commission to assure, that sufficient funds would be available for completion of the reclamation plan if the work had to be performed by an independent contractor. The amount of surety liability should be adjusted to recognize any increases or decreases resulting from inflation, changes in engineering plans, activities performed, and any other conditions affecting costs.*

## 4.0 Description of License Amendment Request

### 4.1 *Request for On-site Disposal through a UIC Class V Well*

LCI proposed to inject treated byproduct material waste into one UIC Class V injection well located near the existing central processing plant and approximately 450 m (1500 ft) from the nearest wellfield, i.e., Mine Unit 1. LCI proposed to use well M-FG7 as its primary injection well with M-FG6 designated as the backup injection well. The Wyoming permit issued to LCI for a Class V facility limits the injection to two wells, M-FG6 and M-FG7. For purposes of NRC staff's evaluation, the primary evaluation criteria are (1) the maximum injection rate of 200 gpm, the injection interval, the 14 year duration of the injection, and the injectate quality. The injection can occur in one or two wells provided the total injection rate is less than or equal to the maximum injection rate, and the wells are located within the area defined by the existing monitoring wells (M-FG6 through M-FG10). In this SER, NRC staff evaluated the impact if the injection was through a single well at the maximum injection rate, which is a conservative assumption because assuming all the injectate occurs through one well maximizes the injection pressure and groundwater mounding.

The injection well(s) will be screened at an approximately 60-m (200-ft) interval within the shallowest saturated formation, which LCI has designated as the DE and FG horizons of the Battle Spring Formation. The depth to the water table in the area of the proposed injection is approximately 60 m (200 ft). The proposed total maximum injection rate is 760 L/min (200 gpm) and the requested maximum permissible injection pressure is 3.15 x $10^5$ Pa (45.7 psi). Based on a continuous injection rate of 265 L/min (60 gpm) for the first 5 years and 760 L/min (200 gpm) during the remainder of an assumed operational period of 14 years, LCI estimates the total injected volume to be 4.2x$10^9$ L (1.48x$10^8$ cubic feet (1.1 billion gallons)).

LCI described the modifications to the water treatment system in Sections 1.0 and 5.2.1 of the TR (LCI, 2015a). The modified water treatment system would be comprised of the following major components (in order of water flow through the plant): (1) uranium ion exchange columns; (2) bag filters (that remove particles greater than 5 micron diameter); (3) reverse osmosis (RO) units; (4) sodium hydroxide addition pumps; (5) a slip stream of well water containing low concentrations of sulfate to minimize dissolution of barium sulfate from the resin surface; (6) two Radium Selective Complexer resin columns (i.e., radium resin vessels); (7) high-density polyethylene pipeline, and; (8) Class V injection and monitor wells. LCI proposed to add (1) low concentrations of sulfate to the fluids prior to the final treatment to minimize dissolution of barium sulfate from the resins and (2) pH neutralizing caustic soda, sodium hydroxide, to increase the pH levels to at least 6.0 standard units. LCI stated the treated fluids will meet the regulatory effluent limits and proposes a monitoring program to ensure those levels are maintained throughout the life of the operations.

### 4.2 *2016 Annual Surety Update*

For the 2016 annual surety update, LCI includes costs for Decommissioning and Decontamination (D&D) of the Central Processing Plant and ancillary equipment, deep disposal wells, and ponds (LCI, 2015d). LCI estimates the total cost to D&D the facility by an independent party at $14,996,900. This figure represents an increase of $356,900 over the surety established for the prior year of $14,640,000. The increase is attributed to: (1) unit cost increases due to inflation; (2) inclusion of reclamation and decommissioning costs for all header houses up to HH13; and (3) costs for performing 5-year Mechanical Integrity Tests. The cost estimate is based on costs of a third party contractor, does not take credit for any salvage value and includes a 29 percent contingency factor.

The period covered for this update is from October 1, 2015 to September 30, 2016. This period coincides with the annual period for WDEQ's Permit to Mine.

## 5.0 Staff's Evaluation

### 5.1 *Request for On-site Disposal through a UIC Class V Well*

The NRC staff evaluated LCI's proposed changes to its radiation protection program for the new system components (Section 5.1.1) and LCI's proposed disposal procedures (Section 5.1.2).

#### 5.1.1 Radiation Protection Program for the New Components

The first three components of the modified water treatment system (items 1 through 3 described above) -- the uranium ion exchange columns, bag filters, and RO units -- are part of LCI's existing licensed process and were previously evaluated and found acceptable by the NRC staff

(NRC, 2011). In addition, staff has not identified any un-reviewed safety-related concerns pertinent to the applicant's characterization of that system. The new components not previously evaluated by NRC staff are the components that are downstream of the RO units (i.e., items 4 through 8 described in Section 4.1 of this SER). In Section 7.4 of the TR (LCI, 2015a), LCI described radiation protection controls to support the proposed modifications to its existing water treatment system.

The NRC staff evaluated LCI's proposed new system components. As stated above, the NRC staff previously evaluated LCI's radiation protection design features and procedures for its existing treatment system for liquid byproduct material waste (NRC, 2011). Since the proposed system treats the same waste (i.e., the waste stream total quantity and quality remain the same as was previously evaluated), the NRC staff determined that, other than the radium resin vessels, the new components would not contain radioactive materials in quantities or concentrations above those already contained in existing systems covered by the NRC-approved LCI radiation protection program. NRC staff also determined that the proposed treatment system will not result in any new air or liquid effluents, or, as described below, direct radiation levels in an unrestricted area above 0.002 rem (0.02 millisievert) in any one hour. For this reason, the NRC staff determined that LCI's current NRC-approved program for ensuring public dose limits are met will remain sufficient for the modified water treatment system. Therefore, the NRC staff focused its evaluation below on the specific controls described by LCI for the radium resin vessels.

In Section 5.2.1 of the TR, LCI described the radium resin vessels as two fiberglass vessels, approximately 4 feet in diameter and 6 feet tall (LCI, 2015a). In Appendix C of the TR, LCI provided information prepared by Dow Chemical Company about the physical properties of the DOWEX Radium Selective Complexer (DOWEX RSC) resin (LCI, 2015a). LCI described radiation protection controls for operation and maintenance of the radium resin vessels in Section 7.4 of the TR (LCI, 2015a).

The NRC staff used the information provided by LCI to independently assess the direct radiation exposure rate that might be expected in the vicinity of fully-loaded radium resin, which could either be in operation inside a radium vessel or stored for disposal. The NRC staff used the computer software MicroShield (Grove Software 2013) to model the radiation exposure rate, assuming the lead column of a two-column series is fully loaded at the resin's maximum design capacity of 20 nanocuries radium-226 per gram of resin. The NRC staff determined the exposure rate would be less than 20 milliroentgen per hour (mR/hr) at a distance of 30 centimeters (cm) from a fully-loaded radium resin vessel. This indicates the area around a loaded radium resin vessel could become a radiation area (i.e., > 5 mrem/hr at 30 cm), but not a high radiation area (i.e., > 100 mrem/hr at 30 cm). The NRC staff also estimated it would take one to three years for radiation levels to rise to this level assuming RO permeate contains radium-226 at about 135 picocuries per liter (pCi/L). The NRC staff's estimated value of 135 pCi/L radium-226 is explained in Section 5.1.2 of this SER. Therefore, LCI's proposal to initially monitor gamma rates at least weekly during the first charge of resin, and no less than monthly thereafter, provides reasonable assurance that area radiation levels will be appropriately posted and occupational doses will be maintained at acceptable levels consistent with LCI's radiation protection program.

All other radiation protection controls described by LCI for the proposed modified water treatment system are consistent the requirements in the existing NRC-approved radiation protection program. These controls include: the use of Standard Operating Procedures (SOPs) and radiation work permits (RWPs) for operation, maintenance, and spill control; the use of Personal Protective Equipment in contamination areas; a contamination control program; and a program for unrestricted release of equipment.

Therefore, NRC staff finds the proposed amendment request consistent with requirements of §§ 20.1101, 20.1301 and 20.1302.

5.1.2 Approval for the Proposed Disposal Procedures

For this type of waste disposal, the proposed procedures must satisfy requirements in 10 CFR Part 20, Subpart K "Waste Disposal", specifically §§ 20.2001 and 20.2002. Guidance on meeting these requirements is provided in NUREG-1569 "Standard Review Plan for in Situ Leach Uranium Extraction License Applications" (NRC, 2003). Although written for Deep Well injection (i.e., UIC Cass I wells) rather than shallow injection wells (UIC Class V wells), Acceptance Criterion (13) of Section 6.1.3 of NUREG-1569 states the following:

> Proposals for disposal of liquid waste from process water by injection in deep wells must meet the regulatory provisions in 10 CFR 20.2002 and demonstrate that doses are ALARA and within the dose limits in 10 CFR 20.1301. The injection facility should be described in sufficient detail to satisfy the NRC need to assess environmental impacts. **Specifically, proposals must include: (i) a description of the waste, including its physical and chemical properties important to risk evaluation; (ii) the proposed manner and conditions of waste disposal; (iii) an analysis and evaluation of pertinent information on the nature of the environment; (iv) information on the nature and location of other potentially affected facilities; and (v) analyses and procedures to ensure that doses are ALARA, and within the dose limits in 10 CFR 20.1301** (emphasis added).

The five items listed in the above guidance are adopted from language in 10 CFR 20.2002 "Method for obtaining approval of proposed disposal procedures". The NRC staff's evaluation of LCI's proposal relative to these five items is provided below.

(i) Description of the Waste (10 CFR 20.2002(a))

Section 10 CFR 20.2002(a) requires applicants to provide a description of the waste. LCI provided a description of the waste by describing (a) the source of the material to be injected into the Class V wells, (b) the treatment of the material prior to injection, (c) the estimated constituent concentrations in the waste after the treatment, and (d) the proposed constituent concentration limits for the waste.

The source of material to be injected consists of fluids derived from (1) the operational bleed including both the operation and restoration periods, (2) plant processing, (3) laboratory wastewater, (4) wastewater from drilling, completion and maintenance of the wells, and (5) waste from spills. These materials are 11e.(2) byproduct material, which is subject to NRC jurisdiction. In addition, because the disposal is through injection into the subsurface, the disposal is subject to Wyoming jurisdiction under the Water Quality Division Underground Injection Control program.

LCI estimates that the injection rate to be on the order of 40 to 260 Lpm (10 to 70 gpm) during uranium recovery operations and 190 to 760 Lpm (50 to 200 gpm) during aquifer restoration.

On Table 3.3 of the TR (LCI, 2015a), LCI reported the proposed concentration limits in the waste for the radionuclides of concern. The radionuclides of concern consist of several decay products in in the uranium decay chain (i.e., natural uranium (U-nat), radium-226 (Ra-226), radium-228 (Ra-228), thorium-230 (Th-230), lead-210 (Pb-210), polonium-210 (Po-210)), and the indicator parameters gross alpha and gross beta. The proposed limits are based on (1) the maximum concentration detected in the aquifer (background) for natural uranium, total radium (Ra-226 and Ra-228), gross alpha[1] and gross beta, and (2) the effluent concentration in Table 2, Appendix B in 10 CFR Part 20 for Th-230, Pb-210 and Po-210.

LCI reported the expected concentrations for U-natural and Ra-226 in the treated waste based on the RO manufacturer's calculation of brine and permeate quality using the LCI's expected RO feed chemistry (LCI, 2015a). For the remaining radionuclides, LCI included a footnote that the "[v]alue not determined, but RO rejection estimated to be approximately 98 percent of feed concentration." In the Class V amendment request, LCI did not include a summary of the feed concentration. The NRC staff's evaluation of the expected radionuclide concentrations in the waste is provided below.

*Natural Uranium:*

In Table 3-3 of the TR (LCI, 2015a), LCI reported the expected post treatment concentration of U-nat to be 0.012 milligrams per liter (mg/L). While staff agrees that these levels are achievable, LCI did not provide details of the RO manufacturer's analysis (e.g., the pre-treatment concentration and whether the RO treatment consists of a single stage or two stages). In its approved license application (LCI, 2008), LCI stated that the expected uranium concentrations in the lixiviant after the IX treatment (and pre-RO treatment) would be less than five parts per million (i.e., < 5 mg/L). LCI also stated that the RO treatment is effective in reducing the activity of most ions in the fluid by 95 to 99 percent. NRC staff calculated that, if the pre-treatment U-nat concentration was 5 mg/L, the RO treatment needed to be 99.8 percent efficient to achieve the reported expected concentration of 0.012 mg/L, or 96.8 percent efficient to achieve the proposed limit of 0.158 mg/L. NRC staff has reasonable assurance that LCI can achieve the 0.158 mg/L level in the treated waste because properly treated RO units are usually at least 96.8 percent efficient for the reduction of uranium and the treated fluids will be routinely monitored and will verify through monitoring that the RO efficiency is as anticipated.

*Radium-226:*

[1] The proposed gross alpha is based on the measured measurement minus radon and uranium.

In Table 3-3 of the TR (LCI, 2015a), LCI reported an expected post-treatment Ra-226 concentration of 0.78 picocuries per liter (pCi/L). However, the statement in LCI's amendment request that "the levels are based on the RO manufacturer's information" does not apply to Ra-226. In general, Ra-226 concentrations increase in the lixiviant during operations and Ra-226 levels are difficult to return to background levels following restoration even with RO treatment. For example, LCI provided information in 2016 which indicated that Ra-226 levels prior to RO treatment are as high as 2,700 pCi/L (LCI, 2016b). The NRC staff estimated that if the efficiency of the RO equipment is 95 percent, then the radium-226 concentration in RO permeate could be 135 pCi/L.

LCI's proposed use of specialized resin for the additional treatment eliminates the need for a settling pond. Whether or not the expected Ra-226 concentrations in treated liquid waste (i.e., 0.78 pCi/L) will be achieved is based on the efficiency of the specialized resin treatments. The documentation provided by LCI on the specialized resin indicates the resin can reduce radium-226 concentrations from 135 pCi/L to below 0.78 pCi/L. However, NRC staff will include a LC that incorporates LCI's commitment for monthly monitoring for the first six months of operation to verify that the proposed post-treatment radium concentrations are achievable (Note: LCI proposed monthly composite and quarterly grab samples in its request for disposal in Class V wells).

*Radium-228:*

In Table 3.3 of the TR, LCI does not report an expected post-treatment concentration of Ra-228 in liquid waste but provides a footnote that the expected concentration will be 2 percent of the pre-treatment concentration (i.e., 98 percent removal by the RO system; see discussion below regarding thorium-230 removal). The NRC staff does not expect elevated Ra-228 concentrations in the aquifer or in the waste because Ra-228 is a daughter product of thorium-232, which is not expected to be present in ore bodies at Lost Creek. Furthermore, the half-life of Ra-228 is relatively short compared to that for Ra-226 (5.75 years versus 1622 years). This short half-life means that any small concentrations of Ra-228 present in liquid waste injected into a Class V disposal well will decay within a few half-lives (e.g., less than 20 years) to concentrations indistinguishable from natural background concentrations. Most importantly, however, the permitted limit is for total radium (combined Ra-226 and Ra-228) (WDEQ, 2016).

For the reasons stated above, the NRC staff's evaluation conservatively assumes the total radium is comprised of only Ra-226 and Ra-228 is not considered further in this evaluation.

*Thorium-230:*

In Table 3-3 of the TR (LCI, 2015a), LCI provides a footnote for the expected level for Th-230, which states:

- *Value not determined, but RO rejection estimated to be 98% of feed concentration.*

Consequently, LCI proposed a Th-230 concentration limit of 100 pCi/L for the treated waste based on the NRC's effluent concentrations in 10 CFR Part 20, Appendix B. This limit is included on Wyoming's discharge permit for the proposed action (WDEQ, 2016).

The NRC staff does not anticipate elevated Th-230 levels dissolved in the groundwater (see discussion in NUREG--1569) because thorium has an extremely high distribution coefficient (EPA, 1999). A high distribution coefficient means that this element will be strongly partitioned to the soils rather than dissolved in groundwater, lixiviant or byproduct material liquid waste. Consequently, the levels in the treated liquid waste are not likely to exceed the 100 pCi/L standard.

The NRC staff determined that LCI's proposed treated waste concentration limit of 100 pCi/L for Th-230 should not be approved. This is because Th-230 is the parent radionuclide for Ra-226. If Th-230 was injected at a concentration of 100 pCi/L, then over long periods of time the ingrowth of Ra-226 from the decay of Th-230 will cause elevated concentrations of Ra-226 in groundwater, up to a maximum of 100 pCi/L Ra-226. This is well above background Ra-226 concentrations in groundwater and thus, injection of Th-230 at a limit of 100 pCi/L is not acceptable.

The NRC staff anticipates that the Th-230 concentration in the treated waste will be below the levels in the receiving aquifer as a result of the proposed treatment. In particular, Th-230 will be present in suspended matter in groundwater, rather than dissolved in groundwater. The suspended fraction will be removed by the proposed filtering of the liquid waste during its treatment. NRC staff will require by license condition that the concentrations of Th-230 in the treated waste not exceed the background levels in the receiving aquifer of 1.8 pCi/L.

*Lead-210 (Pb-210) and Polonium-210 (Po-210):*

In Table 3-3 of the TR (LCI, 2015a), LCI provides a footnote for the expected levels of Pb-210 and Po-210 in the injectate, which states:

- *Value not determined, but RO rejection estimated to be 98% of feed concentration.*

Consequently, LCI proposed concentration limits for Pb-210 and Po-210 of 10 pCi/L and 40 pCi/L, respectively, in the treated waste based on the NRC's effluent concentrations in 10 CFR Part 20, Appendix B. This limit is included on Wyoming's discharge permit for the proposed action (WDEQ, 2016).

Pb-210 and Po-210 are intermediate decay products in the uranium decay series (which includes Ra-226). These radionuclides are long-lived decay products of Rn-222. In a system with elevated concentrations of Rn-222, there would be elevated concentrations of Pb-210 and Po-210. However, while Rn-222 is dissolved in groundwater, Pb-210 and Po-210 are strongly absorbed to the aquifer matrix (EPA, 1999).

The NRC staff anticipates that Pb-210 and Po-210 concentrations in the treated liquid waste will be below the concentrations in the receiving aquifer because of the proposed treatment. Pb-210 and Po-210 are commonly absorbed to suspended matter rather than dissolved in groundwater, which will cause them to be removed by the proposed filtering of the liquid waste during its treatment.

Therefore, NRC staff does not consider Pb-210 and Po-210 significant contributors to public dose following license termination; NRC staff is proposing a LC that will require that the concentrations of Pb-210 and Po-210 in the treated waste do not exceed background levels in the receiving aquifer.

*Gross Alpha:*

In Table 3.3 of the TR (LCI, 2015a), LCI proposes a concentration limit of 57 pCi/L for gross alpha based on the receiving aquifer's background concentrations. This limit is incorporated into LCI's Class V permit (WDEQ, 2016). In its response to the NRC staff's request for additional information about the calculation of the proposed gross alpha concentration limit, LCI described the laboratory analytical method used to measure gross alpha concentrations. While that information was informative, it did not address staff's RAI, which was:

- *Please provide calculations for determining Gross Alpha levels in the Receiving Aquifer Background Values*

The focus of this RAI was to elicit the calculations used to establish the proposed concentration limits. Unlike uranium, radium, and gross beta, for which LCI used the maximum detected levels in the aquifer as the background level, LCI incorporated a level which was less than any of the reported detectable levels in the aquifer (i.e., 92.6 to 146 pCi/L).

LCI provided a reference to the calculations that were used by Footnote (6) of Table 3.3 in its report, which states:

- *Gross Alpha value presented does not include uranium or radon contributions.*

This footnote reflects an adjusted gross alpha concentration when used for comparison to the Federal Primary Drinking Water Maximum Contaminant Level (MCL) for gross alpha of 15 pCi/L, which excludes uranium and radon, rather than the laboratory analytical result. Based on established analytical methodologies, the proposed calculation is based on radon being exsolved from the sample during sample preparation and that the measured gross alpha level includes all radionuclides including uranium. Therefore, the calculated gross alpha concentration for comparison to the MCL should be the analytical measurement minus the concentration of uranium.

For the groundwater samples from the wells, the NRC staff calculated the adjusted gross alpha concentration (for comparison to the MCL or "minus radon and uranium") and determined an adjusted gross alpha concentration to be 37, 25, 21, 57 and 41 pCi/L for wells FG6, FG7, FG8, FG9 and FG10, respectively. As seen by these results, the gross alpha background concentration reported by LCI in Table 3.3 of the TR is equal to the adjusted gross alpha concentration calculated by staff for well FG9. In the future, LCI will have to report both the measured (from the laboratory analysis) and adjusted gross alpha concentration (minus radon and uranium) in the reports that are required for this discharge, as their WY permit limit is based on the adjusted gross alpha concentration.

The reported adjusted gross alpha concentrations pose a concern in the NRC staff's evaluation of public dose. LCI's assumption for these samples based on the geological setting from which the samples were obtained is that the gross alpha concentrations are representative of the long-lived radionuclides in the uranium decay chain. The long-lived radionuclides with an alpha decay include Th-230, Ra-226, and Po-210. However, the summation of the analytical results for concentrations of the individual radionuclides is significantly below the respective adjusted gross alpha concentrations for all samples. This discrepancy suggests that the reported gross alpha levels may be inaccurate due to myriad of analytical problems associated with this method (e.g., presence of short-lived radionuclides from the uranium decay series (see, Arndt 2010)). The NRC staff believes that it is likely that due to the elevated uranium and radon concentrations, the discrepancy is due to the licensee's laboratory analytical method.

The NRC staff did not separately evaluate future public dose resulting from gross alpha concentrations because measurements of gross alpha concentrations are representative of specific radionuclide concentrations, which the staff did consider in its evaluation.

Due to the lack of laboratory reports or other supporting documentation that would provide a means for evaluating the validity of the gross alpha analytical methodology, there is uncertainty about the reported adjusted gross alpha activity as representative of the aquifer background concentration. Staff conservatively modeled a background gross alpha activity based on the measured radioisotopes that is less than the established gross alpha MCL of 15 pCi/L. Therefore, the NRC staff is imposing a LC to require LCI to limit the discharge gross alpha limit to the established MCL of 15 pCi/L.

*Gross Beta:*

In Table 3.3 of the TR (LCI, 2015a), LCI proposes a concentration limit of 15.1 pCi/L for gross beta based on the receiving aquifer's maximum background concentration.

For quality assurance that the proposed limit is representative of the aquifer, staff evaluated the contributions of individual radionuclides to the gross beta concentration for one sample. Using the results from well M-FG8, which had the highest gross beta concentration (i.e., 15.1 ± 2.4 pCi/L), NRC staff compared LCI's measurements of beta/gamma-emitting radionuclides in groundwater to LCI's gross beta concentration value in order to establish whether LCI had accounted for all beta/gamma-emitting radionuclides. NRC staff converted elemental potassium results to potassium-40 using a factor of 0.82 pCi/L per mg/L to arrive at an estimate of 3.3 pCi/L K-40. NRC staff also assumed that the two short-lived beta/gamma-emitting progeny of U-238, thorium-234 (Th-234) and protactinium-234m (Pa-234m), were present in secular equilibrium with U-238, which means each radionuclide was present at a concentration of 4.6 pCi/L. Finally, NRC staff included the 2.0 pCi/L result for Pb-210. By adding the K-40, Th-234, Pa-234m, and Pb-210 concentrations, NRC accounted for all of the beta-emitting radionuclides in the sample from well M-FG8, within the precision of the gross beta concentration measurement.

In the entire uranium decay series from U-238 to Pb-206, there are only two beta-emitting radionuclides with sufficiently high branching ratios and long half-lives such that they would persist in the receiving aquifer long enough to have the potential to result in public dose beyond license termination. These are Pb-210, which has a half-life of 21 years, and Bi-210, which is a short-lived daughter to Pb-210 with a half-life of 5 days, which would be present in secular equilibrium with Pb-210. The NRC staff's evaluation of Pb-210 concentration limits for on-site disposal of treated liquid waste is described above. Therefore, the NRC did not evaluate a separate limit for gross beta concentrations.

*Quantity of the Radionuclides Disposed*

Although LCI did not provide a quantitative analysis on the inventories of radionuclides disposed in a Class V well, LCI provided sufficient information for staff to perform a quantitative evaluation. Based on a maximum injection rate of 760 liters L/min [200 gpm] and the discharge concentration of the principal radionuclides, uranium and radium-226, at the maximum proposed concentration limits, the NRC staff calculated the total quantity of the radionuclides disposed of after 14 years of operation is 0.6 Ci natural uranium and 0.03 Ci radium-226.

As discussed above, the NRC staff finds that the description of the license material to be disposed of, including the physical and chemical properties important to a risk evaluation, as supplied by LCI in its request and responses to RAI's was sufficient to meet requirements of 10 CFR 20.2002(a). The NRC staff finds that LCI's assessment of the risk impacts (i.e., that meeting the effluents limits of 10 CFR 20.2001) was insufficient for evaluating the potential long-term dose impacts which is required under 10 CFR 20.2002(d). As discussed below, LCI's description of the waste provided sufficient information for the NRC staff's independent evaluation of the long-term public dose resulting from disposal of treated liquid waste considers natural uranium (U-nat) and radium-226 (Ra-226).

(ii) Proposed Manner and Conditions of Waste Disposal (10 CFR 20.2002(a))

Section 10 CFR 20.2002(a) requires applicants to provide a description of the proposed manner and conditions of waste disposal. In Sections 1.1, 2.2, 2.3 and 2.4 of the TR (LCI, 2015a), LCI describe the conditions of the waste disposal, including the location of the proposed injection wells, depth and subsurface strata for the injection, proposed injection rates and pressures. LCI described the need for this action is the desire to use technology that will be more cost effective than the Class I disposal wells and to reduce consumptive use by the operations.

The proposed action for this amendment request consists of additional treatment of the clean or permeate portion of the byproduct material such that it can be disposed of on-site in a Class V well. LCI described the proposed manner for treatment of permeate to achieve permitted disposal concentrations.

In Section 4.13 of the ER (LCI, 2015a), LCI stated approximately 1.5 cubic meters (2 cubic yards) of spent Dowex resin will be generated each year. Unlike the ion exchange resin to capture uranium, the Dowex resin is designed not to be regenerated and will require disposal when filled to capacity. The volume estimated by LCI is equivalent to the volume of one ion exchange vessel. This volume estimated was verified by NRC staff calculations that a first stage vessel of resin should last between one and three years using conservative flow rates and loading. In addition, staff verified the information on disposal in the recent surety update (LCI, 2015c). As noted in the ER, the waste will be sent to a facility licensed to receive and dispose of 11e.(2) byproduct material, such as the Shirley Basin Tailings Facility.

Staff finds that LCI's descriptions of the manner and conditions of waste disposal are sufficient to meet the requirements of 10 CFR 20.2002(a) and provide input to support staff's evaluation that long-term dose limits are met.

(iii) Analysis and Evaluation of Pertinent Information on the Nature of the Environment (10 CFR 20.2002(b))

Section 10 CFR 20.2002(b) specifies that applicants perform an analysis and evaluation of pertinent information of the environment for a proposed waste disposal. In Sections 2.3 and 2.4 of the TR (LCI, 2015a), LCI described the affected environment including the geologic and hydrogeological characteristics of the aquifer receiving the injection. The geologic characteristics are consistent with those reported for this horizon in the approved license application. LCI provided hydrogeological qualitative and quantitative information for the area affected by the proposed injection including the aquifer background quality, radius of influence, and estimated hydraulic properties.

LCI stated that the radium and gross alpha concentrations exceed standards for a groundwater classification of Class I (suitable for drinking water), Class II (suitable for agriculture) or Class III (suitable for livestock watering) by the State of Wyoming and thus believes the groundwater classification should be Class VI. Based on Wyoming Department of Environmental Quality, Water Quality Division Guideline 8, groundwater with a groundwater classification of Class VI may be unusable or unsuitable for use due to: (1) excessive concentrations of total dissolved solids (TDS) or specified constituents; (2) contamination that would be economically or technically impracticable to make the water usable; or (3), a location, e.g., depth, that makes its use economically or technologically impracticable.

LCI provided a comprehensive summary of water rights within one-mile based on a review of the Water Rights in the State of Wyoming State Engineering Office database. The water rights are largely owned by LCI but LCI reports 11 water rights are jointly owned by BLM and LCI. LCI has two water supply wells (LC1148W and LC229W) located approximately 73 m (240 ft) and 52 m (169 ft) of the proposed injection well M-FG7 (LCI, 2015a; 2016a). The water supply wells are used as a source for potable water and fire protection, respectively. The water supply wells are screened below the Class V receiving aquifer and at depth such that the receiving aquifer at the waste supply well aquifer are separated by over 122 m (400 ft) of fine-grained (i.e., relatively impermeable) strata.

LCI provided two differing analyses on the area of the aquifer affected by the injection. The analyses are based on a “radius of fluid displacement” calculation, which is required by WDEQ, Chapter 27. In the initial March 2015 application, LCI calculated a maximum area of impact (radius of impact) of 162 m (533 ft) based on injection of fluids at a rate of 225 L/min (60 gpm) for 14 years. In the April 2015 revised report, LCI revised its calculation used to determine an area of influence rather than a radius of influence as follows: (1) injecting at a rate of 225 L/min (60 gpm) for the first five years followed by injecting at rate of 760 L/min (200 gpm) for years 6 through 14; and (2) in lieu of the assumption of a homogeneous, isotropic aquifer, the impacts were bounded by the faulting in the subsurface.

In Appendix B of the TR (LCI, 2015a), LCI provided a geochemical analysis of the proposed action using the fate and transport modeling software PHREEQC/PHAST. The fate and transport modeling effort focused on reactions of major phases affecting the geochemical processes (e.g., pH, calcium, magnesium, sodium, potassium, quartz, alkalinity, aluminum, iron) rather than individual transport of trace levels of ionic phases (e.g., uranium, radium). LCI stated that the injection will likely have minor impacts to the aquifer. Based on an injection rate of 506 L/min (135 gpm) for 12 years, the licensee predicts the outer reaches of a mixed zone extending just beyond 305-m (1000-ft) radius and complete displacement of the injectate with the aquifer groundwater occurring to a radius of approximately 213 m (700 ft).

Wyoming regulations restrict the location of a Class V Facility to distances greater than 61 m (200 ft) from active public water supply wells (WDEQ, 2010). NRC staff reviewed the EPA Region 8 database for public water systems in Sweetwater County, Wyoming, and well LC1148W is listed as a source of water for the non-transient, non-community public water system WY5601664 (EPA, 2016). Because the distance to the Class V wells is greater than 61 m (200 ft), the setback distance in the Wyoming regulations is met.

As part of NRC's analysis of impacts to nearby receptors, the NRC staff relied on Wyoming's set-back distance to have reasonable assurance that, even in the unlikely event of the loss of casing integrity for the water supply well, that doses to the public will still be acceptable and that the routine monitoring will provide early warning of any unanticipated levels not reviewed. It is common practice for states to establish setback distances for public water supply sources. These setback distances range from 50 to 500 feet, depending largely on the withdrawal rates of the water supply well and the potential source of contamination. In general, most setback distances are between 150 and 200 feet. Based on the quality limits for the proposed Class V discharge and the relatively low withdrawal rate for the water supply well, staff finds that the Wyoming setback distance of 200 feet is sufficient to protect the public.

Staff reviewed the approved license application for potential historic drill holes in the area (LCI, 2008). Staff identified one drill hole, D-20, located within 500 feet of the proposed injection wells. In response to NRC staff's question, LCI responded that the location of that drill hole was incorrect in the approved application and that drill hole is located 670 m (2200 ft) from the proposed location of the Class V well(s) (LCI, 2016a). Furthermore, LCI state that only drill holes drilled by LCI existed in that area and those drill holes are properly abandoned.

Based upon the above, the NRC staff finds that LCI has provided pertinent information on the nature of the affected environment and performed an analysis and evaluation of the environment or provided information that the NRC staff used to verify independently that the licensee's analysis and evaluation. Consequently, the NRC staff finds that the licensee adequately satisfied requirements of 10 CFR 20.2002(b).

(iv) Information on the Nature and Location of other Potentially Affected Facilities (10 CFR 20.2002(c))

Section 10 CFR 20.2002(c) specifies that applicants provide information on the nature and location of other potentially affected facilities. LCI identified the location for the proposed Class V facility and estimated the area of potential affects (LCI, 2015a). The stratigraphic horizon in the area of the proposed injection zone is barren of mineralization. LCI stated that the nearest occurrence of the existing or future facilities associated with its uranium recovery operations is 805 m (0.5 mile) to the south and also reported that two existing water supply wells are located within approximately 61 m (200 ft) horizontally and 122 m (400 ft) vertically from the Class V facility. The wells are used as supply for potable and fire suppression uses.

LCI reported that the injection will increase the hydrostatic pressure of the aquifer during operation. The increase includes both saturated and unsaturated portion of the formation. However, LCI stated that the increase in pressure would not result in the water table rising to the surface due to the presence of numerous shale units in the subsurface strata above the injection interval.

In response to RAIs (LCI, 2015b), LCI stated it believed the injected waste would not impact operations at the nearest mine unit, Mine Unit 1, due to the presence of faults, which would be a barrier to flow, or during the life of Mine Unit 1. In addition, routine monitoring of the quality and water levels will be performed at monitoring well M-FG8, which is located between the proposed Class V facility and Mine Unit 1.

The NRC staff independently analyzed the proposed injection on the existing operations using licensee's numeric groundwater flow model provided in its original application license and adapted by the NRC staff to the current evaluation (for details on staff's adaptations, see NRC (2016b). Based on the hydrogeologic information, the NRC staff estimates that the migration of waste in the subsurface during its operation will be limited to a radial distance of 305 meters (1000 feet). The difference between NRC staff's estimate of 305 meters (1000 feet) and LCI's estimate of 213 meters (700 feet) (see Section iii above) is attributable to the NRC staff's use of a higher injection rate (760 L/min (200 gpm) versus 506 L/min (135 gpm)) and duration of the injection (14 versus 12 years). In addition, the NRC staff evaluated the migration without the faults acting as a barrier. The fluid migration without the northernmost fault will remain on-site from the location of the injection well(s) at the maximum injection rate and operation for 14 years. With the fault as a barrier, the migration will be further limited. Monitoring at well M-FG-10 will provide information on the efficiency of the barrier due to the migration of the fluids.

In addition to the migration of the injectate in the subsurface, the NRC staff evaluated the impacts to aquifer pressures and water table elevations in the area using the adapted numeric groundwater flow model to verify the licensee's qualitative analysis on the nearby facilities. Based on the numeric flow model that the NRC staff adapted for this analysis (NRC, 2016b), the NRC staff estimates a rise in the water table in the unsaturated portion of the aquifer or pressures in the fully saturated confined portions of the aquifer of approximately 32 meters (104 feet) of water column. Because the water table is found at a depth of approximately 200 feet below grade, the NRC staff's modeling results indicate the water table would not rise above the ground surface.

The NRC staff also determined that the injection will result in a rise in water levels extending to Mine Unit 1 wells screened in the overlying aquifer, and to some degree, water levels in the perimeter wells along the northern margins of Mine Unit 1. Based on the numeric modelling, staff estimates the increase in water levels in groundwater at the monitoring wells in Mine Unit 1 will be between 2.4 meters (8 feet) and 4.3 meters (14 feet). This change in water levels will have a negligible impact on water quality because fluid migration from the injection wells will not migrate to the wells in the overlying aquifer or perimeter wells, consistent with LCI's application.

Consequently, the NRC staff finds LCI's information on the nature and location of potentially affected facilities adequately addresses requirements of 10 CFR 20.2002(c).

(v) Analyses and Procedures to Ensure that Public Doses are Low (10 CFR 20.2002(d))

Section 10 CFR 20.2002(d) specifies that applicants provide analyses and procedures to ensure that doses are maintained as *as low as reasonably achievabl*e (ALARA) and within regulatory dose limits. The relevant dose limits in Part 20 include the occupational dose limits contained in Subpart C and the public dose limits contained in Subpart D. As stated in Section 5.1.1 above, NRC staff finds LCI's NRC-approved radiation protection program measures will ensure public and occupational doses are ALARA and within the dose limits of 10 CFR Part 20 during the operational period. Therefore, the NRC staff's focus in this independent evaluation is the potential future public dose that could be received after license termination resulting from exposure to source and byproduct material disposed of in a Class V injection well.

Potential future public dose would arise from future uses of either contaminated groundwater or contaminated subsurface soil. In the case of groundwater, NRC and Wyoming will restrict by license and permit the concentrations of radionuclides in discharged waste to an MCL or background levels. Therefore, the NRC staff determined that the migration after license termination of the injected, treated, waste water poses a negligible increase in dose to the public. In addition, the WDEQ Class V permit states that the groundwater in the part of the upper Battle Spring Formation is classified as Class IV(A) industrial water (WDEQ 2015), which is not suitable for domestic use, including stock water use. Therefore, this designation eliminates the future use of the aquifer for drinking water and stock water as reasonable pathways for potential future public dose.

With regard to future public dose arising from contact with contaminated subsurface soil, the injection of fluids in the subsurface may have the potential to accumulate in the subsurface soils. With regard to potential public dose after license termination resulting from exposure to byproduct material disposed on-site, as further described in the NRC staff guidance in NUREG-1757, *Consolidated Decommissioning Guidance*, Section 15.12, "On-site Disposal of Radioactive Materials Under 10 CFR 20.2002," the current NRC staff practice is to approve on-site disposal of radioactive materials based on a dose criterion of a few millirem per year (NRC, 2006). Due to the depth of disposal between 61 and 122 meters (200 and 400 feet) below the ground surface, upon closure of the Class V injection wells, the NRC staff finds there would be no direct or indirect pathways for exposure of the public to source and byproduct material in the injection zone, consistent with LCI's analysis. For example, in Section 1.2 of the ER (LCI, 2015a), LCI states that there is no risk of increasing concentrations of undesirable constituents in the soil. However, a future well driller installing a well to obtain water for industrial use could contact the disposed waste water that has accumulated onto the subsurface strata during the injection of the waste. Because LCI focused their analysis on soils at the ground surface without addressing the subsurface strata, LCI did not address this potential pathway. While the NRC staff agrees that the proposed injection will have negligible impacts on the near surface soils, the NRC staff considers the exposure to the subsurface strata as a potential pathway. Therefore, the NRC staff independently evaluated a scenario in which a future potential well driller is exposed to contaminated drill cuttings brought to the surface from the disposal zone. The NRC staff analysis of the future potential pathway and exposure to the subsurface strata is documented in this SER. More details on the specific calculations and modeling results used for this analysis can be found at NRC (2016b).

For purposes of this analysis, the NRC staff did not evaluate radionuclides which are expected to be present in RO permeate at levels less than a few percent of the "Effluent Limit" in Table 3-3 of Addendum 1 of the TR (e.g., thorium-230, lead-210, and polonium-210). In addition, NRC staff assumed the total radium was comprised of radium-226, the longest lived isotope of radium, which would be the more conservative analysis. Therefore, the radionuclides the NRC staff considered in its evaluation are isotopes of natural uranium and radium-226.

The NRC staff's evaluation is based on the following conservative assumptions:

- the treated discharge concentrations of natural uranium and radium-226 was 0.158 milligrams per liter (mg/L) and 5.5 pCi/L, respectively; the maximum concentration limits in the discharge permit.
- the treated discharge is injected for maximum 14 years at a maximum rate of 760 Lpm (200 gpm) into a single well over the entire thickness of the receiving aquifer.
- the receiving aquifer background concentrations of natural uranium and radium-226 are 0.0813 mg/L and 1.0 pCi/L, respectively, which are the minimum values detected in groundwater at wells in the area.
- the accumulated levels of natural uranium and radium-226 on the aquifer matrix attributed to the proposed injection is staff's estimated distribution coefficient by the increase in groundwater concentration from the aquifer background levels to the discharge concentration.

The NRC staff determined the distribution coefficient for the constituents of concern by estimating the constituent concentrations in the aquifer matrix (Table 1). The NRC staff estimated the concentrations in the soil by first assuming the activity of radon-222 measured in the groundwater equaled the radium-226 activity in the system (for details on the methodology and rationale for NRC staff's evaluation of the distribution coefficient, see Appendix A of this SER). Similarly, staff assumed that uranium-234 was in secular equilibrium with radium-226.

Because the system is open (i.e., the radionuclides potentially migrate in groundwater at differing rates), the assumption of secular equilibrium may be tenuous. For radium-226, the assumption of secular equilibrium with radon-222 is a reasonable estimate for reasons discussed in Appendix A. In addition, the calculated distribution coefficients are consistent, in particular, for samples FG6, FG7 and FG8. For a conservative analysis, the estimated distribution coefficient for radium-226 was based on data from samples FG6, FG7 and FG8.

The NRC staff included a factor of safety in its analysis. A factor of safety is commonly used in engineering evaluations to account for uncertainties in the analysis or provide a level of confidence in a risk assessment. In some cases where the risks can be quantified by existing data, a lower factor of safety may be employed (EPA, 2002). For example, in the design of stability for embankments surrounding surface impoundments with seepage, Regulatory Guide 3.11 recommends a factor of safety of 1.5 in the NRC staff's evaluation (NRC, 2008). For more qualitative analyses of uncertainties, the general consensus is a default factor of safety of 10 (e.g., EPA, 2002; Pohl and Abadin, 1995).

Because of the relatively narrow range of radon-222 results and the fact that radon-222 is the direct progeny of radium-226, the NRC staff qualitative assessment of the uncertainty in the calculated distribution coefficient for radium-226 is low. Consequently, a factor of safety of 2 is used by the staff to calculate the distribution coefficient for radium based on the factors described above.

For uranium-234, a justification based solely on the principle of secular equilibrium between uranium-234 and radon-222 may not be sufficient. The primary reason the assumption of secular equilibrium may be invalid is that radon-222 is the third-generation progeny from uranium-234. To be in secular equilibrium, the intermediate radionuclides, radium-226, and thorium-230, also need to be in secular equilibrium.

The half-life of radium-226 is 1,590 years and the half-life of thorium-230 is 80,000 years requiring several hundred thousand years for equilibrium to be established. While the generally accepted age of mineralization for sandstone-hosted uranium deposits in Wyoming would be sufficient to establish equilibrium (Ludwig, 1979; Sharp, 1964), the processes affecting the partitioning of the various radionuclides into groundwater and groundwater flow will have an impact on the equilibrium. This is evident from the lack of correlation between uranium and radium-226 concentrations in groundwater at most ISR settings.

The calculated uranium concentrations in the soil using the secular equilibrium method is between 1.75 and 6.8 milligrams per kilogram (mg/kg), and an average for the three wells discussed above of 5.2 mg/kg. To evaluate the uncertainty in these values, staff evaluated the bounding conditions, and pertinent information on the specific site setting. In the request, LCI stated that the injection horizons (includes the DE and FG horizons) are naturally oxidized and barren of uranium mineralization. In the approved application (LCI, 2008), LCI stated that minimum grade in the mineralized areas was 0.03 percent “equivalent uranium oxide ($eU_3O_8$)”. Therefore, after correcting LCI’s minimum grade to an equivalent level of “natural uranium”, NRC staff estimates the maximum natural uranium in this barren uranium mineralization to be 250 mg/kg. This concentration could be used as an upper bound of 48 for a factor of safety (i.e, 250 mg/kg divided by 5.2 mg/kg).

The NRC staff elected to use a factor of safety of 10 due to the oxidizing conditions as suggested in the amendment request (LCI, 2015a). If the conditions are such that uranium is oxidized to the hexavalent state, then the uranium will become more soluble. The variation in solubility of uranium under differing oxidation states will inversely affect the distribution coefficient (i.e., in the case where uranium is more soluble, the distribution coefficient would be less). To verify that the FG aquifer is indeed oxidized, NRC staff reviewed the uranium and radium concentrations in groundwater reported for Mine Unit 1. In general, the uranium concentrations in groundwater at the FG aquifer are generally greater than 0.3 mg/L and the radium-226 concentrations are generally less than 10 pCi/L (Figure 1). In contrast, the uranium concentrations in the ore zone within the HJ aquifer (the aquifer below the FG aquifer) are generally less than 0.2 mg/L and radium-226 concentrations are generally high (up to several hundred pCi/L). This variation in uranium concentrations between the FG and HJ aquifers is consistent with a more oxidized state in the FG aquifer (i.e., although the uranium concentrations in the matrix are lower in the FG aquifer, the relatively higher uranium concentrations suggest the uranium is more soluble). Therefore, the NRC staff assigned a factor of safety of 10 to its estimate of the distribution coefficient for uranium to conservatively account for uncertainty.

Given the licensee’s reported groundwater concentration of radium-226, $C_{water}^{Ra-226}$, the NRC staff estimated the radium $K_d$ in each of wells FG6, FG7, and FG8. The calculation of the radium-226 concentration sorbed to solids, $C_{solid}^{Ra-226}$, is explained in Appendix A. For example, using the safety factor of 2 described above, the value of the $K_d$ for well FG8 is

$$K_d = \frac{C_{solid}^{Ra-226}}{C_{water}^{Ra-226}} = \frac{2{,}326}{2.2}\ x\ 2 = 2{,}115\ L/kg$$

As shown in Table 1, the average value of the $K_d$ for radium in wells FG6, FG7, and FG8, is 2,200 L/kg.

The NRC staff performed similar calculations for natural uranium. The licensee measured the dissolved natural uranium concentration in well FG8 to be 0.158 mg/L. Using a specific activity for natural uranium of 6.77 x $10^{-7}$ Ci/g (see 10 CFR Part 20, Appendix B, footnote 3) and assuming the activity of uranium-234 is 48.9% of the activity of natural uranium, the staff estimated the uranium-234 concentration in groundwater to be 52.3 pCi/L. The NRC staff also assumed that the solid concentration of uranium-234 is in secular equilibrium with radium-226. For example, using the safety factor of 10 described above, the value of the $K_d$ for uranium in well FG8 is:

$$K_d = \frac{C_{solid}^{U-234}}{C_{water}^{U-234}} = \frac{2{,}326}{52.3}\ x\ 10 = 445\ L/kg$$

As shown in Table 1, the average value of the $K_d$ for uranium in wells FG6, FG7, and FG8, is 460 L/kg.

The distribution coefficients determined by the NRC staff for radium and uranium are within the reported ranges (EPA, 1999). Using the NRC staff's distribution coefficients, the maximum concentration of natural uranium and radium-226 sorbed to subsurface strata as a result of the proposed injection after 14 years is estimated by NRC staff to be:

$$C_{solid}^{Ra-226} = K_d x\left[\, C_{injected}^{Ra-226} - C_{background}^{Ra-226}\right] = 2{,}200\ \frac{L}{kg}\ x\ \left[5.5\frac{pCi}{L} - 1\frac{pCi}{L}\right] = 9{,}900\ \frac{pCi}{kg} = 9.9\frac{pCi}{g}$$

$$C_{solid}^{Nat-U} = K_d x\left[\, C_{injected}^{Nat-U} - C_{background}^{Nat-U}\right] = 460\ \frac{L}{kg}\ x\ \left[107\frac{pCi}{L} - 55\frac{pCi}{L}\right] = 23{,}700\ \frac{pCi}{kg} = 24\frac{pCi}{g}$$

NRC staff conservatively disregarded removal of uranium and radium by radioactive decay. The NRC staff assumed a future well driller will place drill cuttings from a 265-foot length of an 8-inch well into a mud pit, as this is the common practice for drilling a typical well. Therefore, the staff assumed the volume of drill cuttings in the mudpit from a 265-foot length of 8-inch well would be approximately 92 cubic feet. The NRC staff assumed such a mud pit would have dimensions 6 feet wide by 8 feet long by 2 feet deep. For purposes of this simplified analysis, the NRC staff conservatively assumed that contaminated drill cuttings are not diluted by uncontaminated drill cuttings from areas laterally outside or above the contaminated zone, and the mud pit would receive mud containing uranium and radium at the concentrations stated above. Using MicroShield v. 10 (Grove Software 2013), the NRC staff estimated the gamma dose rate beside the mud pit of about 8 microroentgen per hour (µR/hr) at a location half way down the long side of the pit and 3 feet off the ground. This radiation exposure rate would nearly double the exposure rate from natural background gamma exposure rates alone of about 10 μR/hr. The NRC staff calculated that even if a well driller, or any other worker, were present near the mudpit for a 40-hour workweek, the external dose rate would be less than 0.3 mrem per year.

The NRC staff also evaluated internal dose resulting from exposure to downwind concentrations of radon-222 and its progeny resulting from decay of radium-226 in the hypothetical mud pit described above. NRC staff estimated downwind concentrations of radon-222 using a simple screening model described in Equation 2.1 of NCRP 1996:

$$C = \frac{fQ}{V}$$

where *C* = average atmospheric concentration at receptor, (pCi/L)
*f* = fraction of time the wind blows toward the receptor (dimensionless)
*Q* = effluent release rate (pCi per second, pCi/s)
*V* = volumetric flow rate at point of release (liter per second, L/s)

The NRC staff conservatively assumed the fraction of time the wind blows toward the receptor is 0.5 (i.e., a simplified assumption that the wind is either blowing toward the receptor or not). The NRC staff estimated a radon-222 release rate, Q, of about 10 pCi radon-222 per second using a specific flux factor of 1 pCi radon-222/$m^2$-s per pCi radium-226/g from Regulatory Guide 3.59 (NRC 1987). The NRC staff estimated the volumetric flow rate, V, assuming an annual average wind speed of 4.5 m/s, and an area of the release equal to the area of the mud pit (48 sq. ft., or about 4.5 $m^2$). Using these assumptions, the staff estimated annual average radon-222 concentrations immediately downwind of the mud pit would be less than 0.001 pCi/L. Using a conservative dose factor of 500 mrem/year per 1 pCi/L derived from the effluent concentration in table 2 of appendix B to 10 CFR 20.1001-20.2401 for radon-222 with daughters present (i.e., 0.1 pCi/L = 50 mrem per year), the staff estimated a dose result from inhalation or radon-222 and its progeny of about 0.1 mrem per year for an occupancy of up to 2,000 hours per year. The dose factor used by the staff is conservative because it is assumed that radon progeny would be in equilibrium with radon-222, which is unlikely at locations near the source.

The NRC staff also considered three less significant pathways of exposure: (1) an internal dose from inadvertent ingestion of drilling mud by a well driller; (2) an internal dose from inhalation of contaminated soil from the mud pit which is resuspended and blown downwind; and (3) external dose to a well driller from mud-contaminated skin and clothing. For the ingestion scenario, the NRC staff assumed the well driller ingests 1 gram of contaminated soil at the maximum concentrations described above (i.e., 9.9 pCi/g radium-226 and 24 pCi/g natural uranium). Using the stochastic ALIs for ingestion in table 1 of appendix B to 10 CFR 20.1001-20.2401, the staff estimated a total ingestion dose of less than 0.02 mrem. For the inhalation of resuspended dust, the staff used Peterson's (1983) resuspension methodology. Specifically, the NRC staff used equation 5.27 and a value for the resuspension constant, Kz, from Table 5.8 of Peterson (1983) of $10^{-10}$ to estimate a maximum dose of about 0.002 mrem for a 40-hour exposure. With regard to the skin and whole body dose from mud-contaminated skin and clothing, the staff estimated this would add about 1 percent to the total dose.

Combining the external and internal doses described above, the combined total effective dose equivalent to a hypothetical future person working in this area would be about 0.4 mrem per year. Therefore, the NRC staff finds that the alternative disposal of treated RO permeate in a Class V well should be approved because it meets the dose criterion of a few millirem per year.

5.2 *2016 Annual Surety Update*

NRC Staff reviewed the unit costs for the D&D and finds the unit costs are consistent with those listed in WDEQ Guideline 12 (WDEQ, 2015). The unit costs in Guideline 12 reflect anticipated costs in Wyoming for this year. Therefore, Staff finds the unit costs acceptably reflect changes due to inflation.

NRC Staff reviewed the calculations to determine the extent of changes in the engineering planning. The calculations include the following changes:

- Expanding operations to 13 header houses in Mine Unit 1
- Construction and operation of the Class V Injection Wells (in anticipation of the amendment request)
- Cost for remediating one spill area
- Abandonment of drill holes in Mine Unit 2
- Abandonment of 4 deep disposal wells

NRC Staff finds the changes are consistent with the actual conditions in the field and represent activities expected to be performed during the reporting period.

The difference in total cost from the previous annual update is $356,900, or approximately 2.44 percent of the previous total cost. The increase in total cost is relatively small considering an increase in wellfield area within Mine Unit 1 of 25 percent for this year's activity, and groundwater restoration, which is a significant portion of the cost, is based on the wellfield area.

The reason for the small total cost increase is attributed to two items. First, LCI included the cost for installation and use of the Class V well for injection of the treated permeate in the financial assurance update calculations. The use of Class V wells eliminated the need to dispose of the permeate into the Class I well and produced a slight net reduction in overall cost for disposal of liquid byproduct material. More importantly, however, for last year's update, LCI was required to extend the restoration time to 4 years due to limitations on the waste disposal capacity. For this year, the restoration time was reduced to 2.8 years because LCI installed the third of five-permitted Class I waste disposal wells The addition of the third well provided additional waste disposal capacity . This reduction in restoration time affected the costs in areas such as man-hours, sampling, etc.

Based on the above, NRC Staff finds that the values used in the financial surety update are based on current dollars and reasonable costs for the required reclamation activities are defined. Therefore, staff finds that the licensee has established an acceptable financial assurance cost estimate based on the requirements in 10 CFR Part 40, Appendix A, Criterion 9.

The instrument to be used by LCI for the financial assurance update is a reclamation performance bond to be held in favor of the WDEQ. An original copy of the financial instrument remains with WDEQ for uranium recovery licensing activities based on an agreement between the State and the NRC. The NRC maintains a copy on file of the instrument as well. Along with WDEQ's portion, the bond should include 100 percent of the NRC's portion. The NRC will obtain a copy of the updated instrument upon NRC approval of the cost estimate. The surety bond will have a face value of at least $14,996,900. Staff will confirm that the surety instrument meets the applicable criteria in 10 CFR Part 40, Appendix A, Criterion 9, once receipt of the updated instrument has been received.

In accordance with 10 CFR Part 40, Appendix A, Criterion 9, a Standby Trust Agreement (STA) must be established by LCI to receive funds in case of the NRC's need to collect the surety. Because LCI does not have an STA in place at this time, as required by 10 CFR Part 40, Appendix A, Criterion 9, in accordance with 10 CFR 40.14(a), staff has elected to grant a limited exemption to the STA requirements in 10 CFR Part 40, Appendix A, Criterion 9, for the current surety arrangement. The limited exemption was noticed in the Federal Register during last year's update and extended to February 2017. By LC 9.5, LCI is required to submit update calculations 90 days before the anniversary date of February $10^{th}$ for the first instrument. The exemption expires during the period for next year's update, at which time LCI would be subject to the standby trust requirement.

## 6.0 Environmental Review

### 6.1 *Request for On-site Disposal through a UIC Class V Well*

The NRC staff prepared an Environmental Assessment for approval of the Class V Well Injection Amendment Request in accordance with the requirements in 10 CFR Part 51, *Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions*. NRC's regulations in 10 CFR Part 51 implement Section 102(2) of the National Environmental Policy Act of 1969, as amended (NEPA). The EA includes an evaluation of the potential environmental impacts (NRC, 2016a).

### 6.2 *2016 Annual Surety Update*

The licensing action of approving a surety update meets the categorical exclusion provisions in 10 CFR 51.22(c)(10)(i). Therefore, preparation of an environmental assessment is not required for this amendment.

The NRC staff has determined that a consultation under Section 7 of the Endangered Species Act is not required because the proposed action is administrative/procedural in nature and will not affect listed species or critical habitat. The NRC staff has also determined that the proposed action is not a type of activity that has potential to cause effects on historic properties because it is an administrative/procedural action. Therefore, no further consultation is required under Section 106 of the National Historic Preservation Act.

## 7.0 Conclusions

The NRC Staff has reviewed Lost Creek ISR, LLC's Class V Amendment Request and the 2016 Surety update for the Lost Creek ISR facility and, as documented in this SER, finds that LCI provided grounds for the amendment requests in accordance with requirements in Section 10 CFR 40.44.

By email dated August 4, 2016, Lost Creek ISR, LLC agreed to the proposed license conditions (LCI, 2016c).

Therefore, staff recommends approval of the amendment requests as Amendment No. 5 to Source Material License SUA-1598, upon completion of the environmental assessment required by NEPA, as noted above. The NRC staff proposes the following revised and additional LC's in Amendment No. 5:

Revised LC 9.2:

> The licensee shall conduct operations in accordance with the commitments, representations, and statements contained in the license application dated March 31, 2008 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML081060525), which is supplemented by the submittals dated December 12, 2008 (ML090080451), January 16, 2009 (ML090360163), February 27, 2009 (ML090840399), August 5, 2009 (ML092310728), April 22, 2010 (ML102100263, ML102420249), May 14, 2010 (ML101600528), June 17, 2010 (ML101720161), June 24, 2010 (ML101820155), November 11, 2010 (ML103210590), November 16, 2010 (ML103280186), December 3, 2010 (ML103490862), September 13, 2011 (ML112580267), November 8, 2011 (ML11319A196), January 6, 2012 (ML120470353), February 10, 2012 (No. ML12048A678), February 17, 2012 (ML12053A326), March 5, 2012 (120670278), July 27, 2012 (ML12219A076), July 31, 2012 (ML12244A404), November 8, 2012(ML13029A734), November 29, 2012 (ML12335A016), March 27, 2013 (ML13100A138), January 16, 2015 (ML15029A423), March 3, 2015 (ML15076A380), July 28, 2015 (ML15218A055), August 17, 2015 (ML15239A726), January 26, 2016 (ML16043A365) and February 8, 2016 (ML16042A069). The approved application and supplements are, hereby, incorporated by reference, except where superseded by specific conditions in this license. The licensee must maintain the approved license application on site.
>
> Whenever the word "will" or "shall" is used in the above referenced documents, it shall denote a requirement. The use of "verification" in this license with respect to a document submitted for U.S.
>
> Nuclear Regulatory Commission (NRC) staff review means a written acknowledgement by NRC staff that the specified submitted material is consistent with commitments in the approved license application, or requirements in a license condition or regulation. A verification will not require a license amendment.
>
> [Applicable Amendment: 1, 2, 3, 4, 5]

Revised LC 9.5:

Financial Assurance. The licensee shall maintain an NRC-approved financial surety arrangement, consistent with 10 CFR Part 40, Appendix A, Criterion 9, adequate to cover the estimated costs, if accomplished by a third party, for decommissioning and decontamination, which includes off-site disposal of solid byproduct material and groundwater restoration as warranted. The surety shall also include the costs associated with all soil and water sampling analyses necessary to confirm the accomplishment of decontamination.

Proposed annual updates to the financial assurance amount, consistent with 10 CFR Part 40, Appendix A, Criterion 9, shall be provided to the NRC 90 days prior to the anniversary date on which the first surety instrument was submitted to NRC. The anniversary date established by the NRC for this license is February 10. If the NRC has not approved a proposed revision 30 days prior to the expiration date of the existing financial assurance arrangement, the licensee shall extend the existing arrangement, prior to expiration, for 1 year. Along with each proposed revision or annual update of the financial assurance estimate, the licensee shall submit supporting documentation, showing a breakdown of the costs and the basis for the cost estimates with adjustments for inflation, maintenance of a minimum 15-percent contingency of the financial assurance estimate, changes in engineering plans, activities performed, and any other conditions affecting the estimated costs for site closure.

Within 90 days of NRC approval of a revised closure (decommissioning) plan and its cost estimate, the licensee shall submit, for NRC review and approval, a proposed revision to the financial assurance arrangement if estimated costs exceed the amount covered in the existing arrangement. The revised financial assurance instrument shall then be in effect within 30 days of written NRC approval of the documents.

At least 90 days prior to beginning construction associated with any approved planned expansion or operational change that was not included in the annual financial assurance update, the licensee shall provide, for NRC review and approval, an updated estimate to cover the expansion or change. The licensee shall also provide the NRC with copies of financial-assurance-related correspondence submitted to the State of Wyoming, a copy of the State's financial assurance review, and the final approved financial assurance arrangement. The licensee also must ensure that the financial assurance instrument, where authorized to be held by the State, identifies the NRC-related portion of the instrument and covers the (a) aboveground decommissioning and decontamination, (b) cost of off-site disposal of solid byproduct material, (c) soil and water sample analyses, and (d) groundwater restoration associated with the site. The basis for the cost estimate is the NRC-approved site closure plan or the NRC-approved revisions to the plan. Reclamation or decommissioning plan cost estimates and annual updates should follow the outline in Appendix C, "Recommended Outline for Site-Specific In Situ Leach Facility Reclamation and Stabilization Cost Estimates," to NUREG-1569, "Standard Review Plan for In Situ Leach Uranium Extraction License Applications—Final Report."

The licensee shall continuously maintain approved surety instrument(s) for the Lost Creek ISR Project, in favor of the State of Wyoming, in the amount of no less than $14,996,900, for the purposes of complying with 10 CFR Part 40, Appendix A, Criterion 9, until a replacement is authorized by both the State of Wyoming and the NRC.

[Applicable Amendment: 1, 2, 3, 5]

Revised LC 10.9:

The licensee shall establish and conduct an effluent and environmental monitoring program in accordance with those programs described in Section 5.7.8.2 (Surface Water Monitoring, Private Well Monitoring, and Life-of-Mine Wells) and Section 5.7.7.1 (radon, air particulate, direct radiation, and soil) of the approved license application, and in the Class V Amendment (ML16074A080) as modified by license condition 10.20.

[Applicable Amendment: 5]

Additional LC 10.20:

The license is authorized to dispose of treated liquid byproduct material on-site through injection well(s) in the area of the proposed injection wells designated as M-FG6 and M-FG7 at a combined rate not to exceed 200 gallons per minute, in accordance with commitments in the Class V Amendment request (ML16074A080). For the first six months of operation of the Class V injection well, the licensee will collect a monthly composite sample of the treated byproduct immediately prior to injection and analyze it for gross alpha, gross beta, natural uranium, radium-226, radium-228, lead-210, polonium-210 and thorium-230. The parameter concentrations in injected permeate shall be less than the values in the "effluent limit" column of Table 3-3 of the UIC Class V Permit Application (ML16074A080), except that the limits for thorium-230, lead-210, and polonium-210 shall be less than the values in the "receiving aquifer background" column and the limit for the adjusted gross alpha is 15 pCi/L.

[Applicable Amendment: 5]

## 8.0 References

10 CFR Part 20. *Code of Federal Regulations*, Title 10, Energy, Part 20, "Standards for Protection Against Radiation." Washington, DC.

Arndt, M.F., 2010. "*Evaluation of Gross Alpha and Uranium Measurements for MCL Compliance*," sponsored by the Water Research Foundation and U.S. Environmental Protection Agency, published by the Water Research Foundation, Denver, Colorado, 2010. http://www.waterrf.org/PublicReportLibrary/3028.pdf

EPA, 1999. "*Understanding Variation in Partition Coefficient, $K_d$, Values, Volume II: Review of Geochemistry and Available Kd Values for Cadmium, Cesium, Chromium, Lead, Plutonium, Radon, Strontium, Thorium, Tritium (3H), and Uranium*", U.S. Environmental Protection Agency Office of Air and Radiation, EPA402-R-99-004B, August 1999.

EPA, 2002. "*Determination of the Appropriate FQFA Safety Factor(s) in Tolerant Assessment*", U.S. Environmental Protection Agency Office of Pesticide Programs, accessed from https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/determination-appropriate-fqpa-safety-factors on June 15, 2016.

EPA, 2016. Webpage entitled "*Drinking Water Watch*", URL at https://sdwisr8.epa.gov/Region8DWWPUB/JSP/WaterSystemDetail.jsp?tinwsys_is_number=718316&tinwsys_st_code=WY&wsnumber=WY5601664, Accessed March 9, 2016, Search Criteria "Lost Creek ISR, LLC" as company name.

LCI (Lost Creek ISR, LLC), 2008. "*Lost Creek ISR, LLC, Lost Creek Project South-Central Wyoming, Technical Report*," Casper, WY, March 31, 2008, ADAMS Accession Nos. ML081060503, ML081060504, ML081060505, ML081060507, ML081060509, and ML081060510.

LCI (Lost Creek ISR, LLC), 2015a. Letter from J. Cash, LCI to NRC, dated March 3, 2015, Re: Addendum 1 to Technical and Environmental Reports UIC Class V Amendment Lost Creek ISR Project License SUA-1598, Docket 040-09068. NRC ADAMS Accession No. ML15076A400.

LCI (Lost Creek ISR, LLC), 2015b. Letter from J. Cash, LCI to NRC, dated August 17, 2015, Re: Response to NRC RAIs Dated July 23, 2015 UIC Class V Amendment Lost Creek ISR Project License SUA-1598, Docket 040-09068. NRC ADAMS Accession No. ML15239A726.

LCI (Lost Creek ISR, LLC), 2015c. Letter from J. Cash, LCI to BLM. WDEQ and NRC, dated December 27, 2015, Re: Response to WDEQ-LQD Comments and Submission of Surety Estimate for Permit 788, BLM WYM-166318, NRC License # 1598 Docket 040-0068. NRC ADAMS Accession No. ML16021A490.

LCI (Lost Creek ISR, LLC), 2015d. Letter from J. Cash, LCI, to NRC, dated December 27, 2015, Re: Request to NRC to Review the 2015-2016 Suety Estimate for the Lost Creek Project pursuant to license condition 9.5, NRC License # 1598 Docket 040-0068. NRC ADAMS Accession No. ML16012A116.

LCI (Lost Creek ISR, LLC), 2016a. Email from Lost Creek ISR, LLC with Selective Pages from the April 2015 Revised UIC Class V Permit Application Subclass 5C3 Report, February 8, 2016, ADAMS Accession No. ML16042A069.

LCI (Lost Creek ISR, LLC), 2016b. Lost Creek ISR, LLC Reply to NRC's December 8, 2015 Letter regarding removing license conditions, January 26, 2016, ADAMS Accession No. ML16043A365.

LCI (Lost Creek ISR, LLC), 2016c. Lost Creek ISR, LLC email agreeing to the License Amendment 5 proposed license conditions, August 4, 2016, ADAMS Accession No. ML16221A023.

Ludwig, K.R., 1979. Age of uranium mineralization in the Gas Hills and Crooks Gap districts, Wyoming, as indicated by U-Pb isotope apparent ages: Economic Geology, v. 74, no. 7, p. 1654–1668.

*Microshield*, Lynchburg, VA: Grove Software, 2013.

NCRP (National Council on Radiation Protection and Measurements). 1996. “Screening Models for Releases of Radionuclides to Atmosphere, Surface Water, and Ground.” NCRP Report No. 123, Bethesda, MD.

NRC (U.S. Nuclear Regulatory Commission). 1983. *Radiological Assessment: A Textbook on Environmental Dose Analysis.* NUREG/CR-3332 (ORNL-5968). Washington, D.C.

NRC (U.S. Nuclear Regulatory Commission). 1987. Regulatory Guide 3.59, “*Methods for Estimating Radioactive and Toxic Airborne Source Terms for Uranium Milling Operations*”, Washington, DC: NRC, Office of Nuclear Regulatory Research. Accession No. ML003739503.

NRC (U.S. Nuclear Regulatory Commission), 2003. “*Standard Review Plan for In-Situ Leach Uranium Extraction License Applications—Final Report*,” NUREG1569, Washington, DC: NRC, Office of Nuclear Material Safety and Safeguards. June 2003, ADAMS Accession No. ML031550302.

NRC (U.S. Nuclear Regulatory Commission), 2006. NUREG-1757, Volume 1, Revision 2, “*Consolidated Decommissioning Guidance: Characterization, Survey, and Determination of Radiological Criteria*”, September 2006. NRC ADAMS Accession No. ML063000243.

NRC (U.S. Nuclear Regulatory Commission). 2008. Regulatory Guide 3.11, “*Design, Construction, and Inspection of Embankment Retention Systems at Uranium Recovery Facilities*”, Washington, DC: NRC, Office of Nuclear Regulatory Research. Accession No. ML082380144.

NRC (U.S. Nuclear Regulatory Commission), 2009. Regulatory Guide 4.1, Revision 2, “*Radiological Environmental Monitoring for Nuclear Power Plants*” Washington, DC: NRC, Office of Nuclear Regulatory Research. Accession No. ML091310141.

NRC (U.S. Nuclear Regulatory Commission). 2011. Letter from K. McConnell, NRC to W. Heili, Lost Creek ISR, LLC, dated August 17, 2011, Re: Materials License SUA-1598, Lost Creek ISR, LLC, Lost Creek Project in Sweetwater County, Wyoming (TAC J00559). NRC ADAMS Accession No. ML111940057.

NRC (U.S. Nuclear Regulatory Commission). 2015. Letter from J. Saxton, NRC to J. Cash, Lost Creek ISR, LLC, dated July 23, 2015, Re: Request for Additional Information, Class V

Disposal Amendment, Lost Creek ISR, LLC, Sweetwater County, Wyoming, License SUA-1598 (TAC L00782). NRC ADAMS Accession No. ML15198A240.

NRC (U.S. Nuclear Regulatory Commission). 2016a. Environmental Assessment for Lost Creek's lass V Amendment Request, Materials License SUA-1598, Lost Creek ISR, LLC, Lost Creek Project in Sweetwater County, Wyoming. NRC ADAMS Accession No. ML16216A273.

NRC (U.S. Nuclear Regulatory Commission). 2016b. Staff's Calculation Package including Results of Modeling used for the Analysis of the Class V Injection Amendment Request, Materials License SUA-1598, Lost Creek ISR, LLC, Lost Creek Project in Sweetwater County, Wyoming. NRC ADAMS Accession No. ML16208A231.

Peterson, Harold T. "Terrestrial and Aquatic Food Chain Pathways." In *Radiological Assessment*, edited by John E. Till and H. Robert Meyer, 5-30 to 5-32. Washington, D.C: 1983.

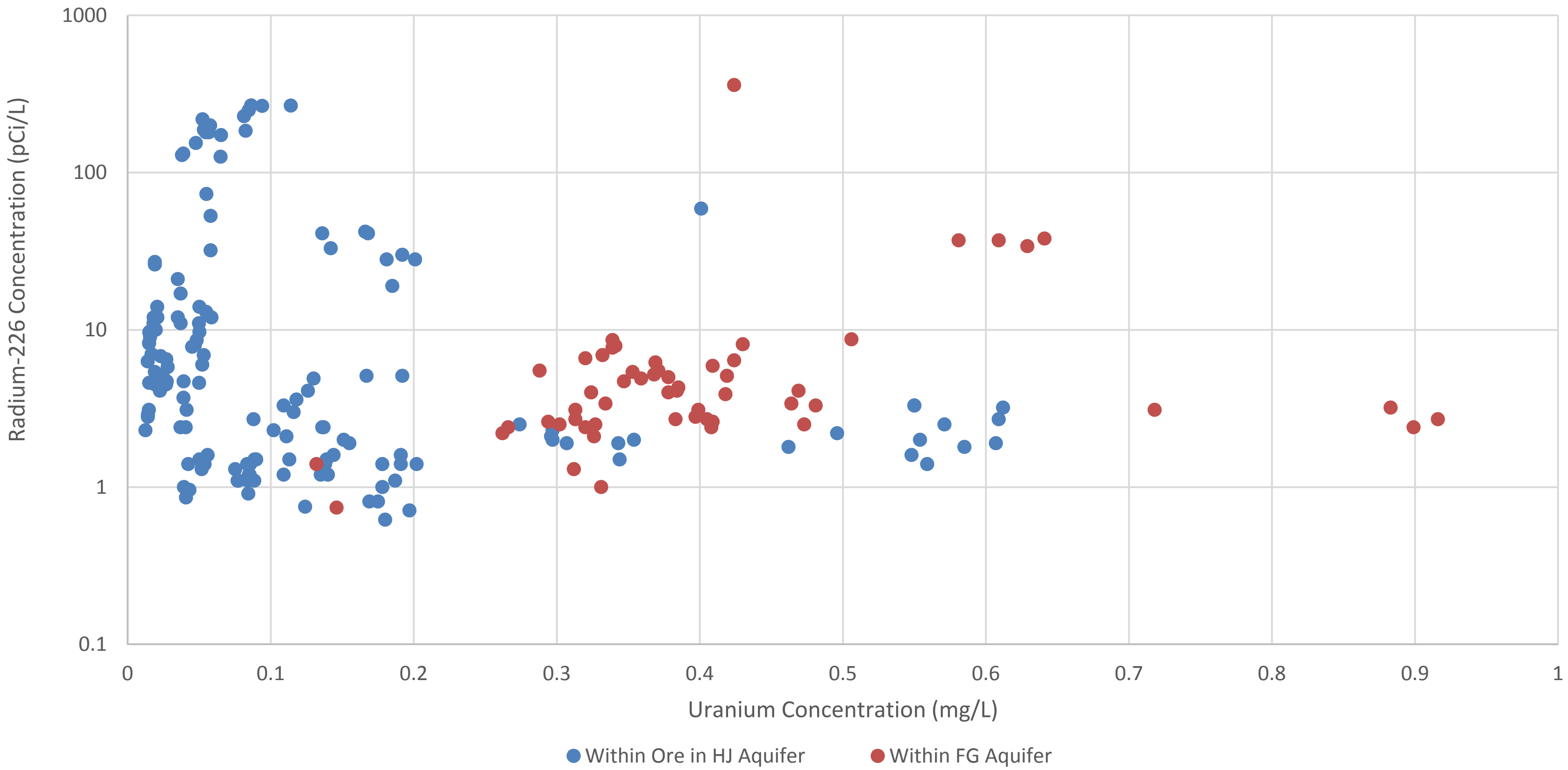
Pohl, H.R. and H.G. Abadin, 1995. Utilizing Uncertainty Factors in Minimal Risk Levels Derivation, Regulatory Toxicology and Pharmacology, v 22, pp 180-188.

Sharp, W. N., E. J. McKay, F. A. McKeown and A. M. White, 1964. "Geology and Uranium Deposits of the Pumpkin Buttes Area of the Powder River Basin, Wyoming", U.S. Geological Survey, Bulletin, 1107-H, 1964.

Sheppard, M.I., and D. H. Thibault, 1990. "Default Soil Solid/Liquid Partition Coefficients, Kds, for Four Major Soil Types: A Compendium." *Health Physics*. 59(4):471-482. Philadelphia, PA.

WDEQ (State of Wyoming Department of Environmental Quality), 2016. *Underground Injection Control Permit Issued Under Wyoming Water Quality Rules and Regulations, Chapter 16, Class V Injection Well*. Dated November 23, 2015. Permit Number 15-081. Accessed from http://gem.wqd.apps.deq.wyoming.gov/Wellsearch.aspx?Permit=true on March 14, 2016.

Figure 1. Comparison of Uranium and Radium-226 in Groundwater within the FG and HJ Aquifers at Mine Unit 1




Source: Mine Unit 1 Wellfield Package

Table 1. Concentrations and Calculated Distribution Coefficients for Uranium and Radium-226

| **Radionuclide** Media concentrations and $K_d$ | Data Source | Concentration / Distribution Coefficient for the Wells | | | | | Distribution Coefficient for the Aquifer | | |
|---|---|---|---|---|---|---|---|---|---|
| | | FG6 | FG7 | FG8 | FG9 | FG10 | Average | FOS | Estimated |
| **Radon-222** | | | | | | | | | |
| GW (pCi/L) | 1 | 1600 | 2820 | 3400 | 8.1 | 878 | | | |
| **Radium-226** | | | | | | | | | |
| Soil (pCi/kg) | 2 | 1095 | 1929 | 2326 | | 601 | | | |
| GW (pCi/L) | 1 | 1 | 1.7 | 2.2 | 3.6 | 2.9 | | | |
| Kd (L/kg) | 3 | 1095 | 1135 | 1057 | | 207 | 1096 | 2 | 2200 |
| **U-234 / Nat U** | | | | | | | | | |
| Soil (pCi U-234/kg) | 2 | 1095 | 1929 | 2326 | | 601 | | | |
| GW (mg Nat-U/L) | 1 | 0.0813 | 0.113 | 0.158 | 0.132 | 0.0913 | | | |
| GW (pCi U-234/L) | 4 | 26.9 | 37.4 | 52.3 | | 30.2 | | | |
| Kd (L/kg) | 3 | 40.7 | 51.6 | 44.5 | | 19.9 | 46 | 10 | 460 |

Media is soil or groundwater (GW), $K_d$ is the distribution coefficient, units as shown.

Data Source: (1) Laboratory Analysis; (2) Calculation - Secular Equilibrium; (3) Calculation – Soil/Groundwater concentration; (4) Calculation

Calculation parameters (Details in Appendix A):

- Porosity of the aquifer matrix is 0.26
- Bulk Density of the aquifer matrix is 1.9 grams per cubic centimeter
- Emanation factor for radon-222 from the matrix to groundwater is 0.2
- The activity of uranium-234 is 0.489 of the activity of natural uranium
- The estimate of uranium-234 concentration in soil is based on secular equilibrium of uranium-234 in soil and groundwater with radium-226
- Average is based on the average for wells FG6, FG7 and FG8
- FOS is Factor of Safety

**Appendix A: Staff's Rationale and Methodology for Using the Distribution Coefficient in a 10 CFR 20.2002 Analysis of Public Dose Resulting from Disposal of Liquid Wastes in a Class V Well**

## A.1) Statement of the Issue

Lost Creek ISR, LLC (LCI) proposes disposing of on-site treated liquid byproduct material waste by injecting it into the shallow subsurface. The treated byproduct material will meet NRC-approved concentration limits before it is injected. The proposed concentration limits for most radionuclides are the maximum detected concentrations in the receiving aquifer.

The proposed process is considered an alternative disposal procedure for a licensed material under 10 CFR 20.2002 rather than an effluent. In Section 10 CFR 20.2001(a)(3), the term "effluents" as used in the phrase "release of effluents within the limits in 10 CFR 20.1301" means "releasing the radioactive material into the atmosphere if it is in gaseous or airborne particulate form, or into a body of water if it is in liquid form" based on guidance on obtaining approval for disposal procedures (10 CFR 20.2002) contained in NUREG-1736, "Consolidated Guidance: 10 CFR Part 20 – Standards for Protection Against Radiation," on the 10 CFR 20.2002 (p. 3-152). Similar guidance is provided on p. 3-72 of NUREG-1736, which states:

> The concentrations of released materials are to be measured at the boundary of the unrestricted area. For many facilities, this means at the point of release to the atmosphere, such as the top of the stack, for airborne releases, and at the point of discharge to a body of water, for liquid releases.

NRC guidance on approving alternative disposal procedures in accordance with 10 CFR 20.2002 is contained in Section 15.12 of NUREG-1757, "Consolidated Decommissioning Guidance: Decommissioning Process for Materials Licensees." As stated in Section 15.12.3.1 of NUREG-1757, as assessment of doses to critical groups of exposed persons after license termination should include site-specific, realistic scenarios. In addition to the specific requirements in 10 CFR 20.2002, NRC's current practice is to approve requests for on-site disposal that result in doses not exceeding a "few millirem" per year.

In its request, LCI analysis was focused on exposure risks to groundwater and concluded the long-term risks to the aquifer would be minimal. However, a risk analysis should account for long-term buildup of radioactive material from the discharge to both groundwater and the aquifer matrix, and potential pathways other than drinking the groundwater.

Staff independently evaluated LCI's conclusion that the long-term effects on the aquifer would be minimal by estimating the dose to a future well driller at the Lost Creek site. In its evaluation, the NRC staff used the equilibrium-controlled linear sorption model that relates levels in groundwater (dissolved phase) to those absorbed onto the aquifer matrix (sorbed phase). The NRC staff's rationale and methodology for this evaluation are documented below.

## A.2) Use of Radon in Groundwater as Surrogate for Parent Levels in Aquifer Matrix

The equilibrium-controlled linear sorption model states that at any location, the sorbed concentration on the aquifer matrix is proportional to the dissolved concentration in groundwater. The proportional constant is defined as the distribution coefficient, $K_d$. In general the greater the value for a distribution coefficient the higher the concentration in the sorbed phase.

NRC staff's method to estimate the radium-226 and natural uranium concentrations in the soil matrix is to use the radon-222 concentrations in groundwater, which LCI provided in the amendment request, and, assuming secular equilibrium, estimate the radium-226 and uranium-234 concentrations in the aquifer matrix. This method differs from those typically used to establish a distribution coefficient (e.g., laboratory batch, in-situ batch, laboratory flow through methods (EPA, 1999)). However, each of those methods have inherent assumptions and limitations. Inter-laboratory comparisons of the reported distribution coefficients for the same samples yield a 3-order range of values. Unfortunately, the range of values for a distribution coefficient for the constituents of concern from the literature is too broad to yield a meaningful analysis for any particular site. The primary limitations on the method used by staff are the assumptions of secular equilibrium and radon emanation factor. As discussed below, staff's use of conservative estimates provides a reasonable bounding limit.

The assumption of secular equilibrium is conservative because the system is open, i.e., the individual constituents can be mobilized at different rates through the migration of groundwater. For reasons discussed below, the use of conservative parameters in the analysis including a factor of safety, performing a bounding analysis, consistency of the results for data from the various wells and consistency of the results with published data, staff has reasonable assurance that the distribution coefficients calculated in this analysis provides a conservative analysis and thus protective of human health and the environment.

First, the half-life of radon-222 is relatively short at 3.8 days. This half-life is sufficiently fast relative to groundwater flow that it is reasonable to assume the system is closed with respect to radon-222. For example, based on information on the hydraulic properties for the aquifer in LCI's request, NRC staff calculated the groundwater movement during one half-life of radon-222 to be 0.25 centimeters [0.1 inches]. Therefore, the assumption that the radon-222 concentrations measured in the groundwater are in equilibrium with radium-226 in the aquifer matrix is valid.

Second, the NRC staff reviewed published literature and determined that there is a consensus of views that: (1) once in groundwater, radon does not effectively sorb to the aquifer matrix because it is a noble gas (i.e., the value of the distribution coefficient is zero); (2) radon is transmitted from the solid matrix to the pore space due recoil energy during the alpha decay process; and (3) the percentage of radon that is transmitted to the pore space from that undergoing decay in the matrix (herein referred to as the "emanation factor") is based on the site physical conditions such as grain size of the aquifer matrix, pore volume and configuration, and degree of saturation of the strata. The emanation factor for strata saturated above 30 percent (i.e., the pores are 30 percent filled with water and 70 percent filled with gas) is equivalent to emanation factor for a fully saturated aquifer and the emanation factor for a fully saturated aquifer is between 0.2 and 0.8 (Mackin et al., 2001; EPA, 1999; Sun and Furbish, 1995). Therefore, the quantity of radon-222 in the water per unit volume is:

$$A_{water}^{Rn-222} \cong A_{total}^{Rn-222}\, x\, f \quad (1)$$

where,

$A_{water}^{Rn-222}$ is the total activity of radon-222 in the water per unit volume
$A_{total}^{Rn-222}$ is the total activity of radon-222 per unit volume
$f$ is the emanation fraction described above.

Since it is assumed that radon-222 is in equilibrium with radium-226 in the solid,

$$A_{total}^{Rn-222} \cong A_{solid}^{Ra-226} \quad (2)$$

we can substitute $A_{solid}^{Ra-226}$ for $A_{total}^{Rn-222}$ in Equation (1) to write:

$$A_{water}^{Rn-222} \cong A_{solid}^{Ra-226}\ x\ f \quad (3)$$

Separately, the concentrations of radon-222 in water, $C_{water}^{Rn-222}$, and radium-226 in the solid phase, $C_{solid}^{Ra-226}$, can be written,

$$C_{water}^{Rn-222} = \frac{A_{water}^{Rn-222}}{V_T\ x\ \theta} \quad (4)$$

$$C_{solid}^{Ra-226} = \frac{A_{solid}^{Ra-226}}{V_T\ x\ \rho_B} \quad (5)$$

where,

$V_T$ is the unit volume (L)
$\theta$ is the porosity of the aquifer (dimensionless)
$\rho_B$ is the bulk soil density of the aquifer (g/cm$^3$)

The values assumed by the NRC staff for $\theta$ and $\rho_B$ are described in Sections A3 and A4 below. We can rearrange equations (4) and (5) by solving for the activity terms,

$$A_{water}^{Rn-222} = C_{water}^{Rn-222} x V_T\ x\ \theta \quad (6)$$

$$A_{solid}^{Ra-226} = C_{solid}^{Ra-226} x V_T\ x\ \rho_B \quad (7)$$

The right sides of equations (6) and (7) are substituted into equation (3) to write,

$$C_{water}^{Rn-222} x V_T\ x\ \theta = C_{solid}^{Ra-226} x V_T\ x\ \rho_B\ x\ f \quad (8)$$

Solving for $C_{solid}^{Ra-226}$, we arrive at,

$$C_{solid}^{Ra-226} = \frac{C_{water}^{Rn-222}\ x\ \theta}{\rho_B\ x\ f} \quad (9)$$

As shown in Table 1, assuming the following parameter values for well FG8,

$C_{water}^{Rn-222}$=1,600 pCi/L
$\theta$ = 0.26 (see Section A3 below)
$\rho_B$= 1.9 g/cm$^3$ (see Section A4 below), and
$f$= 0.2

the estimated value of $C_{solid}^{Ra-226}$ is 2,326 pCi/kg.

## A.3) Porosity

LCI identified a porosity, $\theta$, of 0.26 (26 percent) based on analyses of core samples in the license application (LCI, 2008). The NRC staff used this value in its analysis.

## A.4) Bulk Density

LCI did not provide a value for bulk density for the formation. For this evaluation, NRC staff used a value derived from published literature for similar geologic formations as the proposed setting. The geologic formation for the discharge is the Battle Spring Formation. The Battle Spring Formation consists of semi-consolidated sediments that were locally derived from terrestrial fluvial deposits. These sediments are equivalent (both in time and spatially inter-fingering) with sediments forming the Wasatch Formation. Both the Battle Spring and Wasatch formations overly the Fort Union Formation. The Fort Union Formation also consists of terrestrial fluvial deposits, though this formation generally has finer grained material than the overlying formations because the sediments were deposited in more distal environments (i.e., coastal environment).

Manger (1963) provides a compilation of bulk density measurement on a variety of formations throughout United States. The compilation includes those for the Fort Union Formation from a location in Montana. The reported bulk density values for the Fort Union Formation ranged from 1.63 through 2.32 grams per cubic centimeter ($g/cm^3$), generally higher values associated with coarser grained lithologies and water saturated samples.

The NRC staff assumed a bulk density for this analysis of 1.9 $g/cm^3$ as the formation is a more coarse grained horizon in the Battle Spring Formation. Staff elected to use this value as it is consistent with the reported porosity value of 0.26 and the predominant mineral grains of quartz and feldspar that form a large part of the arkosic aquifer matrix. Quartz and feldspar have specific gravities in the range of 2.55 to 2.76. Using the density of water of 1 $g/cm^3$, an average specific gravity of 2.65 for the minerals forming the aquifer matrix and a porosity of 0.26 ram per 6 grams per centimeter, a calculated bulk density would be 1.96 g/cm3 (2.65x 1 $g/cm^3$ x (1-0.26)). Furthermore, the total range in possible bulk density yields a maximum error in the calculated distribution coefficient of 20 percent, which would not affect the staff's conclusions using this value.

## A.5) Rationale for Use of the Distribution Coefficient in the Analysis

In the most simple of terms, the fate and transport of constituents in transient groundwater systems are described by a partial differential equation which the rate of change of a dissolved constituent concentration is equal to the spatial change of (a) the dissolved constituent concentration due to dispersion and advection, (b) inflow or outflow of the constituent from external sources/sinks or (c) chemical reactions, which include sorption to the aquifer matrix, or, radiological or biological decay. For this analysis, the NRC staff assumed the primary effects are those attributable to advective flow, sorption to the matrix and inflow due to the disposal (i.e., effects of dispersion are not included, and the sinks are located sufficiently far from the area of interest). Of these effects, the focus of this analysis is sorption and impacts to the aquifer matrix.

The left side of the generalized fate and transport differential equation is written as follows:

$$\theta \frac{dC^k_{Diss}}{dt} + \rho_b \frac{dC^k_{Sorbed}}{dt} = \cdots \qquad (6)$$

where,

$\frac{dC^k_{Diss}}{dt}$ is the rate of change in concentration of constituent *k* dissolved in the groundwater (mg/(L-days)

$\frac{dC^k_{Sorbed}}{dt}$ is the rate of change in concentration of constituent *k* sorbed on the aquifer matrix (mg/(Kg-days)

In this analysis, staff used the "$K_d$ approach" as the model for the fate and transport of constituents in groundwater. The "$K_d$ approach" is based on the assumption of an equilibrium-controlled linear sorption under constant temperature (isotherm). The basic tenet of this model is that the concentration of a constituent dissolved in groundwater is proportional to the concentration of that constituent sorbed on the aquifer matrix:

$$C^k_{Sorbed} = K_d \times C^k_{Diss} \qquad (7)$$

where,

$K_d$ is the distribution coefficient (L/kg)

The "$K_d$ approach" assumes that equilibrium conditions exist. This assumption is thought to be valid for typical groundwater flow rates. However, the increased flow rates due to the injection may question the validity of the equilibrium-controlled linear sorption model. To test the assumption of equilibrium, staff developed a MODFLOW numerical groundwater flow model coupled with a MT3DMS fate and transport model using both the equilibrium-controlled linear sorption and the first-order, non-equilibrium (kinetic) sorption models.

The first-order, non-equilibrium (kinetic) sorption model can be described as follows:

$$\frac{dC^k_{Sorbed}}{dt} = k_2 C^k_{Diss} - K_3 C^k_{Sorbed} \qquad (8)$$

where,

$k_2$ is the forward rate constant (dissolved to sorbed) $(^L/_{day - Kg})$

$k_3$ is the backward rate constant (sorbed to dissolved) $(^1/_{day})$

For the computer program MT3DMS, the equation (multiplied by the bulk density) is written in a slightly different form:

$$\rho_b \frac{dC^k_{Sorbed}}{dt} = \beta (C^k_{Diss} - {C^k_{Sorbed}}/{K_d}) \qquad (9)$$

where,

$\beta$ is the mass transfer rate $\left(1/_{day}\right)$

The kinetic model (Equation 8) differs from the equilibrium model due to two rate constants, the forward and backward rate constants, which may be defined independently. However, inspection of the equations for the kinetic model in the computer software MT3D, the forward rate constant is related to the backward rate constant by the "equilibrium" distribution coefficient. From a comparison of Equations (8) and (9), the relation between the kinetic rate constants and the equilibrium distribution coefficient is as follows:

$$k_2 = \rho_b \beta \qquad (10)$$

$$k_3 = {}^{\rho_b \beta}/_{K_d} = {}^{K_2}/_{K_d} \qquad (11)$$

$$K_d = {}^{k_2}/_{k_3} \qquad (12)$$

NRC staff used the above-referenced computer modeling software to evaluate the sensitivity of the proposed discharge to various values for the distribution coefficient for the equilibrium model and mass transfer rates for the kinetic model. All simulations consisted of the following:

- Injection of 200 gpm for 14 years
- Injection concentration of constituent K of 100 mg/L
- Initial dissolved concentration of constituent K of 1 mg/L
- The porosity and bulk density values from sections A3 and A4, respectively
- Equilibrium has been established in the aquifer prior to the injection

The parameter and their values used for five sensitivity simulations are as follows:

| Simulation | Kd (L/Kg) | Mass Transfer Rate |
|---|---|---|
| 1 | 10 | 1 per day |
| 2 | 10 | 1 per hour |
| 3 | 10 | 1 per second |
| 4 | 1000 | 1 per second |
| 5 | 10 | N/A (equilibrium-controlled isotherm) |

Results of the model simulations are shown on Figure 1 through 3. Based upon inspection of the simulation results, staff concludes the following:

- The maximum levels sorbed to the aquifer matrix in the kinetic model are those defined by the equilibrium distribution coefficient.
- For distribution coefficient values between 10 and 1000 L/Kg, the aquifer matrix concentration was at the maximum level to a radial distance of 75 and 13 feet, respectively, at the end of the injection period.
- The temporal concentration profiles are relatively insensitive to mass transfer rate and approach the equilibrium values within the first 180 days of operation.

Therefore, based on the above, staff concludes that the equilibrium-controlled linear isotherm model is appropriate for this analysis.

## A.6) Methodology

The methodology staff used was to estimate the changes to the aquifer matrix attributed to the injection consists of the following:

i. The injection had a concentration of the constituent that equaled the maximum WDEQ Permit limit
ii. The initial dissolved concentration of the constituent in the aquifer equaled the minimum detected concentration in the aquifer within the areas of influence of the injection
iii. A distribution coefficient was established for that constituent using the methodology in Section A.2 above
iv. The concentration of the constituent absorbed to the aquifer matrix was calculated by multiplying the difference in concentration values in steps i. and ii. by the distribution coefficient determined by step iii.

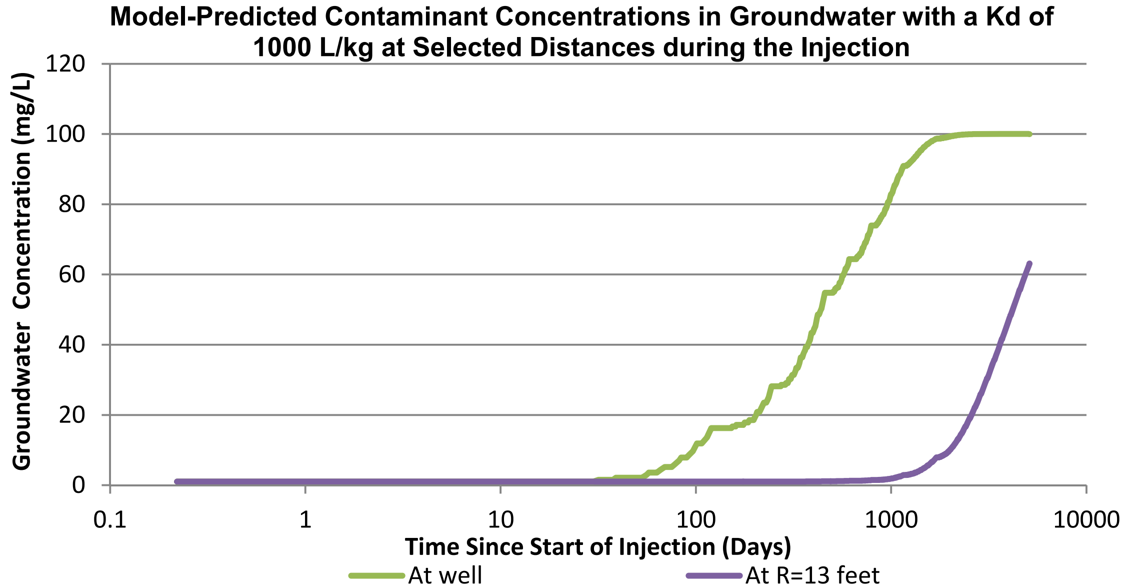
## A.7) References

Manger, G.E., Porosity and Bulk Density of Sedimentary Rocks, U.S. Geological Survey Bulletin 1144-E, 55 pp.  1963

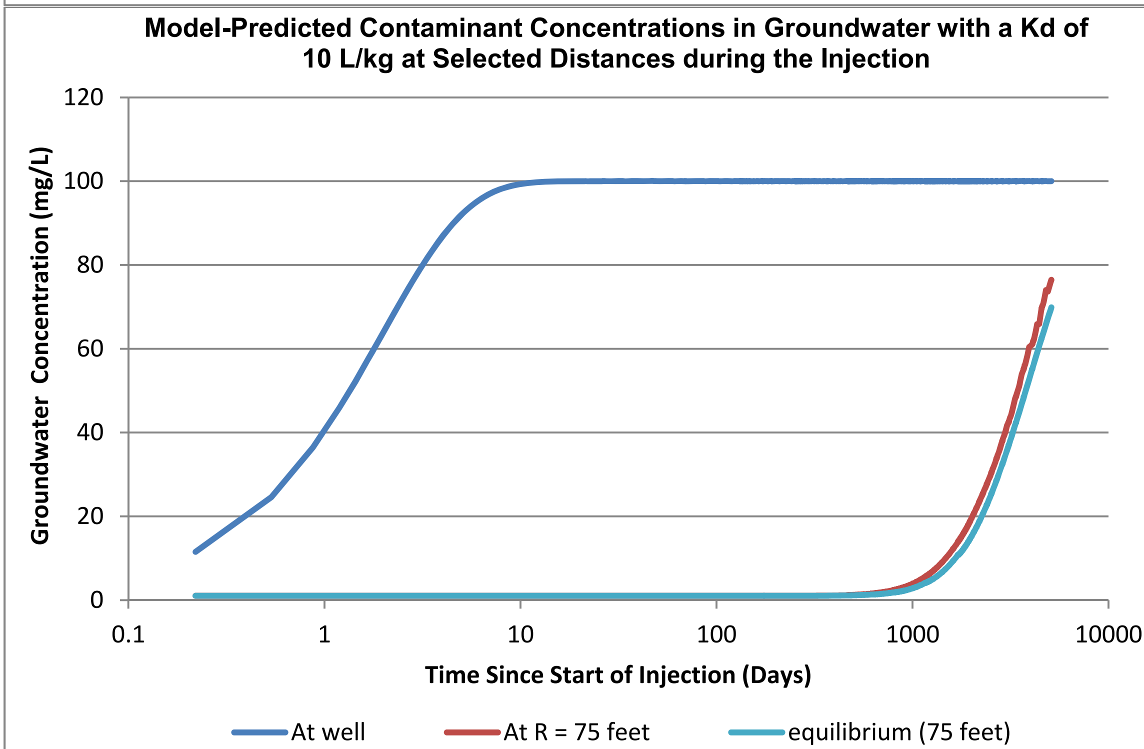
Mackin, P.C., Daruwalla, D., Winterle, J., Smith, M. and A. Pickett, 2001. A Baseline Risk-Informed, Performance-Based Approach for the\\\In Situ Leach Uranium Extraction Licensees, NUREG/CR-6733, September 2001.

Sun, H. and D.J. Furbish, 1995, Moisture Content Effect on Radon Emanation in Porous Media, Jour of Contaminant Hydrology, V 18 pg 239-55.

Figure A1  Theoretical Contaminant Concentrations in Groundwater

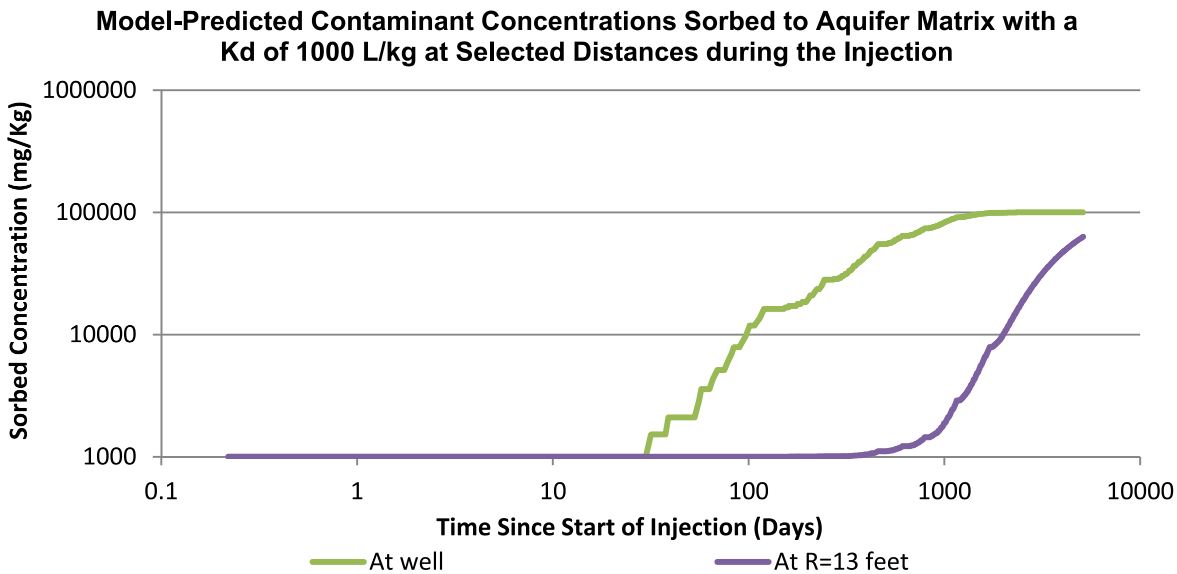



Injection at 200 gpm for 14 years.  Injection concentration 100 mg/L,  Background Dissolved Concentration  1 mg/L, Mass Transfer Rate =1 per second.

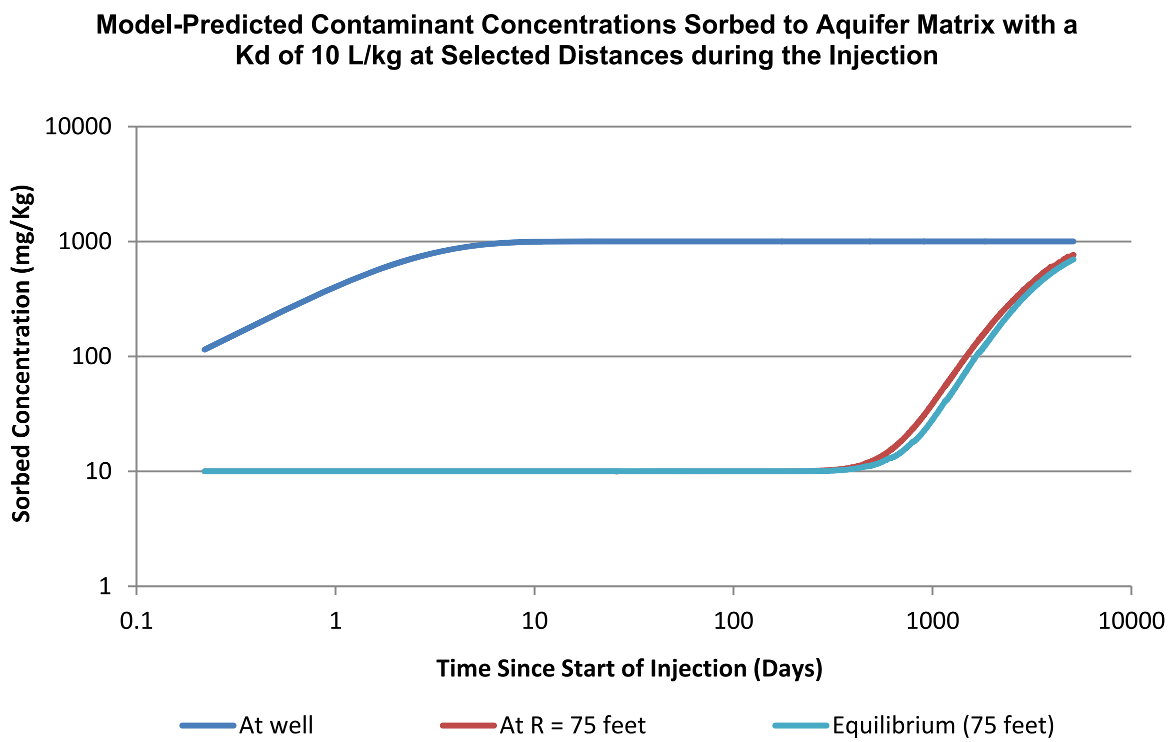



Injection at 200 gpm for 14 years.  Injection concentration 100 mg/L,  Background Dissolved Concentration  1 mg/L, Mass Transfer Rate =1 per second.

Figure A2  Theoretical Contaminant Concentrations sorbed to the Aquifer Matrix

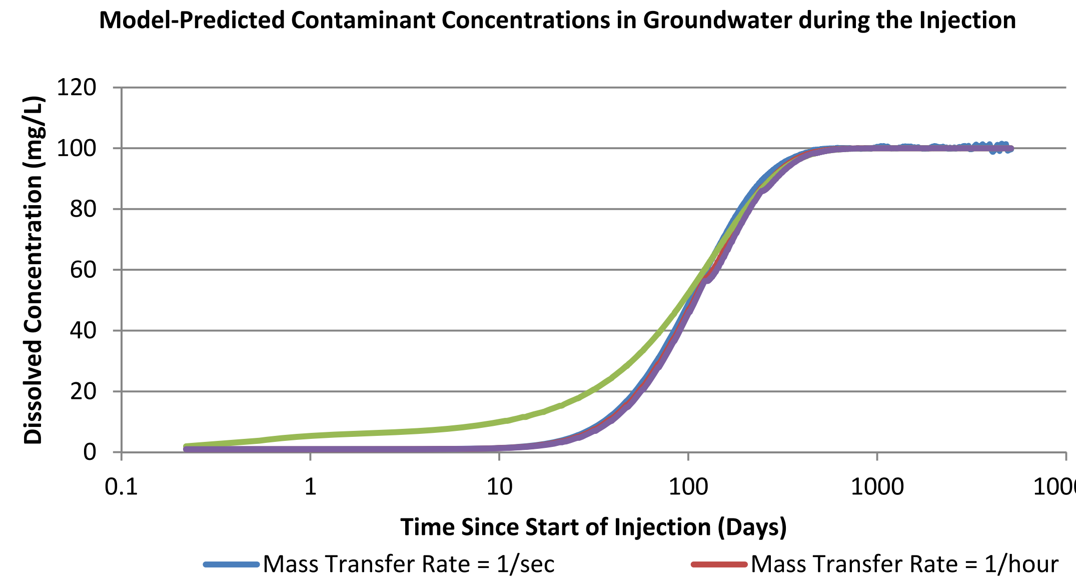



Injection at 200 gpm for 14 years.  Injection concentration 100 mg/L,  Background Dissolved Concentration  1 mg/L, Mass Transfer Rate =1 per second.

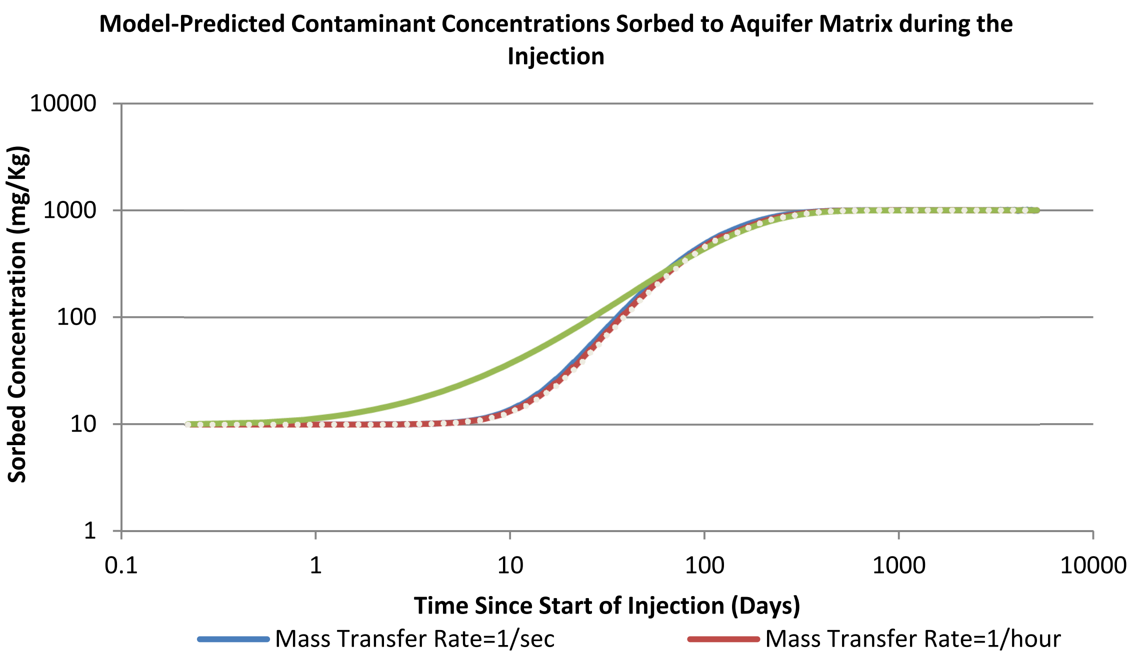



Injection at 200 gpm for 14 years.  Injection concentration 100 mg/L,  Background Dissolved Concentration  1 mg/L, Mass Transfer Rate =1 per second.

Figure A3 Comparison of the Model-Predicted Concentrations for Various Mass Transfer Rates for the Kinetic Model




Injection at 200 gpm for 14 years. Injection concentration 100 mg/L, Background Dissolved Concentration 1 mg/L. Distribution Coefficent = 10 L/Kg. Distance = 13 feet.




Injection at 200 gpm for 14 years. Injection concentration 100 mg/L, Background Dissolved Concentration 1 mg/L. Distribution Coefficent = 10 L/Kg. Distance = 13 feet.

Enclosure 2
Amendment 5, SUA-1601