Documentation of the Engineered Covers Technical Group (ECTG) Activities

October 2011

Hans Arlt, Robert L. Johnson, Doug Mandeville, George Alexander, Matthew Meyer, Jake Philip*, Joseph Kanney*, Mark Fuhrmann*, and Ted Johnson[+]

Division of Waste Management and Environmental Protection (DWMEP)
Office of Federal and State Materials and Environmental Management Programs (FSME)
U.S. Nuclear Regulatory Commission (NRC)
Washington, D.C. 20555-001

*** Office of Nuclear Regulatory Research (RES)**
U.S. Nuclear Regulatory Commission (NRC)
Washington, D.C. 20555-001

[+] Consultant

Executive Summary

The Office of Nuclear Regulatory Research (RES) has completed the research project, "Effectiveness of Engineered Covers: From Modeling to Performance Monitoring," (hereafter referred to as the RES report) conducted by the University of Wisconsin under a U.S. Nuclear Regulatory Commission (NRC) contract with the US Geological Service (NUREG/CR-7028, *in print*). An important conclusion of the RES report is that compacted soil materials used in cover materials at the sites studied did not retain "as built" properties over periods of regulatory interest. The properties of these materials change to values more typical of surrounding soils within 5 to 10 years after installation. Changes in low permeable cover soils can be rapid and can result in an increase to the saturated hydraulic conductivity by three to four orders of magnitude. The RES report focuses on changes to engineering properties of soil covers; however it does not address cover elements designed for erosion protection.

The Division of Waste Management and Environmental Protection (DWMEP) established a working group designated the "Engineered Covers Technical Group," or ECTG, to discuss and review the implications of the RES report. The technical group was tasked to assess the technical merits of the findings in RES report and its potential impact on low-level waste (LLW), uranium recovery (UR), and decommissioning licensing activities. The ECTG conducted a qualitative assessment to identify and prioritize by risk existing sites that may be impacted by the findings from the RES report[1]. Processes contributing to risk include both radon flux from the disposal cell and effects to the groundwater due to the potential of an increased rate of water infiltration through the covers. The prioritization of sites based on risk-informed judgments is especially important in order to start activities at those sites deemed needing the most attention.

Quantitative analyses to determine both radon flux rates and seepage rates from the tailings to the aquifer are difficult since quantitative data are lacking. Important parameters for calculating infiltration have not been gathered so ECTG decided to do a qualitative assessment for each of the disposal sites. Various characteristics and related parameters were used to assess the potential for increased groundwater contamination from tailings seepage: total amount of precipitation, potential evapotranspiration, extent of overburden, depth to aquifer, unsaturated zone hydrogeological characteristics, the existence of a bottom liner plus leachate collection system, and the status of the groundwater, i.e., the quality and usability of the groundwater or nearest aquifer. Although some of these parameters do not influence the infiltration rate through the cover, it was included in the tables so as to give insights into potential risks to public health and safety. A higher potential for increasing groundwater contamination for an aquifer that is potable and used by nearby communities is of greater concern than groundwater which is not potable, stagnant, and/or made unusable by previous contamination. The types of information to reduce the uncertainty associated with the risk from radon release can vary from overburden thicknesses on top of the radon barrier; to soil moisture content; calculations of dose equivalent showing that public health, safety, and the environment are protected; or actual direct measurements of radon flux. Measured concentration values appear to have a higher uncertainty associated with them than actual measured radon flux rates.

The ECTG determined that the assessment of sites located in Agreement States should be deferred until after the ECTG assessed sites for which the NRC's responsibilities were more direct. UR sites and LLW sites in Agreement States were therefore temporarily removed from

[1]Sites were classified with a five point scale and graded from either low, low/moderate, moderate, moderate/high, or high.

the compiled table, as were the disposal sites for various wastes for which covers have been designed but not constructed. The RES report findings showed that covers with composite components do not appear to significantly degrade over the short-term and no sites with composite covers were assessed including planned covered disposal sites for waste incidental to reprocessing (WIR). The ECTG qualitatively assessed 20 Title I, 6 Title II, and 11 Title II in closure sites, in addition to one decommissioning site where decommissioning activities have not been completed (Cimarron, OK).

The NRC staff is aware that the standards and regulations for engineered radon barriers at UR sites apply to design, and that monitoring after disposal is not required to demonstrate compliance. However, the result of recent research on covers is not something anticipated when the regulations were promulgated, especially the rate at which compacted clay soil structure changes and secondary structure develop. The NRC staff members strive to remain current in their knowledge within their disciplines and maintain the flexibility to adapt expanding knowledge within a particular field to the NRC's guidelines and regulations. The utilization of engineered surface barriers or covers is relatively recent and studies relating to their effectiveness are even more recent. The above-mentioned recent research on covers are some of the first results to be obtained from the field and must be seen in context with the general licenses for custody and long-term care of residual radioactive material disposal sites and of uranium byproduct materials disposal sites. The purpose of the general licenses is to ensure that the disposal sites are utilized in such a manner as to protect the public health, safety, and the environment after closure.

Although there are differences in design between the covers exhumed in the RES Benson report and the engineered surface covers at NRC regulated sites, the RES report clearly shows that the properties of the engineered soil may degrade in relatively short times on exposure to natural conditions. Staff evaluated available information for each site, comparing the specific results of the report to the specific conditions of the existing sites. From the sites qualitatively assessed for possible increased contaminated seepage into groundwater due to processes documented in NUREG/CR-7028, no sites were assessed higher than moderate/high. The two disposal sites assessed with moderate/high are Shirley Basin North (Pathfinder) and Gas Hills West (ANC) in Wyoming. The main reason for the higher ratings was the relatively thin resistive, compacted clay layers and the lack of supporting documentation to negate the effects of the degradation processes. For many of the Title I and II sites above potable, usable aquifers, assessment summaries with rating potentials greater than low contained recommendations that periodic water quality sampling and measurement be part of the monitoring program.

Key Recommendation:

1) The ECTG qualitatively assessed seven mill tailings covers from Title I and II sites to have a moderate/high or high potential for increased radon release due to processes described in the RES Benson report. They include Mexican Hat, UT; Tuba City, AZ; Bluewater, NM; Church Rock (UNC), NM; Gas Hills West (ANC), WY; Grants (Homestake), NM [planned cover only]; and Shirley Basin North (Pathfinder), WY. It is recommended that average radon release be measured for these six existing sites with verifiable quality assurance (QA) over the entire engineered surface cover for those cells which are considered complete and for a duration of one-year or longer. Radon concentration measurements should be performed for one or more of these seven sites where flux measurements prove to be too difficult. If flux rates higher that the regulatory standard of 20 $pCi/m^2/s$ are observed, additional actions for those sites should be

reviewed, and additional flux rates should be gathered from those sites ranked low/medium and higher.

2) The ECTG qualitatively assessed three mill tailings covers from Title I and II sites to have a moderate/high potential for increased groundwater contamination from tailings seepage due to processes documented in the RES Benson report. Routine monitoring by the U.S. Department of Energy at the Lakeview, Oregon site shows that groundwater is currently not becoming more contaminated, however groundwater monitoring at the Lakeview site should continue. Tailings Pond 1 from Gas Hills West (ANC) is only in the design phase, but if the final cover design remains unchanged it is recommended that monitoring instruments should be incorporated into the engineered surface barrier so that the infiltration rate through the cover can be determined or estimated. Shirley Basin North (Pathfinder) remains open to the disposition of in-situ leach byproduct materials with closure and final reclamation of the waste disposal site to be conducted at a later date. If the final design relies on the relatively thin clay layer in place over portions of the site, additional monitoring and evaluation of cover infiltration should be conducted. The staff would need to explore with the licensees the best way to implement these recommendations with the current regulatory framework under 10 CFR 40, Appendix A, e.g., criterion 5B(4) and 5B(5).

3) The ECTG recommends that the current groundwater monitoring programs at Title I disposal sites should not be discontinued. Instead, the U.S. Department of Energy/Legacy Management (DOE/LM) should be encouraged to compile information from the monitoring program and extract information that might indicate the degree and extent of possible changes in cover performance and potential increased infiltration through the cover.

4) In general, a monitoring program, under adequate QA/quality control (QC) procedures is recommended that is based on confirming main assumptions and significant performance for planned and future engineered surface barriers at all waste facility sites, where credit is taken for the engineered cover in performance assessment (PA) modeling. This could include periodic radon flux measurements, direct and indirect sampling or monitoring of additional seepage from the waste, and confirming groundwater and vadose water quality. In addition, ECTG recommends a coupling of design and monitoring, where integrating monitoring features into the cover design is standard procedure.

5) NRC staff should exchange information and engage in cooperation with the Agreement States. Detailed discussions should be held in the near future with the Agreement States on how management of their waste facilities may be effected by the findings and implications of the RES Benson Report and the recommendations of the ECTG.

<u>Short- and long-term recommendations included:</u>

● Continue to keep a contract with Center for Nuclear Waste Regulatory Analyses (CNWRA) to compile and develop a database of site-specific data on radon and groundwater, evaluate site-specific engineered cover performance, and recommend future site-specific radon and groundwater monitoring and data analyses.

● Both the DOE/LM and NRC staffs were in agreement with the interpretations of the latest field study results, the need to be proactive, and the advantages of LM and the NRC sharing and working together.

● Continue the ECTG as a “community of practice” or “technical advisory group” to support project managers and technical staff in reviewing future infiltration/radon cover designs, data, or issues. The ECTG, having expertise in different fields and now some experience with all the disposal sites in question, could also review progress made during the DOE’s cover renovation research. The ECTG could also evaluate what new information and insights might be included in the draft NUREG-1757, Vol. 4 for uranium recovery facilities.

● Knowledge obtained by the ECTG on infiltration/radon cover designs could be combined with knowledge from erosion control design documents currently being completed in order to provide a comprehensive overview of cover issues and sites that need tracking by the staff. Combine the site conclusions from both reports as a management tool to focus on those sites with cover issues where action is required.

Recommendations on future research activities:

● Build risk-informed, monitored test pad cover simultaneously with construction of future mill tailings cover.

● Pedogenic study of the cover soil layers. Evolution of soil properties is a significant process that can play a major role in determining cover performance.

● Detailed study of the biotic activity and bioturbation of cover soil layers. Biological activity within the cover can be a significant process and influence cover performance.

● Studies related to the changing cover performance as documented in the RES Benson report, including cover properties returning to a state of equilibrium with the surrounding environment.

● Develop a QA performance assessment checklist for geosynthetic component installation, including geomembranes and geosynthetic clay liners.

Recommendations for future guidance:

● In case current standards are not revised, the NRC/ Office of the General Counsel (OGC) should interpret the limit of leeway to change current guidelines based on the current standards, so that guidance such as the Standard Review Plan for Title I sites and NUREG-1620 take a more risk-informed, performance-based approach. Such revisions will bring UR guidance more in line with NRC’s risk-informed, performance-based decommissioning guidance in NUREG-1757.

● New information and insights could be included in Volume 4 of NUREG-1757 that is currently being prepared for uranium recovery facilities.

● Future guidance should rely on confirmatory-based regulation.

Table of Contents

1 Planned Public Release of NUREG/CR-7028 on Engineered Covers for Waste Containment

The Office of Nuclear Regulatory Research (RES) has completed the research project, "Effectiveness of Engineered Covers: From Modeling to Performance Monitoring," conducted by the University of Wisconsin under a U.S. Nuclear Regulatory Commission (NRC) contract with the US Geological Service. A report on the project is under print at present (NUREG/CR- 7028, "Engineered Covers for Waste Containment: Changes in Engineering Properties & Implications for Long-Term Performance Assessment") and is referred to hence forth as the RES Benson report. This report incorporates responses to comments and suggestions from the technical peer review of the report. The research project involved assessments of the performance of engineered soil/composite cover materials with regard to infiltration of water through the covers at disposal sites. The final peer reviewed report will be made available publicly in ADAMS and the NRC's public website.

An important conclusion of the RES Benson report is that compacted soil materials used in cover materials do not retain "as built" properties over the period of regulatory interest as assumed in most performance assessments. The properties of these materials change to values typical of surrounding soils within 5 to 10 years after installation. For some properties the change may be several orders of magnitude, which may potentially lead to increased water infiltration and augmented radon flux out of the system. Their short-term performance (up to about 10 years) and conditions under which these materials may perform satisfactorily are documented. The RES Benson report also addresses the performance of geosynthetic materials that are sometimes used in conjunction with soil cover materials.

2 Engineered Covers Technical Group

The Division of Waste Management and Environmental Protection (DWMEP) established a working group designated "Engineered Covers Technical Group," (referred to hence forth as the ECTG) to discuss and review the implications of the RES Benson report. This technical group consisted of Jake Philip (to coordinate with RES), Ted Johnson, Robert L. Johnson, Doug Mandeville, George Alexander, Joseph Kanney, and Mark Fuhrmann, with Hans Arlt as technical group lead. The technical group was tasked to assess the technical merits of the findings in RES Benson report and its potential impact on low-level waste (LLW), uranium recovery (UR), and decommissioning licensing activities, assess the short-term/long-term significance of impacts as related to performance of engineered covers on the health and safety of the public and the environment, assess possible short-term/long-term remedies of potential impacts, evaluate assumptions and input parameters in DWMEP analysis to account for credible technical findings in the report, and interact and coordinate with RES as they have the lead to coordinate with other Federal agencies (e.g., U.S. Environmental Protection Agency (EPA), U.S. Department of Energy (DOE), U.S. Army Corp of Engineers, etc.) as well as concerned Agreement States. In addition, ECTG was asked to assist the RES in developing the Communication Plan for the public release of the RES Benson report. The first task was quickly completed when individual members of ECTG reviewed the technical merits of the RES Benson report findings and provided comments to the project manager for the author to incorporate into the report. No comments challenged the technical merits of the report.

3 Communications Plan for the Public Release of U.S. NRC Research Report

The key objectives of the NRC Research Report are to communicate the findings from the RES Benson report with other affected Federal agencies. The findings will primarily consist of changes to engineering and hydraulic properties of the cover soils and composite materials (geosynthetics) employed to isolate 11e.(2) tailings byproduct material. In addition, the report will discuss the impacts to cover performance and their effectiveness to contain and isolate the tailings byproduct material. The final objective will be to reach a consensus among the stakeholders to establish a path forward.

The key message is that changes to low permeable cover soils can be rapid and can result in an increase to the saturated hydraulic conductivity by three to four orders of magnitude. The RES Benson report focuses on changes to engineering properties of soil covers, which is an important protective element of the total disposal cell system. This report does not address cover elements designed for erosion protection. Based on this information, the NRC plans to evaluate degradation of soil covers at all of its licensed sites to determine if there is a further need to increase evaluative effort, employ monitoring and/or commence mitigation. The NRC staff conducted a qualitative assessment to identify and prioritize by risk existing sites that may be impacted by the findings from the RES Benson report. These include both radon flux rates from the disposal cell and effects to the groundwater due to the potential of an increased rate of water infiltration through the covers.

Previous studies of soil cover performance have indicated a potential for degradation of compacted soil covers designed to limit the infiltration of water into disposal cells. This information is documented in NRC's decommissioning regulatory guidance NUREG-1757, Volume 2. This document discusses potential cover degradation and provides guidance for analyzing potential degradation and its effects on compliance with regulatory criteria. In 2006, the NRC began the research described in the RES Benson report to further understand degradation in soil/composite covers. The report's findings are important to over 30 existing sites where the NRC has regulatory authority and where covers have already been constructed. These uranium mill tailings sites are owned and maintained by the DOE/Legacy Management (DOE/LM) and are regulated by the NRC by a general license under 10 CFR Part 40.27 or 40.28 for long-term surveillance and maintenance. The DOE has been conducting studies for many years of the potential for degradation and is conducting large-scale field studies of the potential for degradation including methods to renovate or repair degrading covers. The DOE are also monitoring a few sites for radon emissions from disposal cells. The DOE plans to continue evaluating the potential for degradation of soil covers, total disposal system performance, and potential mitigation options for covers determined to need mitigation in the future. The NRC plans to continue exchanging information on cover performance with the DOE, the EPA, and others involved with covers to further understand potential cover degradation, design options, and options for monitoring and mitigation. The NRC has an ongoing research project to investigate the coupling of erosion and hydrology and its impacts on the performance of waste covers.

4 Compilation of Sites with Engineered Surface Covers

The ECTG was aware of the important considerations needed while assessing various sites with covers. All of the covers at the sites documented in the RES Benson report were vegetated with a mixture of annual and perennial grass mixtures, i.e., no covers were studied with a riprap surface or without vegetative root systems. The change in cover properties occurred between a time period of 3.8 and 8.9 years. The report does not document

degradation processes or performance over the long-term (greater than 100 years). Increasing hydraulic conductivity caused by wet-dry and freeze-thaw cycles happened after the initial cycle(s) and the rate of change slowed with increasing cycles. The thickness of the overburden over the compacted soil barrier of the conventional covers exhumed for the RES Benson study ranged approximately between 6 and 35 in (15 – 89 cm), averaging roughly 17 in (43 cm).

In order to assess potential impacts as related to performance of engineered covers on the health and safety of the public and the environment, the ECTG needed an overview of the sites with engineered surface covers for which the NRC shared some degree of oversight and responsibility. Tables were subsequently compiled (Appendixes A and B) and reviewed. The ECTG determined that the immediate assessment of sites located in Agreement States should be deferred until after the ECTG assessed sites for which the NRC's responsibilities were more direct. Uranium recovery sites and LLW sites in Agreement States were therefore temporarily removed from the table, as were the disposal sites for various wastes for which covers have been designed but not constructed.

Planned covers currently being designed for disposal sites with various radioactive wastes were evaluated by the ECTG. The findings of changing cover property values documented in the RES Benson report were judged inapplicable to the cover components at these LLW, waste incidental to reprocessing (WIR), and complex materials waste sites. Analysis in the RES Benson report showed that geosynthetic clay liners (GCLs) have very low saturated hydraulic conductivity ($< 5x10^{-11}$ m/s) when placed on a moist subgrade (water content > 10%) and covered with a geomembrane and cover soil soon after installation, although GCLs installed under other conditions can be much more permeable. In addition, changes in geomembranes and geosynthetic drainage layers during the short period of the study were modest or small. Greater reductions in transmissivity and permeability were observed for drainage layers covered with soils having higher fines content. However, this effect was modest, and all of the drainage layers functioned as anticipated. All of the planned covers designed to isolate LLW, WIR, and complex materials wastes are of a composite design and therefore are not as impacted by the short-term findings of the RES Benson report as those covers relying on compacted clay barriers. Although antioxidant depletion rates indicated a minimum service life for geomembranes on the order of 50-125 yr, the actual service life is estimated using methods described in Koerner et al. (2005) and Rowe et al. (2009). In summary, covers with composite components do not appear to significantly degrade over the short-term while covers that are currently being designed for the long-term will be evaluated during a technical review of the disposal site and the anticipated performance over the long-term closely evaluated. One decommissioning site with a cover (Cimarron, OK) was carried forward in the tables and evaluated by the ECTG.

Appendixes A and B list the disposal sites with covers that ECTG assessed. The engineered surface covers are located at three types of disposal sites: Title I (20 disposal sites), Title II (six disposal sites), Title II sites in closure (eleven disposal sites), and one decommissioning site where decommissioning activities have not been completed. The Title I sites are DOE licensed under 10 CFR 40.27 and must comply with the regulations in 40 CFR 192(A) and 192(B). NRC staff reviews annual inspection reports and conducts occasional site visits. The Title II sites are DOE licensed under 10 CFR 40.28 and must comply with the applicable regulations in 10 CFR 40, Appendix A, which is equivalent to or more stringent than 40 CFR 192(D) and 192(E). The NRC staff reviews annual inspection reports and conducts occasional site visits. Title II sites in closure are operated by the NRC licensees and must comply with the regulations in 10 CFR 40, Appendix. A. The NRC staff reviews inspection reports and other documents, and develops technical evaluation reports for the sites. The covers constructed to encapsulate the 11e.(2)

byproduct material at the sites listed in the tables in the appendixes serve three main purposes: slow radon release from the tailings into the atmosphere, minimize seepage of contaminants from the tailings into groundwater, and provide long-term stability by protecting against erosion. Cover performance to minimize radon release and seepage were reviewed and qualitatively assessed by the ECTG in combination with the findings of the RES Benson report. Cover performance to minimize erosion was not reviewed by the ECTG.

5 Potential for Increased Radon Release due to Processes Documented in NUREG/CR-7028

Uranium mill tailings covers have typically been designed with an assumed conservatism that accounted for (a) difficult to determine, long-term parameter values (e.g., soil moisture content and permeability), and (b) the potential degradation of the cover over time (Regulatory Guide 3.64). However, recent research has shown that the properties of engineered cover barriers may change more quickly and perhaps to a greater extent than anticipated, in particular the saturated hydraulic conductivity appears to increase rapidly. The RES Benson report has demonstrated that the saturated hydraulic conductivities of engineered barriers at each site investigated have increased from that of the original as-built conditions. These increases are variable in magnitude due to differences in (i) compaction conditions, (ii) soil composition, (iii) climate, and (iv) service life. Due to the variability of engineered barrier types, only some sites studied in the RES Benson report (Albany, Apple Valley, Cedar Rapids, and Underwood) are closely related to Title I and Title II Uranium mill tailing sites. Caution must therefore be exercised in drawing conclusions about sites that are beyond the scope of the sampled barrier population. Conventional covers with clay barriers built to block water flow and mitigate radon release to the environment have been the most susceptible with increases from as-built hydraulic conductivity ranging from 1 – 4 orders of magnitude (RES Benson report). For nearly all sites, saturated volumetric water content increased while in service, which corresponds to an increase in porosity or a decrease in dry unit weight due to formation of soil structure. The results of the RES Benson report suggest that changes in the soil structure consisted primarily of the formation of large pores without altering the distribution of smaller pores.

Changes in cover properties that are responsible for increasing the hydraulic conductivity may also affect the migration of radon-222 through the cover. Cover materials are designed to inhibit radon migration, so that radon flux at the surface is reduced by radioactive decay (NUREG/CR-3533). The RES Benson report, Albright et al. (2006a), and Albright et al. (2006b) stated that preferential flow paths developed in clay barriers in conventional covers. Such preferential flow paths may lead to advective transport of radon. Typically radon migration is controlled by diffusion which is dependent on the inter-connected porosity and moisture content of the soil or clay radon barrier (Regulatory Guide 3.64). In addition to enhanced diffusive transport, advection may also contribute to significant migration of radon via these preferential pathways (NUREG/CR-3533). NUREG/CR-3395, "*Influence of Cover Defects on the Attenuation of Radon with Earthen Cover*" stated that models for radon migration in cracks were designed for simple geometries that do not account for all dynamic processes; this may result in the significant underestimation of radon flux (NUREG/CR-3395). The recommendation from NUREG/CR-3395 was to apply methods to avoid the formation of defects (i.e., avoid cracks) in light of this uncertainty.

As stated previously, the RES Benson report also observed increased porosity in cover systems as evidenced by increased saturated moisture content. The cover materials tended towards a porosity of 0.35 to 0.45. The change in radon release would then depend on the degree of saturation of the clay. If the clay is close to saturation, the effect of increased porosity on radon

diffusion rates will be low. However, as the fraction of water volume becomes less vis-à-vis the volume of air, radon diffusion and release may increase via the interconnected pore structure. This relationship is difficult to constrain as the diffusion coefficient changes rapidly with varying moisture contents and is highly nonlinear as soil saturation approaches unity.

Determination of compliance with regulatory standards for radon release from in-service engineered barriers is difficult to determine due to the aforementioned evolution of material properties and parameter uncertainties. NUREG/CR-3533 and Regulatory Guide 3.64 describe methods for calculating radon fluxes through earthen covers. The most important parameter determining the necessary thickness of a radon clay barrier is the radon diffusion coefficient of that cover. If measurements are not available, radon diffusion coefficients are estimated using a correlation function based on previous measurements of various earthen materials with compactions generally in the range of 80 to 105% of standard Proctor maximum dry density. The results of the RES Benson report indicate that the earthen material is loosening due to the formation of larger soil structures. Therefore, the compaction range of 80-105% of standard Proctor maximum dry density on which the correlation function is based may no longer be given. Although parameter values for radon clay barriers were selected conservatively, e.g., selecting the moisture content at which permanent wilting occurs (circa 15 atmospheres) as a reasonable lower bound over the long term, and took into account potential degradation of the cover over time, the uncertainties associated with radon flux attenuation calculations have increased. It therefore follows that the uncertainties associated with reasonable assurance that the radon-222 release rate will not exceed 20 $pCi/m^2/s$ for a period of 1000 years to the extent reasonably achievable and in any case for at least 200 years as stated in 40 CFR Part 192 and 10 CFR Part 40 have increased. It, however, does not therefore follow that the radon release rate from mill tailing covers is currently greater than 20 $pCi/m^2/s$ since calculations used conservative values (e.g. wilting point moisture content) and design incorporated multiple barriers (clay thicker than calculated, attenuation in the tailings themselves, overburden on top of the radon barrier, etc.).

The types of information to reduce uncertainty, or to increase confidence, can vary from thickness of the overburden on top of the radon barrier, soil moisture content, calculations of dose equivalent showing that public health, safety, and the environment are protected, or actual direct measurements of radon flux. Measured concentration values appear to have a higher uncertainty associated with them than actual measured radon flux rates.

The NRC staff is aware that the standards and regulations for radon barriers apply to design, and that monitoring after disposal is not required to demonstrate compliance. However, the result of recent research on covers is not something anticipated twenty years ago, especially the rate at which compacted clay soil structure changes and secondary structure develop. The NRC staff members strive to remain current in their knowledge within their disciplines and maintain the flexibility to adapt expanding knowledge within a particular field to the NRC's guidelines and regulations. The utilization of engineered surface barriers or covers is relatively recent and studies relating to their effectiveness are even more recent. The above-mentioned recent research on covers are some of the first results to be obtained from the field and must be seen in context with the general licenses for custody and long-term care of residual radioactive material disposal sites and of uranium byproduct materials disposal sites. The purpose of the general licenses is to ensure that the disposal sites are utilized in such a manner as to protect the public health, safety, and the environment after closure.

6 Qualitative Assessment Summary of the Potential for Increased Radon Release

From the 20 Title I sites evaluated, eleven disposal site covers were assessed with a low potential for increased radon release due to processes documented in the RES Benson report. Two sites were rated moderate/low; five sites with moderate potential; and two sites with moderate/high. These last two disposal sites are Mexican Hat in Utah and Tuba City in Arizona. The Mexican Hat site has a desert climate with an annual precipitation of 6 in (15 cm) and an estimated potential evapotranspiration (ET) rate of 84 in (213 cm). Although the cover is not vegetated, the overburden is relatively thin and cover layers could dry out leading to desiccation cracking or freeze-thaw cracking and higher radon release. Overall total radioactivity of the waste is relatively high at 1800 Ci. The Tuba City site is located in an arid climate with an estimated precipitation rate from 5 - 10 in/yr (13 to 25 cm/yr). Average Ra-226 concentration is about 470 pCi/g. The radon barrier is relatively thick at 3.5 ft (1.1 m), however the overburden is relatively thin and consists of a 6 in (15 cm) bedding layer and a 6 in (15.2 cm) rock cover on top of the cell. This leaves the radon barrier more susceptible to the processes documented in the report, such as wet-dry and freeze-thaw cycles.

From the 17 Title II sites evaluated, eight disposal site covers are thought to have low potential for increased radon release due to processes documented in the RES Benson report. One site was rated low/moderate; three sites with moderate potential; two sites with moderate/high; and three sites high. These last three disposal sites are the Bluewater and the Church Rock (UNC) sites in New Mexico and Shirley Basin North (Pathfinder) site in Wyoming. All sites are arid with precipitation around 11 – 12 in/yr (28-30 cm/yr). The Bluewater site was rated high since the source term is relatively high (11,200 Curies of Ra-226), the radon barrier is not thick, 2 - 2.5 ft (0.6 to 0.76 m]), and the 4 – 12 in (10 to 30 cm) rock cover is lying directly on the compacted layer with no frost protection layer in between. The Church Rock site has a thinner radon barrier (18 in [46 cm]), thin overburden/frost protection (6 in [15.2 cm]), and a vegetated cover, with the potential for root penetration, a process much discussed in the RES Benson report. The Shirley Basin North (Pathfinder) site has a proposed minimum radon barrier of 6 in (15 cm) and equally thin overburden of sandy soil. Licensee's radon flux calculation using RADON predicted a radon flux of 14.6 $pCi/m^2/s$. An independent analysis by the NRC calculated a flux of 18.9 and 22.9 $pCi/m^2/s$ depending on parameterization.

Many of the Title I and II site assessments with rating potentials greater than low contained recommendations that radon flux be measured periodically as part of the monitoring program.

7 Potential for Increased Contaminated Seepage into Groundwater due to Processes Documented in NUREG/CR-7028

The RES Benson report documented changes to the engineering properties of materials used in final covers changed while in service. Final covers at test facilities and operating waste containment facilities were exhumed to evaluate how the properties of the cover materials changed 5 to 10 years after installation. The saturated hydraulic conductivity and the parameter for the soil water characteristic curve (SWCC) increased, which reflects the formation of larger pores due to pedogenic processes such as wet-dry and freeze-thaw cycling. Larger changes were observed for soils with lower as-built saturated hydraulic conductivity and soils with a greater proportion of clay particles in the fines fraction. Hydraulic properties of the cover soils were similar when exhumed, regardless of the as-built condition. The saturated hydraulic conductivity at field scale ranged between 2.5×10^{-8} and 6.0×10^{-6} m/s, compared to design specifications of 10^{-9} m/s.

Over longer periods of time, soil structure is the product of processes that flocculate, cement, compact, or unconsolidated soil material causing the formation of stronger soil aggregates, structural units separated by planes of weakness. Structural development is influenced by secondary mineralization, illuviation of fines, solutes, and organic residues. If the borrow soil used to construct a cover is well developed and has stable soil aggregates, and is not mechanically broken apart, as with a pug mill, the aggregates and the fractures between the aggregates may be retained during construction. For some disposal sites, it is possible that the aggregates and planes of weakness or macropore structures may already exist immediately after cover construction (Email correspondence [June 22, 2010] with Jody Waugh from Stoller Corp.).

Analyses from the report showed that GCLs had very low saturated hydraulic conductivity ($<5 \times 10^{-11}$ m/s) when placed on a moist subgrade (water content > 10%) and covered with a geomembrane and cover soil soon after installation. GCLs that underwent complete hydration maintained low hydraulic conductivity even when the native Na was replaced by Ca and Mg. However, GCLs installed under other conditions were much more permeable, therefore QA during cover construction is of great importance. Changes in geomembranes and geosynthetic drainage layers were modest or small. Greater reductions in transmissivity and permittivity were observed for drainage layers covered with soils having higher fines content. However, this effect was modest, and all of the drainage layers functioned as anticipated. Analysis of antioxidants in the geomembranes showed that antioxidant depletion was consistent with expectations based on first-order kinetics and laboratory-measured depletion rates. Based on these rates, the minimum service life of geomembranes is on the order of 50-125 yrs. Actual service lives are likely to be longer, but are difficult to estimate. Because covers change over time, it was recommended that covers should be monitored to ensure that they are functioning as intended. Monitoring using large pan lysimeters combined with secondary measurements collected for interpretive purposes (water content, temperature, vegetation surveys, etc.) was recommended, as well as studying analogs of natural environments.

As previous stated in the section on determining which disposal site covers are potentially susceptible to the degradation processes that changed material properties as documented in the RES Benson report, the engineered surface covers for uranium mill tailings with their dependence on compacted soil/clay layer were listed as most susceptible. Covers with composite components do not appear to significantly degrade over the short-term if good quality assurance is maintained during construction. Uranium Mill Tailings Radiation Control Act (UMTRCA) was enacted in 1978 and established programs for stabilization and control of both inactive/abandoned (Title I) and active/licensed (Title II) mill tailings sites. The Title I sites are DOE licensed under 10 CFR 40.27 and must comply with the regulations in 40 CFR 192(A) and 192(B). Based on the measured concentration of the contaminants of concern, one of three types of groundwater protection standards can be used as stated in 40 CFR 192.02(c)(3): background concentrations, representative values from table 1 to subpart A [maximum concentration limits (MCLs)] if the background level of the constituent is below the value given in the Table, or alternative concentration limits (ACLs). The Title II sites are DOE licensed under 10 CFR 40.28 and must comply with the applicable regulations in 10 CFR 40, App. A, which are equivalent to or more stringent than standards found in 40 CFR 192(D) and 192(E). Title II sites in closure are operated by NRC licensees and must also comply with the regulations in 10 CFR 40, App. A. Criterion 5B(5) from Appendix A establishes the same groundwater protection standards: background, MCLs, or ACLs.

Increased saturated hydraulic conductivity within the resistive layer of a cover relied upon to keep infiltration to a minimum could signal a potential increase of contaminates moving from the

milling tailings to unsaturated zone and subsequently the saturated zone. If the saturated zone below the disposal site is part of an aquifer being utilized by the surrounding community, the potential risk to human health and safety could increase. Infiltration, therefore is important, and can be described using standard vadose-zone models. Many modeling approaches are used, however obtaining consistent results using different modeling approaches has been difficult. As with other aspects of near-surface disposal facility designs, an engineer's ability to design and construct an elaborate cover system may exceed an analyst's ability to predict its performance with confidence (NCRP Report No. 152, 2005). Quantitative analysis to determine infiltration through the cover is difficult since quantitative data are lacking. Important parameters for calculating infiltration have not been gathered so ECTG decided to do a qualitative assessment for each of the disposal sites as compiled in the table of Appendix B. Various characteristics and related parameters were used to assess the potential for increased groundwater contamination from tailings seepage: total amount of precipitation, potential evapotranspiration, extent of overburden, depth to aquifer, unsaturated zone hydrogeological characteristics, the existence of a bottom liner plus leachate collection system, and the status of the groundwater, i.e., the quality and usability of the groundwater or nearest aquifer. Although some of these parameters do not influence the infiltration rate through the cover, it was included in the tables so as to give insights into potential risks to public health and safety. A higher potential for increasing groundwater contamination for an aquifer that is potable and used by nearby communities is of greater concern than groundwater which is not potable, stagnant, and/or made unusable by previous contamination.

8 Qualitative Assessment Summary of the Potential for Increased Contaminated Seepage into Groundwater

From the 20 Title I sites evaluated, 15 disposal site covers were thought to have a low potential for increased groundwater contamination from tailings seepage due to processes documented in the RES Benson report. It must be remembered, these qualitative assessments are not evaluating the overall potential performance of the engineered surface barrier, but the potential for degradation due to the processes documented in the RES Benson report. One site was rated low/moderate, three sites with moderate potential, and one site as moderate/high. Routine monitoring at the moderate/high site in Lakeview, Oregon shows that groundwater is currently not becoming more contaminated, however groundwater monitoring at the Lakeview site should continue. The main reasons for the somewhat higher ratings are the higher susceptibility for the compacted layers and overburden to increased infiltration from the degradation processes and relative high precipitation rates of the sites.

As with the ratings for potential radon release, the Title II ratings are higher than Title I sites, e.g., overburdens are generally thicker for Title I sites than Title II sites. From the 17 Title II sites evaluated, seven disposal site covers were assessed with a low potential for increased groundwater contamination. Three sites were rated low/moderate; five sites with moderate potential; and two sites with moderate/high. These last two disposal sites are Shirley Basin North (Pathfinder) and Gas Hills West (ANC) in Wyoming. The main reason for the higher ratings was the relatively thin resistive, compacted clay layers and the lack of supporting documentation to negate the effects of the degradation processes. For many of the Title I and II sites above potable, usable aquifers, assessments with rating potentials greater than low contained recommendations that periodic water quality sampling and measurement are part of the monitoring program.

The ECTG recommends that the current groundwater monitoring programs at disposal sites should not be discontinued. Instead, DOE/LM should be encouraged to compile information

from the monitoring program and extract information that might indicate the degree and extent of possible changes in cover performance and potential increased infiltration through the cover.

9 Conclusions

The RES Benson report has important implications for existing sites where NRC has regulatory authority and where covers have already been constructed. Most of these sites are uranium mill tailings sites owned and maintained by DOE/LM under an NRC general license for long-term surveillance and maintenance. Most of the surface covers over mill tailings have a radon barrier designed to have low permeability to decrease the atmospheric release of radon and decrease the amount of precipitation contacting the buried waste. However, disposal facilities are not identical. Each waste cell location has its own individual setting and particular waste characteristics. Due to other conservatisms with which the mill tailings covers were designed (e.g., many of the design calculations were made assuming a moisture content equivalent to the wilting point), their performance may be within the range of conservatism for which the cover was designed, or compensated for by additional barriers. In addition, the 20 $pCi/m^2/s$ atmospheric release rate standard is considered by many to be a relatively low rate.

Due to the variability of engineered barrier types, only several sites studied in the RES Benson report (Albany, Apple Valley, Cedar Rapids, and Underwood) are closely related to Title I and Title II Uranium mill tailing sites. Most of the other covers exhumed did not have a compacted clay layer and relied instead on evapotranspiration as the main mechanism for keeping water away from the waste. Caution was therefore exercised by the ECTG in drawing conclusions about sites that are beyond the scope of the Report's sampled barrier population.

Desiccation cracking due to wet-dry cycles has been identified as a possible cause of increased saturated hydraulic conductivity. As previously mentioned, all covers examined for the Report were vegetated. Most uranium mill tailings covers are not, and transpiration does not generally take place, making it more difficult to dry out the cover soil exclusively through evaporation. Therefore, some processes associated with vegetation could cause additional infiltration into the top of the cover. In addition, active and growing root systems played a major role in increasing the saturated hydraulic conductivity of the surface cover soils. Almost all of the existing sites where NRC has regulatory authority try to prevent vegetation from growing on the surface and most are covered with rip-rap (layers of rocks).

Freeze-thaw cycles were identified as one of the possible causes of increased saturated hydraulic conductivity and decreasing dry bulk density. Many of the existing sites where NRC has regulatory authority have a frost protection layer to prevent such an occurrence. No relationship was documented in the Report between the rates of degradation (increasing saturated hydraulic conductivity) within the compacted clay soil and the depth of the clay layer below surface (or the thickness of the overburden). Sufficient depth below grade, i.e., the overburden thickness, may limit the rate of material property change.

The change in cover properties documented in the RES Benson report occurred between a time period of 3.8 and 8.9 years and does not document degradation processes or performance over the long-term (greater than 100 years). However, the Report noted that short-term results such as increasing hydraulic conductivity caused by wet-dry and freeze-thaw cycles happened after the initial cycle(s) and the rate of change slowed with increasing cycles. Degradation processes appear to slow exponentially and the saturated hydraulic conductivities seem to coalesce around between $2.5x10^{-8}$ and $6.0x10^{-6}$ m/s, but long-term effects are unknown.

The NRC staff is aware that the engineered surface cover may be only one component of the entire disposal system, i.e., other components besides the engineered surface cover are being relied upon to isolate the waste and minimize contaminate release. However, for some disposal facilities, engineered surface covers are significant to performance. Although there are differences in design between the covers exhumed in the RES Benson report and engineered surface covers at NRC regulated sites, the Report clearly shows that the properties of the engineered soil may degrade in relatively short times on exposure to natural conditions. Staff evaluated available information for each site, comparing the specific results of the Report to the specific condition of the existing sites. The ECTG qualitatively assessed seven mill tailings covers from Title I and II sites to have a moderate/high or high potential for increased radon release due to processes described in the RES Benson report. The ECTG qualitatively assessed two mill tailings covers from Title I and II sites to have a moderate/high potential for increased groundwater contamination from tailings seepage due to processes documented in the RES Benson report.

10 Recommendations

10.1 Short-Term Recommendations

The ECTG qualitatively assessed seven mill tailings covers from Title I and II sites to have a moderate/high or high potential for increased radon release due to processes described in the RES Benson report. They include Mexican Hat, UT; Tuba City, AZ; Bluewater, NM; Church Rock (UNC), NM; Gas Hills West (ANC), WY; Grants (Homestake), NM; and Shirley Basin North (Pathfinder), WY. It is recommended that average radon release be measured (with verifiable QA) over the entire engineered surface cover for those cells which are considered complete and for a duration of 1 year or longer.

If low radon release rates are measured for the seven mill tailings disposal sites listed above, no further immediate action is recommended. If higher rates are observed, additional actions for those sites should be reviewed, and additional flux rates should be gathered from those sites ranked low/medium and higher.

The ECTG qualitatively assessed three mill tailings covers from Title I and II sites to have a moderate/high potential for increased groundwater contamination from tailings seepage due to processes documented in the RES Benson report. Routine monitoring at the Lakeview, Oregon site shows that groundwater is currently not becoming more contaminated, however groundwater monitoring at the Lakeview site should continue. Tailings Pond 1 from Gas Hills West (ANC) is only in the design phase, but if the final cover design remains unchanged it is recommended that monitoring instruments should be incorporated into the engineered surface barrier so that the infiltration rate through the cover can be determined or estimated. Shirley Basin North (Pathfinder) remains open to the disposition of in-situ leach byproduct materials with closure and final reclamation of the waste disposal site to be conducted at a later date. If the final design relies on the relatively thin clay layer in place over portions of the site, additional monitoring and evaluation should be conducted.

The ECTG recommends that the current groundwater monitoring programs at disposal sites should not be discontinued. Instead, DOE/LM should be encouraged to compile information from the monitoring program and extract information that might indicate the degree and extent of possible changes in cover performance and potential increased infiltration through the cover.

Ongoing work toward license transfers for Title II-in-closure sites should continue. However, the recommended monitoring should be completed and contribute to the basis for transferring the site to DOE. If the above recommended actions show that there is a danger to public health and safety, the license transfer should be delayed and appropriate actions immediately implemented.

NRC staff should exchange information and engage in cooperation with the Agreement States. This was started by engaging Agreement States during the NRC\Organization of Agreement States\Conference of Radiation Control Program Directors (NRC\OAS\CRCPD) teleconferences, and devoting a workshop session to State speakers during the Workshop on Engineered Barrier Performance Related to Low-Level Radioactive Waste, Decommissioning, and Uranium Mill Tailing Facilities in August 2010. Discussions should be held in the near future with the Agreement States on how their management of waste facilities relate to the findings and implications of the RES Benson Report and recommendations of the ECTG.

An earlier ECTG recommendation was approved before September 2010 and a 2 year contract was signed with the Southwest Research Institute's Center for Nuclear Waste Regulatory Analyses (CNWRA) to compile and develop a database of site-specific data on radon and groundwater, evaluate site-specific engineered cover performance, and recommend future site-specific radon and groundwater monitoring and data analyses. The CNWRA contract might result in additional recommended long-term work based on the analyses of monitoring data or the recognition of missing information that is needed at these sites.

10.2 Long-Term Recommendations

NRC staff should continue to keep contract with CNWRA to compile and develop a database of site-specific data on radon and groundwater, evaluate site-specific engineered cover performance, and recommend future site-specific radon and groundwater monitoring and data analyses. This includes detecting trends in radon concentrations and rates and looking at the groundwater monitoring data at all the Title II sites. If the results of groundwater sampling can be obtained, trends not only in the radium/uranium but also sulfate, pH, etc. would be evaluated which potentially moves faster than radium and thus early indicators of cover degradation in the time since the covers have been completed. The CNWRA contract assures that data will continue to be collected and stored in known location, and that the data will continue to be analyzed in a consistent manner.

NRC staff should continue to work with DOE/LM. NRC staff is aware that the standards and regulations for radon barriers apply to design, and that monitoring after disposal is not currently required to demonstrate compliance. However, the results of recent research on covers contradicts the conventional wisdom of twenty years ago, especially the rate at which compacted clay soil structure changes and secondary structure develop, potentially leading to degraded cover performance. The type of evidence and the sources of data needed by the NRC to reduce uncertainty can vary from effects of moisture content inhibiting radon release, or direct measurements of radon flux over radon barriers from a select group of mill tailing disposal sites. The latter method is the most direct and would decrease uncertainty greatly. Further data would include core samples from the unsaturated zone or even the cover itself. Databases from indirect monitoring might also provide insights. NRC staff participated in a teleconference with the DOE/LM on July 15, 2010. Both LM and the NRC staffs were in agreement with the interpretations of the latest field study results, the need to be proactive, and the advantages of LM and the NRC sharing and working together.

With regards to the groundwater data, the NRC staff should meet with the DOE/LM on their groundwater monitoring lessons learned regarding screening and evaluative monitoring data and analyses for determining disposal cell performance. Discussions could include the elevated uranium data near the Durango site. Further, ECTG recommends that the current groundwater monitoring programs at Title I disposal sites should not be discontinued. Instead, DOE/LM should be encouraged to compile information from the monitoring program and extract information that might indicate the degree and extent of possible changes in cover performance and potential increased infiltration through the cover.

The NRC staff is also aware of LM's Cover Renovation Research, or RECAP program, and very interested in the findings and results of this program. This attempt to transform conventional covers into ET covers, reduce soil bulk density (compaction), increase soil water storage capacity, and enhance establishment of favorable vegetation will provide valuable input when deciding which future paths to follow in cover research and design.

NRC staff should continue to work and cooperate with other agencies that have a role in determining or maintaining performance for engineered surface barriers, for example, by setting up a subcommittee with other agencies within the framework of the Interagency Steering Committee on Radiation Standards (ISCORS). Currently, the NRC is part of the DOE Landfill Partnership. The partnership consists of members of the Consortium for Risk Evaluation and Stakeholder Participation (CRESP) and regulatory stakeholders from the EPA, the NRC, the DOE, and State agencies. These partners will be asked to identify applied research activities necessary to resolve technical issues and develop or recommend technical approaches to remedy technical inconsistencies in existing regulations. The partnership was initiated in fiscal year 10 as a vehicle to address these issues and will conduct applied research and facilitate technical dialogue needed to build confidence in technologies used for on-site disposal facilities, the methodology used to design and assess these facilities, and the systems used for monitoring long-term performance.

In addition, the NRC staff should also compare the results of the RES Benson report with the future results of the research project implemented via an Interagency Agreement between the NRC and the US Geological Survey (USGS). The overall objective of this research project is to assess the performance of erosion controls for cover systems (e.g., rip-rap) and the coupling of erosion control strategies and hydrological performance of the cover. The specific objectives of this work are to prepare an extensive literature review regarding erosion control strategies being employed for waste containment facilities in both humid and arid regions, select a combination of models that can predict erosion and hydrological performance of covers in humid and arid regions and compare/validate the models with field data, and perform model simulations to identify strategies likely to be effective in managing erosion and hydrology of covers.

It is recommended the ECTG be continued as a "community of practice" or "technical advisory group" to support project managers (PMs) and technical staff in reviewing future infiltration/radon cover designs, data, or issues. Sites that might need future reviews include: Church Rock (UNC), NM redesign for the consolidated cell; the State of Wyoming may need help evaluating or redesigning the Gas Hills West (ANC) covers due to lack of sufficient funds. The ECTG, having expertise in different fields and now some experience with all the disposal sites in question, could also review progress made during the DOE's cover renovation research. The ECTG could also evaluate what new information and insights might be included in the draft NUREG-1757, Vol. 4 for uranium recovery facilities. The approach by the ECTG would be risk-informed and performance-based; cover designs demonstrating adequate performance and significant assumptions supported by technical bases would meet compliance metrics.

Knowledge obtained by the ECTG on infiltration/radon cover designs could be combined with knowledge from erosion control design documents currently being completed in order to provide a comprehensive overview of cover issues and sites that need tracking by the staff. Combine the site conclusions from both reports as a management tool to focus on those sites with cover issues where action is required.

10.3 Future Research Recommendations

Recommendations had been made during the Workshop on Engineered Barrier Performance Related to Low-Level Radioactive Waste, Decommissioning, and Uranium Mill Tailing Facilities in August 2010 (see http://www.nrc.gov/about-nrc/regulatory/decommissioning/public-meetings/materials2010.html). Report Recommendation number 10 in that section lists a few research investments with which ECTG agrees with. In addition, ECTG recommends the following research activities:

- Build a test pad cover simultaneously with the construction of future mill tailings cover; preferably as part of the main cover, or if need be as a separate small cover. A heavily monitored test pad cover would help towards characterizing the short-term time-dependence of engineering properties of cover system components used in uranium recovery, develop in-situ methods to detect such changes, and may develop and validate predictive methods for performance assessments that account for time-dependent engineering properties. For example, sensors or geophysical methods currently discussed to monitor for leaks at external nuclear power plant structures could be used. Geophysical surveys measuring moisture content of covers and under covers during a dry period and then after a heavy rain event, or the wet season, may be able to provide information on mass of water entering the system per inch of rainfall. In addition, a long-term, unique tracer may be mixed with clay or other components of the cover during construction, so that detection of this tracer below would be an indication of the extent of infiltration through the cover.
- Pedogenic study of the cover soil layers to determine, among other uncertainties, the relationship between depth of compacted soil and increasing saturated hydraulic conductivity of the compacted layer. Evolution of soil properties is a significant process that can play a major role in determining cover performance.
- Detailed study of the biotic activity and bioturbation of cover soil layers. Biological activity within the cover can be a significant process and influence cover performance. Temporal, conceptual model of monitoring stages required.
- Studies related to the changing cover performance as documented in the RES Benson report, including cover properties returning to a state of equilibrium with the surrounding environment. An attempt could be made to quantify that equilibrium; to compare the properties of the as-built cover with the properties of the immediate surroundings, and to monitor a possible convergence, or divergence, of both properties.
- Develop a quality assurance (QA) performance assessment checklist for geosynthetic component installation, including geomembranes and GCLs. The rising claims of superior performance by geosynthetics, geomembranes in particular, continue to grow. However, if the geomembrane is not installed correctly, or with defects, the performance of the geomembrane can be drastically different, as will the performance of the engineered cover systems used for LLW if the reliance on geosynthetics is great. Validation of QA should guarantee that performance is not relying on inadequate assumptions.

10.4 Recommendations for Future Guidance

NRC staff should keep informed on the revision of 40 CFR Part 192. These are the standards for performance for both Title I and Title II disposal sites. Appendix A of 10 CFR Part 40 relies heavily on 40 CFR Part 192. The RES Benson report and other studies have adequately demonstrated that design-based confirmation is not appropriate for features and structures exposed to the environment. The lack of knowledge associated with many relevant environmental processes, and the uncertainties associated with modeling them, make performance-based confirmation necessary. This is in alignment with the NRC's risk-informed, performance-based philosophy. The NRC staff should stay informed on the development of the revision, and cooperate and become engaged if possible. In case current standards are not sufficiently revised, the NRC/Office of General Counsel (NRC/OGC) should interpret the limit of leeway to change current guidelines based on the current standards, so that guidance such as the Standard Review Plan for Title I sites and NUREG-1620 take a more risk-informed, performance-based approach. Such revisions will bring UR guidance more in line with NRC's risk-informed, performance-based decommissioning guidance in NUREG-1757.

A case in point to support the recommendation above: more attention and emphasis should be given to 40 CFR Part 192.20(a)(4) in Subpart C on guidance for implementation. 40 CFR Part 192.03 requires a groundwater monitoring plan to demonstrate compliance with the requirements of Part 192.02(c). Part 192.20(a)(4) states, "The monitoring plan required under Sec. 192.03 should be designed to include verification of site-specific assumptions used to project the performance of the disposal system. Prevention of contamination of groundwater may be assessed by indirect methods, such as measuring the migration of moisture in the various components of the cover, the tailings, and the area between the tailings and the nearest aquifer, as well as by direct monitoring of groundwater."

Future guidance should rely on confirmatory-based regulation. For example, Section 2.7.2 from NUREG-1620 and Section 2.3.7 from the Standard Review Plan for Title I sites should be changed from, "For any situation in which a $K<10^{-7}$ cm/sec is proposed by the licensee, the staff should verify that either a test fill program will be undertaken to verify the constructability to achieve the desired K value, or the reclamation plan narrative and accompanying analyses have adequately demonstrated the acceptability of the design K value, considering technical papers on this subject" to requiring a test fill program be implemented if the uncertainties are great and the assumptions significant so as to demonstrate the endurance of the barrier's strongest component (compacted layer, drainage, vegetation/transpiration, etc.) out in the exposed environment.

New information and insights could be included in Volume 4 of NUREG-1757 that is currently being prepared for uranium recovery facilities.

In general, a monitoring program is recommended that is based on confirming main assumptions and performance. This could include periodic radon flux measurements, direct or indirect sampling or monitoring of additional seepage from the tailings, and confirming groundwater and vadose water quality. ECTG strongly recommends a coupling of design and monitoring, where integrating monitoring features into the cover design is standard procedure. For example, numerous cover designs at the disposal sites qualitatively assessed included bottom liners, e.g., Durango, Rifle, Spook, and others, however not all of them included a collection system. If assumptions are significant and performance is uncertain, bottom liners can be used and monitored relative easily as a means of substantiating assumptions and assessing performance.

Documentation of future cover design should include a conceptual process model and water budget describing the function of the cover for various time stages. This is important to understanding the overall performance of the cover over the time that it is expected to be effective. The contribution of the major cover components to the distribution of the water budget should be documented. The detail of this description will depend on the type of cover being proposed, the expected time of performance, and the half lives of the radionuclides involved. The components of the water budget: precipitation, ET, runoff, lateral drainage, soil water storage, and infiltration would need to be quantified or at least estimated. After this information is verified through monitoring, e.g., rain gauge, evapotranspiration station, moisture content, pore water core samples from the cover layers, etc., it could be used to support numerical modeling and a performance assessment.

11 References

Albright, W., Benson, C., Gee, G., Abichou, T., McDonald, E., Tyler, S., and Rock, S. (2006a). Field Performance of a compacted clay landfill final cover at a humid site. *Journal of Geotechnical and Geoenvironmental Engineering*, 132(11), 1393-1403.

Albright, W., Benson, C., Gee, G., Abichou, T., Tyler, S., and Rock, S. (2006b). Field performance of three compacted clay landfill covers. *Vadose Zone Journal*, 5(4), 1157-1171.

Koerner, R., Hsuan, Y., and Koerner, G. (2005). Geomembrane Lifetime Prediction: Unexposed and Exposed Conditions, GRI White Paper No. 6, Geosynthetic Institute, Folsom, PA.

National Council on Radiation Protection & Measurements (NCRP). "Performance Assessment of Near-Surface Facilities for Disposal of Low-Level Radioactive Waste." Report No. 152. 2005.

Rowe, R., Rimal, S., and Sangam, H. (2009). Aging of HDPE geomembrane exposed to air, water, and leachate at different temperatures, *Geotextiles and Geomembranes*, 27, 137-151.

U.S. Nuclear Regulatory Commission (NRC). "Calculation of Radon Flux Attenuation by Earthen Uranium Mill Tailings Coves." Regulatory Guide 3.64. 1989

U.S. Nuclear Regulatory Commission (NRC). "Consolidated Decommissioning Guidance Characterization, Survey, and Determination of Radiological Criteria." NUREG-1757, Vol. 2. 2006.

U.S. Nuclear Regulatory Commission (NRC). "Influence of Cover Defects on the Attenuation of Radon with Earthen Cover." NUREG/CR-3395. 1983.

U.S. Nuclear Regulatory Commission (NRC). "Radon Attenuation Handbook for Uranium Mill Tailings Cover Design." NUREG/CR-3533. 1984.

12 Qualitative Assessment of Engineered Covers at NRC Regulated Sites

12.1 Title I Sites

12.1.1 General Background

Under UMTRCA, DOE was charged with completing surface reclamation at 24 inactive uranium mill tailings piles. Two sites in North Dakota were withdrawn and tailings from some sites were combined, resulting in 19 tailings disposal sites. These piles range in size from approximately 60,000 to 4.6 million cubic yards of material. Except for a site at Canonsburg, Pennsylvania, and an associated property at Burrell, Pennsylvania, the inactive sites are located in western states. In 2001, the Atlas site near Moab, Utah was transferred to DOE for remediation under Title I of UMTRCA.

In 1993, DOE became a licensee of NRC under the general license provisions of 10 CFR 40.27. This transpired when NRC concurred in the completion of construction and surface cleanup at the Spook, Wyoming, inactive tailings site and accepted DOE's plan for long-term surveillance at the Spook site. By August 1999, 17 more sites were completed and brought under the general NRC license, including sites at Ambrosia Lake, New Mexico; Burrell, Pennsylvania; Canonsburg, Pennsylvania; Durango, Colorado; Falls City, Texas; Green River, Utah; Gunnison, Colorado; Lakeview, Oregon; Lowman, Idaho; Maybell, Colorado; Mexican Hat, Utah; Naturita, Colorado; Rifle, Colorado; Salt Lake City, Utah; Shiprock, New Mexico; Slick Rock, Colorado; and Tuba City, Arizona. The only remaining sites are those at Grand Junction, Colorado and Moab, Utah. Legislation allows a portion of the Grand Junction site to remain open until 2023 to accept additional waste from tailings contaminated properties. DOE has decided to transfer the Moab mill tailings to a site near Crescent Junction, Utah, and is preparing a remedial action plan for NRC concurrence describing its proposed action.

DOE initiated the groundwater cleanup phase of the Uranium Mill Tailings Remedial Action (UMTRA) Project in 1991. It has completed all of the 20 scheduled baseline risk assessments for the groundwater cleanup phase and has transmitted them to concerned parties. Two sites did not have groundwater contamination. DOE has developed Groundwater Compliance Action Plans for demonstrating groundwater compliance at 13 sites and submitted them to the NRC for concurrence. DOE has demonstrated groundwater cleanup compliance at eight of those sites.

12.1.2 Tables

Table 12.1a: Characteristics of Title I Disposal Site Covers Associated with Radon Release

Characteristics of Title I Disposal Site Covers Associated with Radon Release	Cover Vegetation (Yes or No)	Cover Type - Compacted soil/clay If yes, thickness (ft)	Overburden Thickness on top of compacted soil/clay (ft)	Cover Type - Drainage/bedding/ filter/capillary layer	Cover Type - Geo-membrane	Year Cover Built	Waste Type/ Source Term (Curies [Ci] or volume [yd^3])	Calculated Radon Flux (pCi/m^2/s)	Measured Radon Flux at Completion (pCi/m2/s)	Population Type near Site (no population or rural or near urban)	Public Interest (H, M, or L)	Precipitation Rate (in/yr)	Potentail ET Rate (in/yr)	POTENTIAL for Increased Radon Release due Processes Documented in NUREG/CR-7028 (High, Moderate, or Low)	
		[1 ft = 0.305 m]	[1 ft = 0.305 m]				[1 Ci = 37000 MBq]	[1 pCi/m^2/s =	0.037 Bq/m2/s]			[1 in/yr =	2.54 cm/yr]		
TITLE I SITES DOE Licensed under 40.27; 40 CFR 192(A)(B)							[1 yd^3 = 0.765 m^3]								*TITLE I SITES DOE Licensed under 40.27; 40 CFR 192(A)(B)*
Ambrosia Lake, NM	No (rip rap)	Yes; 2.5 ft	rip-rap 1ft on side slope; 0.5 ft on top slope	Yes; 0.5 ft	No	1995	5.3E+6 yd^3; 1,850 Ci Ra-226	< 20	NA	Rural	L	9	46.1 (Calculated, Hargreaves Model)	M/L	Ambrosia Lake, NM
Burrell, PA	No	Yes; 3 ft	1 ft rip-rap	Yes; 1 ft	No	1987	73000 yd^3; 4 Ci of Ra-226	< 20	NA	Rural	M	40	43.3 (Calculated, Hargreaves Model)	M/L	Burrell, PA
Canonsburg, PA	Yes - Some rock	Yes - clay 3 ft	rock 1.5 ft, top soil 1 ft	Yes	No	1985	100 Ci Ra-226	1.6 area A cell, 7.0 average	NA	Very near urban area	M	38	39.6	M	Canonsburg, PA
Crescent Junction, UT [design only]	No	Yes; compacted clay 4 ft	4 ft	Yes	No	Under construction	12 myd^3, Average activity 565 pCi/g	<20	NA	Rural	H	8	50	M	Crescent Junction, UT [design only]
Durango, CO	Yes - Rock/soil matrix	bentonite/sand/2 geotextiles; 2 ft	4.5	Yes	Yes	1991	436 pCi/g; vol 2.53 mcy	NA	0.2	Rural	NA	15-20	>50	L	Durango, CO
Falls City, TX	Yes - Rock on sides	Yes - clay 3 ft	3.5 ft soil	Yes	No	1994	1277 Ci Ra-226	17.8 assume 3ft	NA	Rural	L	30	59	M	Falls City, TX
Grand Junction, CO	No	Yes, 2 ft	5	Yes	No	1994	340 pC/g; vol 4.43 mcy	NA	0.33	Rural	NA	5-10	65	L	Grand Junction, CO
Green River, UT	No	Yes; 3 ft	1 ft rip-rap plus 0.5 ft	Yes	No	1990	30 Ci of Ra-226	need only 2.4 in.	NA	near urban	M	6	50 (estimated)	L	Green River, UT
Gunnison, CO	No	Yes; 1.5 ft	0.5 ft rip-rap plus 7 ft	Yes	No	1996	175 Ci of Ra-226	9 - 14	NA	Rural	L	11	50 (estimated)	L	Gunnison, CO
Lakeview, OR	Yes - Some rock	Yes - 18 inches	24 inches	Yes	No	1988	42 curies of radium 226	< 20	Background	Rural	M	15-25	52	M	Lakeview, OR
Lowman, ID	Yes	Yes; 1.5 ft	1 ft rip-rap plus 0.5 ft	Yes	No	1992	12 Ci of Ra-226	NA	0.18	Rural	L	20-25	37 (estimated)	L	Lowman, ID
Maybell, CO	No	Yes; 1.5 ft	0.67 ft rip-rap plus 4.5 ft	Yes	No	1997	455 Ci of Ra-226	14.7	0.26	Rural	L	13	50 (estimated)	L	Maybell, CO
Mexican Hat, UT	No	Yes, 2 ft (silty sand; 10% clay)	2 ft rip-rap plus 0.5 ft	Yes	No	1995	1800 Ci of Ra-226	>13	0.05	Rural	L	6	84	M/H	Mexican Hat, UT
Naturita, CO	No	Yes; 3 ft	2 ft rip-rap plus 6 ft	Yes	No	1997	79 Ci of Ra-226	11.8	0.2	Near urban	M	13	50 (estimated)	L	Naturita, CO
Rifle, CO	No	Yes - 18 in (6 in compacted clay 12 in bentonite amended clay)	9.5-20	Yes	No	1996	600 pC/g; vol 3.76 mcy	NA	3.4	Rural	NA	11	55	L	Rifle, CO
Salt Lake City - Clive, UT	No	Yes; 7 ft	2 ft rip-rap plus 0.5 ft	Yes	No	1989	1550 Ci of Ra-226	14	0.3	rural	L	5	>25	L	Salt Lake City - Clive, UT
Shiprock, NM	No	Yes - 6.4 ft top; 7.0 ft sides	1.5	Yes	No	1987	404 pC/g; vol 2.8 mcy	NA	NA	Very near urban area	VH	< 10	58	M	Shiprock, NM
Slick Rock, CO	No, all rock	yes, 18 in	3	Yes	No	1996	140 pC/g; vol 0.86 mcy	NA	0.1	sparce, 10 within 10mi	NA	10-15	58	L	Slick Rock, CO
Spook, WY	Yes	Yes, 18 in	35	Yes	No	1989	310 pC/g; vol 0.32 mcy	NA	NA	sparce, cattle ranches	L	10-15	50	L	Spook, WY
Tuba City, AZ	No, all rock	Yes, 42 in	1.5	Yes	No	1990	470 pC/g; vol 1.4 mcy	9.3	NA	sparce; town within 5 mi	H	5-10	70	M/H	Tuba City, AZ

Table 12.1b: Characteristics of Title I Disposal Site Covers Associated with Seepage from Mill Tailings

Characteristics of Title I Disposal Site Covers Associated with Seepage from Mill Tailings	Precipitation Rate (in/yr)	Potentail ET Rate (in/yr)	Depth to Aquifer (ft)	Unsaturated Zone Hydrogeological Characterisitcs (qualitative)	Disposal Site on Processing Site (Y or N)	Quality of Dis-posal Site Groundwater (Good, Limited Use, Contaminated)	Groundwater Status Corrective Action (Y or N) Standards (NA, Background, MCLs, or ACLs/Suppl.Stnd)	Disposal Site GW Monitoring Program Ongoing (Y or N)	Groundwater Contaminants from Post-Operational Disposal Cell Detected (Y, Potentially, or N)	Existing Liner below Waste (Y or N)	Leachate Collection System (Y o N)	Intensity of Aquifer Use Nearby Use (H, M, L, or None)	POTENTIAL for Increased GW Contamination due Processes Documented in NUREG/CR-7028 (High, Moderate, or Low)	
	[1 in/yr =	2.54 cm/yr]	[1 ft = 0.305 m]											
TITLE I SITES *DOE Licensed under 40.27; 40 CFR 192(A)(B)*														***TITLE I SITES*** *DOE Licensed under 40.27; 40 CFR 192(A)(B)*
Ambrosia Lake, NM	9	46.1 (Calculated, Hargreaves Model)	300-800ft (shallow aquifer not potable)	alluvium	Y	Cotaminated, Limited Use	N	Y	N	N	N	L	L	Ambrosia Lake, NM
Burrell, PA	40	43.3 (Calculated, Hargreaves Model)	>30	alluvium	N	Cotaminated, Limited Use	N	Y	N	N	N	L	L	Burrell, PA
Canonsburg, PA	40	39.6	<10	alluvium/fill	Y	Cotaminated, Limited Use	N; ACL for U, MCL for Mo	Y	Y	Y	N	L to None	M	Canonsburg, PA
Crescent Junction, UT [design only]	8	50	>2400 ft	alluvium/rock	N	Limited Use	N	Y	N/A	N	N	None	L	Crescent Junction, UT [design only]
Durango, CO	15-20	>50	100?	relatively imperm	N	Limited Use	N	Y	Y	Y	Y	M	L	Durango, CO
Falls City, TX	>40	59	10	alluvium	Y	Contaminated	N	Y	Y	N	N	L	M	Falls City, TX
Grand Junction, CO	10-15	>50	50?	permeable .	N	Limited Use	N	Y	N	N	N	L	L	Grand Junction, CO
Green River, UT	6	50 (estimated)	60	alluvium&sand stone	Y	Contaminated	Y; ACLs	Y	N	N	N	M	L	Green River, UT
Gunnison, CO	11	50 (estimated)	100	alluvium	N	Good	N	N	N	N	N	L	L	Gunnison, CO
Lakeview, OR	15-25	52	100	sand, silt, clay	N	Limited Use	N	Y	N	N (Clay liner along hillside under waste)	N	L	M/H	Lakeview, OR
Lowman, ID	20-25	50 (estimated)	27-78	alluvium&igneo us	Y	Good	N	N	N	N	N	L	L	Lowman, ID
Maybell, CO	13	50 (estimated)	35-300	alluvium&sand stone	Y	Limited Use	N	N	N	N	N	L	L/M	Maybell, CO
Mexican Hat, UT	6	84	74?	siltstone [artesian]	Y	Limited Use	N	N	N	N	N	None	L	Mexican Hat, UT
Naturita, CO	13	50 (estimated)	600	Sandstone and Shale	N	Good	N	Y (from TER)	N	N	N	None	L	Naturita, CO
Rifle, CO	11	55	50?	relatively imperm	N	Limited Use	N	N	N	Y	Y	L	L	Rifle, CO
Salt Lake City - Clive, UT	5	>25	250?	silty sand .	N	Limited Use	N	N	N	N	N	L	L	Salt Lake City - Clive, UT
Shiprock, NM	< 10	58	100?	permeable	Y	Contaminated	Y; ACL/SS	Y	N	N	N	None	L	Shiprock, NM
Slick Rock, CO	10-15	58	0	alluvial aquifer below	N	Limited Use	N	N	N	N	N	None, low yield	L	Slick Rock, CO
Spook, WY	10-15	50	? 2 ss aquifers	Sandstone	Y	Limited Use	N	N	N	Y	N	None, low yield	L	Spook, WY
Tuba City, AZ	6.5	67-80	60-75 ft	uncon sand gravel	Y	Contaminated	Y; MCLs	Y	N	N	N	L	M	Tuba City, AZ

12.1.3 Qualitative Assessments

Ambrosia, NM

a) Potential for increased radon release – Moderate/Low

- The design for the disposal cell cover is a 30 in (76.2 cm) thick clay radon barrier (saturated hydraulic conductivity of 10^{-7} cm/s). The clay radon barrier was constructed using local material from a nearby borrow area. The clay barrier is overlain by a 6 in (15.2 cm), thick filter layer with a hydraulic conductivity of 0.1 cm/s and a 6 in (15.2 cm) thick riprap erosion protection layer (12 in [30.5 cm] thick on the slopes). The disposal cell total radioactivity is 1,850 Ci of ^{226}Ra with an average tailings radioactivity of 571 pCi/g of ^{226}Ra.
- In addition, the disposal cell was constructed such that the tailings were covered by a layer of wind-blown soil material before the cap was put in place. The windblown material has, in general, much lower radium concentrations than the tailings. This will provide additional, though un-quantified, protection.
- There are mine workings underlying portions of the disposal cell, at depths greater than 500 ft (152.5 m), so there is some (small) danger from subsidence in addition to settling of the tailings and rubble in the disposal cell.

b) Quality and usability of nearest aquifer – Limited Use; Contaminated

- Groundwater monitoring is not required at the site because supplemental standards of Title 40 CFR Part 192.22 have been applied. The uppermost aquifer consists of 15-75 ft [4.6-22.9m] of alluvium and weathered shale, which is considered a "limited use" aquifer and is not suitable for drinking water nor is it a source of irrigation water because of yields below 150 gallons (567 liters) per day. However, at the request of the New Mexico Environment Department (NMED), DOE conducts limited monitoring at two locations as a best management practice. Selenium concentrations at alluvial monitoring well 0675 have been increasing since 2002 with a reported concentration of 1.25 mg/l in November 2010.

c) Potential for increased groundwater contamination from mill tailings – Low

- It appears that much of the groundwater beneath the pile is the result of activities at the mill and nearby mine. Over time, it is expected that the subsurface moisture distribution will revert to predominantly unsaturated conditions that existed before mining and milling activities commenced. Transient drainage was not modeled at this site because the additional contamination from transient drainage will not affect compliance with the groundwater standards.
- The alluvium/weathered shale is underlain by about 50 ft (15.2 m) of un-weathered shale having a measured hydraulic conductivity of about 4×10^{-8} cm/s, which should be an effective aquitard. The unweathered shale is discontinuous across the site and the Tres Hermanos-C Sandstone subcrops downgradient of the pile. The Tres Hermanos-C is not considered an usable aquifer due to low yields and naturally poor water quality.
- At much greater depths, the site is underlain by the Westwater Canyon Member of the Morrison Formation, which has sufficient yield to be a source of drinking water in the area. However, due to mining in the region, water quality has already deteriorated to the extent that there is some risk to human consumption. Groundwater in the Westwater Canyon Member exceeds the MCLs for cadmium, chromium, lead, molybdenum, selenium, silver, and uranium and activities of radium -226 and -228. Potential mixing of contaminated groundwater from the

Ambrosia Lake site with the Westwater Canyon Member groundwater (via mine shafts and vent holes) should have minimal impact on water quality in the Westwater and result in no significant additional risk to humans.

d) Other:

● A shallow depression around settlement plate SP–4, near the northeast corner of the disposal cell cover, was first noted during the 1997 inspection and continued to grow in depth and area in subsequent years. The depression was repaired in August 2005. Surveys of the eight settlement plates were conducted in September 2005, September 2006, and September 2007 to monitor for continued settlement at SP–4. The surveys indicated no significant changes at the repaired location. Additional surveys will be conducted only if significant settlement is observed. Visual observations during the 2010 inspection indicate that slight settlement may have occurred since the last inspection. This location will continue to be monitored. The northwest portion of the disposal cell consists of fine tailings and slimes.

e) Recommendations:

● Periodic inspection, as currently performed, should be sufficient to detect problems which may lead to degradation of radon barrier. Groundwater monitoring is not currently being performed and does not appear to be warranted.

Burrell, PA

a) Potential for increased radon release – Moderate/Low

● This is a pretty small site (approximately 4 acres [16175 m^2]) and the levels of contamination are low compared to U mill tailing sites (approximately 73,000 cubic yards (55480 m^3) of contaminated material with a total activity of about 4 curies of radium-226).
● The disposal cell cover comprises (1) a low-permeability radon barrier of compacted clay (first layer placed over compacted tailings), (2) a free-draining bedding layer, and (3) a rock (riprap) erosion-protection layer. Precipitation flows down the sloped cell top through the bedding layer and into surrounding rock drains. The immediate area surrounding the cell was graded to promote drainage and was vegetated with native species to minimize erosion.
● However, the entire site, including the area where the disposal cell is located, is composed of high permeability fill (underlain by lower permeability alluvium and colluviums). The fill is comprised of rubble and has so much organic material (e.g., railroad ties) that there is a significant risk for substantial differential settlement.

b) Quality and usability of nearest aquifer – Limited Use; Contaminated

● The nearest groundwater is an unconfined aquifer in unconsolidated alluvium underlying the site (alluvium is up to 50 ft [15.2 m] thick). Depth to the water table is more than 30 ft (9.15 m) below land surface, and groundwater flow is south, towards the adjacent Conemaugh River.
● Available reports indicate there are no known down-gradient groundwater users in the vicinity of the Burrell site. Most of the public water supply in the vicinity of the site is from protected surface water sources.

c) Potential for increased groundwater contamination from mill tailings - Low

● The cell was designed to promote the rapid runoff of precipitation to minimize infiltration. However, water was observed seeping through several areas on the lower portion of the south slope of the disposal cell cover during 1990 and 1991. Water samples collected from the surface seeps exceeded MCLs for combined Ra-226 and Ra-228. Since 1991, the seeps have been dry, or if water was available for sampling, activities of radium were less than the MCL.
● Confined groundwater lies beneath 30 to 40 ft (9.15 to 12.2 m) of impermeable claystone and shale of the Casselman Formation. It appears there is minimal risk to this resource.

d) Other:

● The site is located right next to the Conemaugh River, and the site is located in the flood pool of a downstream dam. The flood risk is stated as being minimal, but the documentation for that assessment is weak. It apparently based upon the site being outside the 100-year flood plain.

e) Recommendations:

● Periodic inspection, as currently performed, should be sufficient to detect problems which may lead to degradation of the radon barrier. DOE currently monitors groundwater quality in samples from eight monitor wells and two seeps every 5 years as a best management practice. This monitoring should be continued.
● An updated quantitative assessment of flooding potential at the site would be useful.

Canonsburg, PA

a) Potential for increased radon release – Moderate

● Cover materials include an 18 in soil and rock layer underlain by a 6 in (15.2 cm) thick filter soil, itself overlying an 18 in thick (45.7 cm) radon barrier. The slopes have a 12 in (30.5 cm) thick rip rap layer underlain by the filter and radon barrier. The activity is low about 42 curies of radium 226.

b) Quality and usability of nearest aquifer – Limited Use; Contaminated

● The disposal site is in an area where the groundwater is shallow. However the shallow aquifer is highly contaminated under ambient conditions and is of limited use. The State's Water Resources Department has an ordinance that requires all new domestic wells to be screened at a minimum depth of 250 ft (76.2 m). Some older wells at depths up to 100 ft (30.5 m) use water treatment systems to improve the quality of water.

c) Potential for increased groundwater contamination from mill tailings – Moderate

● The impact seems to be only on the unusable surficial aquifers but if there are poorly sealed wells that may lead to deeper movement of contaminants. If the ability of the cover to exclude water is compromised, there is the potential to add contaminants to the upper aquifers.

d) Other:

- None

e) Recommendations:

- Because of uncertainty in the potential for Rn emissions, Rn concentrations or emission rates should be measured, if they are not being tested. Groundwater monitoring programs should continue.

Crescent Junction, UT [design only]

a) Potential for increased radon release – Moderate

- Cover materials include a 6 in (15.2 cm) soil and rock layer underlain by a 36 in (91.4 cm) thick frost protection layer, a 6 in (15.2 cm) thick biointrusion layer, a 48 in (121.9 cm) radon barrier and a 12 in (30.5 cm) interim cover. The activity of the radon in the tailings is about 707 picocuries per gram. The cover soils, that include compacted Mancos shale is designed for 10^{-7} cm/sec.

b) Quality and usability of nearest aquifer – Limited Use

- The aquifer is below 2000 ft (610 m) of impermeable shale. The tailings are disposed in an excavation of weathered Mancos shale, about 20 ft (6.1 m) into it. The weathered shale has a saturated permeability of 10^{-3} cm/sec (horizontally fractured) and extends to about 40 to 60 ft (12.2 to 18.3 m). Below the weathered shale is the thousands of feet thick unweathered Mancos shale with a permeability of 10^{-8} cm/sec.

c) Potential for contamination of any aquifer – very Low

- The site subsurface is composed of thousands of feet of unweathered Macos shale.

d) Other:

- None

e) Recommendations:

- Because of uncertainty in the potential for Rn emissions, Rn concentrations or emission rates should be measured. Field scale tests in test sections should be performed to confirm the permeability assumptions for the compacted weathered Mancos shale and the changes of the permeability with time.

Durango, CO

a) Potential for increased radon release – Low

- 7-ft (2.1 m) thick multi-component cover system: 24 in (61 cm) low permeability radon barrier with a bentonite sandwiched between two geotextiles; 18in (45.7 cm) biointrusion rock

layer; 30 in. (76.3 cm) frost protection and rooting moderate. Thickness of cover and layers should reduced freeze/thaw and deep root penetration and degradation of radon barrier (uncertain). The average radon flux measured was 0.2 pCi/m^2/s. The activity in the tailings is 436 pCi/g.

b) Quality and usability of nearest aquifer – Limited Use

● Underlying aquifer not suitable for domestic use because of high total dissolved solids (TDS) and variable quality.

c) Potential for increased groundwater contamination from tailings seepage – Low

● 7ft (2.1 m) thick multi-component cover system: 24 in (61 cm) low permeability infiltration barrier with a bentonite sandwiched between two geotextiles; 6 in (15.2 cm) drain filter layer and bentonite mat; 18 in (45.7 cm) biointrusion rock layer; 30 in (76.3 cm) frost protection layer and rooting moderate; 6in (15.2 cm) rock/soil matrix with native grass on top of cell. Cell designed to promote rapid runoff of precipitation and minimize leachate; evapotranspiration from vegetative cover will reduce infiltration; 24 in (61 cm) low permeability liner on cell sides below contaminated tailings also has high adsorption, ion exchange potential to restrict infiltration and migration of contaminants; potential attenuation of contaminant transport through underlying alluvium. Average annual precipitation is 15-20 in (38.1 to 50.8 cm) and the potential annual evapotranspiration is 50 in (1.27 m). For groundwater samples collected at the disposal site, the concentrations of the indicator parameters (molybdenum, selenium, and uranium) were below their respective 1996 LTSP proposed concentration limits of 0.22 milligram per liter (mg/L), 0.42 mg/L, and 0.077 mg/L. The uranium concentration in well 0618 had been generally increasing since 2005 and is now 0.074 mg/L (2010), which is below the 0.077 mg/L proposed concentration limit. In 2009 well 0618 spiked above the LTSP proposed concentration limit of 0.077 mg/l to 0.115 mg/l.

d) Other:

● Groundwater monitoring: 3 wells in uppermost sandstone aquifer, 4 wells in alluvium. Well 0618 intercepts full saturates zone of alluvial aquifer. Increase in uranium in 0618 well downgradient from disposal cell since 2005 but below the LTSP limit. During cell construction, excessive seepage occurred from above the liner. Source of water was water for dust control and compaction of cover. Liner, holding pond and temporary treatment system.

e) Recommendation:

● Ask DOE to explain the rising uranium concentrations in well 0618 and why they are considering closing the well. Consider continuing the monitoring.

Falls City, Texas

a) Potential for increased radon release – Moderate

● Multicomponent cover system: 36 in (91.4 cm) thick radon barrier, 6 in (15.2 cm) compacted soil, 30 in (76.2 cm) thick growing moderate, and 6 in (15.2 cm) thick topsoil. Source Term is 1277 Ci of ^{226}Ra.

b) Quality and usability of nearest aquifer – Contaminated

● The upper aquifers are Class III, not used for drinking water. They are poor quality due both to naturally high concentrations of sulfate, chloride, TDS, and U, as well as contamination from anthropogenic sources including numerous old U mines in the area. However, one of the upper aquifers (the Dilworth) has been used for watering livestock and gardens; this may be a potential exposure pathway. The Carrizo Sandstone is the major freshwater aquifer in this part of Texas. It lies at a depth of approximately 2000 ft (610 m) below the former mill site.

c) Potential for increased groundwater contamination from mill tailings – Moderate

● There is a contaminant plume related to the site, but it is unclear if it is due to the current disposal cell or earlier ore mining and processing. The impact seems to be only on the unusable surficial aquifers but many poorly sealed wells may lead to deeper movement of contaminants. There is no liner. The cover is designed for evapotranspiration. The site receives 30 in (76.2 cm) of rain per year. If the ability of the cover to exclude water is compromised, there is the potential to add contaminants to the upper aquifers.

d) Other:

● None

e) Recommendations:

● Because of uncertainty in the potential for Rn emissions, Rn concentrations or emission rates should be measured, if they are not being tested. Groundwater monitoring should continue.

Grand Junction, CO

a) Potential for increased radon release – Low

● 6 ft thick multi-component cover: 1.5 ft (45 cm) transition layer above tailings; 2 ft (61 cm) radon layer; 2 ft (61 cm) frost protection layer. Overall thickness and frost protection layer should reduce degradation due to freeze/thaw and other processes (uncertain). The average radon flux measured was 0.33 pCi/m^2/s. The activity in the tailings is 340 pCi/g.

b) Quality and usability of nearest aquifer – Limited Use

● Underlying the Mankos Shale and Dakota Sandstone are both limited use and not drinking water sources. Both are considered Class III. Groundwater in the Mancos Shale is found in discontinuous zones separated laterally and vertically by large areas of unsaturated rock. Pockets of groundwater are in saturated fracture zones. The Dakota Sandstone underlies the Mankos Shale and has a TDS exceeding 10,000 mg/l. There are no shallow wells within 3.5 miles. Anticipated future groundwater use is considered minimal due to low population, low yield, and low quality.

c) Potential for increased groundwater contamination from tailings seepage – Low

● 6 ft (1.8 m) thick multi-component cover: 1.5 ft transition layer above tailings; 2 ft (61 cm) infiltration barrier; 2 ft (61 cm) frost protection layer; 0.5 ft (15.2 cm) coarse grain bedding layer, capillary break promotes drainage; grade and drainage layer divert excessive surface water runoff and minimized deep percolation. Immediate underlying alluvium has paleochannels in vicinity but not under disposal cell; Underlying Mankos Shale under alluvium is unsaturated but groundwater in fracture zones; Dakota Sandstone is 700-750 ft (213.5 – 228.7 m) under the Mankos is hydrologically isolated. There are favorable geochemical conditions in the underlying alluvium and Mankos Shale that would attenuate tailings pore water to at or below the MCLs. There are also reducing conditions in the Mankos Shale that would result in precipitation of uranium and other constituents. Average annual precipitation is 5-10 in (12.7 – 25.4 cm) and the potential annual evapotranspiration is 65 in (1.65 m).

d) Other:

● Dakota Sandstone not monitored due to limited use. Two best practice wells described in long-term surveillance program (LTSP) in alluvium adjacent to cell to evaluate cell performance; described by DOE as early warning of potential cell impact. Continue ongoing DOE lysimeter studies.

e) Recommendations:

● None

Green River, UT

a) Potential for increased radon release - Low

● Although the climate is semiarid with an annual precipitation of 6 in (15.2 cm) and a potential ET rate of approximately 50 in (1.3 m), actual transpiration is low since the cover is not vegetated and root systems causing increased connectivity among pores are kept at a minimum. The most important features contributing to a low estimate of potential radon release is the 3 ft (91.4 cm) thickness of the radon barrier (2.4 in [6.1 cm] was the required thickness calculated) and the relative low total radioactivity of the waste: 30 Ci.
● Additional facts: 382,000 yd^3 (290320 m^3) tailings; 30 Ci Ra-226.
● Cover layers: 1 ft (30.5 cm) riprap; 0.5 ft (15.2 cm) overburden; 3 ft (91.4 cm) radon barrier.

b) Quality and usability of the nearest aquifer (alluvium) – Contaminated

● Limited use groundwater determination (<150 gal/day [567 liters/day]).

Quality and usability of the sandstone aquifer – Contaminated

● ACLs for U, Se, As, and nitrate.

c) Potential for increased groundwater contamination from tailings seepage – Low

● The features contributing to a low estimate of increased groundwater contamination from tailings seepage is the 3 ft (91.4 cm) thickness of the radon barrier, the low annual precipitation of 6 in (15.2 cm) , and relatively low radioactivity of the waste.

d) Other:

● None

e) Recommendations:

● None

Gunnison, CO

a) Potential for increased radon release - Low

● Actual transpiration is low since the cover is located at a high elevation and is not vegetated and root systems causing increased connectivity among pores are kept at a minimum. The most important feature contributing to a low estimate of potential radon release is the 7 ft (2.1 m) thickness of frost protection layer.
● Additional facts: 740,000 yd^3 (562,400 m^3) tailings; 175 Ci Ra-226; slope: 2.5%.
● Cover layers: 0.5 ft (15.1 cm) riprap; 7 ft (1.5 m) overburden; 1.5 ft (45.7 cm) radon barrier.

b) Quality and usability of the nearest aquifer – Usable

● Gravel aquifer below the disposal site has not been contaminated.

c) Potential for increased groundwater contamination from tailings seepage – Low

● The features contributing to a low estimate of increased groundwater contamination from tailings seepage is the 7 ft (1.5 m) thick overburden allowing lateral drainage of the relatively low annual precipitation of 11 in (27.9 cm) and the relatively thick unsaturated zone below the disposal site.

d) Other:

● None

e) Recommendations:

● None

Lakeview, OR

a) Potential for increased radon release – Moderate

● Cover materials include an 18 in (45.7 cm) soil and rock layer underlain by a 6 in (15.2 cm) thick filter soil, itself overlying an 18 in (45.7 cm) thick radon barrier. The slopes have a 12 in

(30.5 cm) thick rip rap layer underlain by the filter and radon barrier. The activity is low about 42 curies of radium 226.

b) Quality and usability of nearest aquifer – Limited Use

- The disposal site is in an area where the groundwater is shallow. However the shallow aquifer is highly contaminated under ambient conditions and is of limited use. The Oregon Water Resources Dept., has an ordinance that requires all new domestic wells to be screened at a minimum depth of 250 ft (76.2 m). Some older wells at depths up to 100 ft (30.5 m) use water treatment systems to improve the quality of water.

c) Potential for increased groundwater contamination from mill tailings – Moderate/High

- The disposal site is in an area where the groundwater is about 100 ft (30.5 m) from the surface. Routine monitoring (J. Waugh et al. 2006)* shows that the groundwater remains protected. However there are high percolation rates through the covers.

*J.Waugh, G. Smith, B. Danforth, G. Gee, V. Kothari, T. Pauling, " Performance of the Engineered Cover at the Lakeview, Oregon, U tailings Site," WM '07 conference, Feb 25-Mar 1, 2006, Yuscon, AZ

d) Other:

- None

e) Recommendations:

- Because of uncertainty in the potential for Rn emissions, Rn concentrations or emission rates should be measured, if they are not being tested. Groundwater monitoring programs should continue.

Lowman, ID

a) Potential for increased radon release – Low

- Annual precipitation is between 20 to 25 in (50.8 to 63.5 cm). Pines and other forested vegetation are being allowed to encroach on the cover. The most important feature contributing to a low estimate of potential radon release is the mechanical milling process used producing radioactive sands resistant to both weathering and chemical alteration and the relative low total radioactivity of the waste: 12 Ci.
- Additional facts: 222,230 yd^3 (168,895 m^3) tailings; 12 Ci Ra-226; slope: 1:5.
- Cover layers: 1 ft (30.5 cm) riprap; 0.5 ft (15.2 cm) overburden; 1.5 ft (45.7 cm) radon barrier.

b) Quality and usability of the nearest aquifer - Usable

- 45 ft (13.7 m) thick alluvium underlain by granodiorite. Groundwater in alluvium at a depth of 27 – 75 ft (8.2 – 22.9 m) below the disposal site has not been contaminated.

c) Potential for increased groundwater contamination from tailings seepage – Low

● The features contributing to a low estimate of increased groundwater contamination from tailings seepage is the mechanical milling process used producing radioactive sands resistant to both weathering and chemical alteration, decreased water movement due to vegetation, and the relatively low radioactivity of the waste.

d) Other:

● None

e) Recommendations:

● Consideration of radon flux testing may be warranted in the future as the roots of the forest vegetation become deeper and the transpiration rate increases (drying out the cover layers).

Maybell, CO

a) Potential for increased radon release - Low

● Although the climate is semiarid with an annual precipitation of 13 in (33 cm) and a potential ET rate of approximately 50 in (1.65 m) , actual transpiration is low since the cover is not vegetated and root systems causing increased connectivity among pores are kept at a minimum. The most important feature contributing to a low estimate of potential radon release is the 4.5 ft (1.4 m) thickness of frost protection layer to prevent desiccation cracking and freeze-thaw cracking.
● Additional facts: 3.5×10^6 yd^3 (2.6×10^6 m^3) tailings; the disposal cell total radioactivity is 455 Ci of ^{226}Ra with an average tailings radioactivity of 200 pCi/g of ^{226}Ra; slope: 3%.
● Cover layers: 0.67 ft (20.4 cm) riprap; 4.5 ft (1.4 m) overburden; 1.5 ft (45.7 cm) radon barrier.

b) Quality and usability of the nearest aquifer – Limited Use

● Limited use groundwater determination (ambient U contaminant).

c) Potential for increased groundwater contamination from tailings seepage– Low/Moderate

● Overburden is relatively thick and climate semiarid, however the pathway through the unsaturated zone can be relatively short (35 ft [10.7 m]) and the radon barrier is not more than 1.5 ft (45.7 cm) thick.

d) Other:

● None

e) Recommendations:

● No additional monitoring for additional groundwater contaminants since naturally occurring ambient contaminants widespread.

Mexican Hat, UT

a) Potential for increased radon release – Moderate/High

- Desert climate with an annual precipitation of 6 in (15.2 cm) and an estimated potential ET rate of 84 in (2.1m). Although the cover is not vegetated, the overburden is relatively thin and so that cover layers could potentially dry out leading to desiccation cracking or freeze-thaw cracking and higher radon release. Overall total radioactivity of the waste is relatively high at 1800 Ci.
- Additional facts: 3.6×10^6 yd^3 (2.7×10^6 m^3) tailings; 1800 Ci Ra-226; slope: 2%.
- Cover layers: 2 ft (61 cm) riprap; 0.5 ft (15.2 cm) overburden; 2 ft (61 cm)radon barrier

b) Quality and usability of the nearest aquifer – Limited Use

- No determination, however "likely unsuitable for human consumption" and only scattered groundwater in the fractures; sporadic and ephemeral.

c) Potential for increased groundwater contamination from tailings seepage - Low

- Annual precipitation is 6 in (15.2 cm). Cover is not vegetated and root systems causing increased connectivity among pores are kept at a minimum.

d) Other:

- Lower groundwater unit under artesian pressure.

e) Recommendations:

- If a useable groundwater unit does develop in the upper portion of the Halgaito Formation sometime in the future due to increase precipitation, a reassessment of the potential for increased groundwater contamination from tailings seepage should be performed.

Naturita, CO

a) Potential for increased radon release – Low

- Although the climate is semiarid with an annual precipitation of 13 in (33 cm) and a potential ET rate of approximately 50 in (1.65 m), actual transpiration is low since the cover is not vegetated and root systems causing increased connectivity among pores are kept at a minimum. The most important feature contributing to a low estimate of potential radon release is the 3 ft (91 cm) thickness of the radon barrier, the 66 in (1.7 m) thickness of the frost protection layer, and the relative small total radioactivity of the waste: 79 Ci.
- Additional facts: 971,762 yd^3 (738,539 m^3) tailings; 79 Ci Ra-226; slope: 4%.
- Cover layers: 2 ft (61 cm) riprap; 6 ft (1.8 m) overburden; 3 ft (91 cm) radon barrier.

b) Quality and usability of the nearest aquifer - Usable

- No groundwater contamination.

c) Potential for increased groundwater contamination from tailings seepage - Low

● Cover is not vegetated and root systems causing increased connectivity among pores are kept at a minimum; 3 ft (91 cm) thick radon barrier; 66 in (1.7 m) thick frost protection layer, 79 Ci total radioactivity of the waste; 4% slope gradient promotes rapid runoff of precipitation.

d) Other:

● None

e) Recommendations:

● None

Rifle, CO

a) Potential for increased radon release – Low

● Multi-component cover system: 18 in (45.7 cm) low permeability radon barrier including 6-in (15.2 cm) compacted clay layer and 12-in (30.5 cm) layer of bentonite-amended clay; a 6-in (15.2 cm) layer to prevent drying; very thick 7.5-18 ft (2.3 – 5.5 m)frost barrier and rooting medium overlying radon barrier. Source term is 2,738 curies of radium-226 and tailings activity is 600 pCi/g. The average radon flux measured was 3.4 pCi/m^2/s.

b) Quality and usability of nearest aquifer – Limited Use

● Underlying unit is an aquitard and not a drinking water source due to naturally poor water quality (10,000mg per liter TDS) and low yield. Groundwater contains natural radium-226 and radium-228 above MCLs. Disposal cell is isolated from the uppermost useable aquifer by 3800 ft (1.15 km) or more of low-permeability units making up the aquitard.

c) Potential for increased groundwater contamination from tailings seepage - Low

● Semiarid climate with low precipitation (11 in/yr [27.9 cm/yr]) and potential evapotranspiration of 55 in/yr (1.4 m/yr); multi-component cover system: 18 in (45.7 cm) low permeability infiltration barrier with 6 in (15.2 cm) compacted clay layer and 12- in (30.5 cm) layer of bentonite-amended clay; a 6-in (15.2 cm) drainage layer; a 7.5-18 ft (2.3 – 5.5 m) frost barrier and rooting moderate; 6-in (15.2 cm) upper bedding layer to promote runoff; large riprap rock erosion layer and no vegetation; topslope (5-11%) and sideslopes designed to promote rapid runoff; surface water diverted away from the cell; leachate collection system installed at toe of cell that will be decommissioned after transient pore water seepage has ceased.

d) Other:

● POC groundwater monitoring not required due to limited use designation of aquitard and its 3800 ft (1.15 km) thickness. Temporary liner and leachate collection system at toe of cell to collect seepage from tailings.

e) Recommendation:

● Determine if DOE is monitoring leachate. If so, consider continuing leachate monitoring and analysis of data trends.

Salt Lake City - Clive, UT

a) Potential for increased radon release – Low

- Although the climate is semiarid with an annual precipitation of 5 in (12.7 cm) and a potential ET rate of over 25 in (63.5 cm), actual transpiration is low since the cover is not vegetated and root systems causing increased connectivity among pores are kept at a minimum. The most important feature contributing to a low estimate of potential radon release is the great thickness of the radon barrier: 7 ft. (2.1 m).
- Additional facts: 2.8×10^6 yd^3 (2.1×10^6 m^3) tailings; 1550 Ci Ra-226; slope: 2%.
- Cover layers: 2 ft (61 cm) riprap; 0.5 ft (15.2 cm) overburden; 7 ft (2.1 m) radon barrier.

b) Quality and usability of the nearest aquifer – Limited Use

- Limited use groundwater determination (>10,000 mg/l)

c) Potential for increased groundwater contamination from tailings seepage - Low

- The features contributing to a low estimate of increased groundwater contamination from tailings seepage is the great thickness of the radon barrier, 7 ft (2.1 m), and the low annual precipitation of 5 in (12.7 cm).

d) Other:

- None

e) Recommendations:

- Consideration of radon flux testing may be warranted due to the relative high total radioactivity of the waste, 1550 Ci, the lack of a thicker overburden or frost protection layer, and the cover now being over 20 years old.

Shiprock, NM

a) Potential for increased radon release – Moderate

- Reliance on single thick 6.4 ft [2.0 m] on top and 7 ft [2.1 m] on sides) radon/infiltration barrier; thin overburden consisting of a 6 in (15.2 cm) bedding layer and a 1 ft (30.5 cm) rock cover; freeze/thaw protection uncertain; root penetration low due to rock cover. The disposal cell total radioactivity is 748 Ci of ^{226}Ra with an average tailings radioactivity of 422 pCi/g of ^{226}Ra.

The cell was designed with a saturated hydraulic conductivity of 1×10^{-7} cm/s. In 2005, DOE measured the saturated hydraulic conductivity, a measure of soil permeability, at five locations on the cover top slope using air-entry permeameters; 20 tests were conducted. The results indicated that saturated hydraulic conductivity was highly variable, ranging between 10^{-8} and 10^{-4} centimeters per second (cm/s).

● Radon monitoring results provided by NN AML/UMTRA (1999/2000 and 2009) indicate that radon fluxes for all monitored periods are comparable to background and are therefore below established standards.

b) Quality and usability of nearest aquifer – Contaminated

● Portions of underlying terrace and floodplain aquifers are not drinking water sources; contamination by past milling operations.
● The contaminants of concern for the Shiprock Disposal Site are ammonia (as nitrogen), manganese, nitrate + nitrite (as nitrogen), selenium, strontium, sulfate, and uranium. Currently, nitrate + nitrite (as nitrogen), selenium, and uranium have been found to exceed 40 CFR 192.02 groundwater standards at numerous locations across the site.

c) Potential for increased groundwater contamination from tailings seepage - Low

● Low annual precipitation (<10 in [25.4 cm]) and potential evapotranspiration of 58 in/yr (1.5 m); thick 6.4 ft [2.0 m] to 7.0 ft [2.1 m] compacted radon/infiltration barrier consisting of predominantly sandy silt compacted to a hydraulic conductivity of not more than 2.5×10^{-5} centimeters per second (cm/s) rather than the typical clay barrier (1994 LTSP), but degradation process uncertain due to thin overburden; 6 in (15.2 cm) bedding/drainage layer consisting mostly of silty sand with some gravel and top and side slopes of the pile have a 2-4% and 20% slope respectively to promote rapid runoff of precipitation; rock cover/no vegetative cover. The upper tailings and lower cover were determined to be saturated by rainwater, given evidence from oxygen and deuterium isotope data, neutron hydroprobe monitoring, in situ saturated hydraulic conductivity measurements with air-entry permeameters, and piezocone tests.

d) Other:

● Ongoing remediation of pre-cover contamination with monitoring; likely high visibility due to location on Navaho Nation land and proximity to river and residential and commercial development of the town of Shiprock.
● In 2009, a conical-shaped depression was discovered on the disposal cell cover, and investigation revealed it to be an historical test pit. Since then, several similar conical depressions have been found, and were mapped during the 2010 inspection. Although no displacement of materials is apparent in these areas, these depressions will be monitored in the future. Vehicle ruts are apparent on the surface of the cell.

e) Recommendations:

● Continue monitoring and evaluation of data

Slick Rock, CO

a) Potential for increased radon release - Low

● 5 ft (1.5 m) multi-component cover system: 18 in (45.7 cm) low-permeability radon barrier; 24 in (61 cm) frost protection layer of compacted soil; rock erosion layer would limit vegetation root penetration. Source term is 175 curies of radium-226 and tailings activity is 600 pCi/g. The average radon flux measured was 0.1 $pCi/m^2/s$.

b) Quality and usability of nearest aquifer – Limited Use

● Disposal cell was excavated into sandstone and shale of upper aquifer, which is limited use because of low yield.

c) Potential for increased groundwater contamination from tailings seepage - Low

● Low average annual precipitation of 10-15 in (25.4 – 38.1 cm) and potential evapotranspiration of 58 in/yr (1.5 m/yr); 5 ft (1.5 m) multi-component cover system; 18 in (45.7 cm) low-permeability infiltration barrier; 24 in (61 cm) frost protection layer; topslope of 4% and sideslopes of 25 % designed along with a bedding layer to allow excess surface water to runoff. Rock erosion cover and no vegetative cover. Maintenance to remove deep rooted plants. Cell was excavated so contaminated material would be place below a permeable sandstone layer of the Dakota Sandstone. There is a potential for lateral migration of transient water (tailings seepage) to migrate into one of permeable sandstone layers of Dakota Sandstone formation.

d) Other:

● No groundwater monitoring required due to groundwater protection strategy is supplemental standards based on low yield of uppermost aquifer. Initial performance of the cell is monitored by water levels at two locations.

e) Recommendations:

● Continue monitoring and evaluation of data.

Spook, WY

a) Potential for increased radon release – Low

● 18 in (45.7 cm) radon barrier with 35 ft (10.7 m) of backfill overlying the radon barrier. Very thick backfill/deep burial could eliminate degradation of radon barrier as a result of freeze/thaw, root penetration, and other processes. Source term is 125 curies of radium-226 and tailings activity is 310 pCi/g.

b) Quality and usability of nearest aquifer – Limited Use

● Two aquifers underlie the site. The upper aquifer is not a drinking water source due to natural contamination of uranium and selenium above MCLs. Milling-related contamination also. The lower aquifer not contaminated but not connected to upper aquifer.

c) Potential for increased groundwater contamination from tailings seepage - Low

● Low average annual precipitation of 10-15 in (25.4 – 38.1 cm) and potential evapotranspiration of 50 in/yr (1.27 m/yr); multi- component system designed to minimize infiltration: 3 ft (91.4 cm) leachate-reduction layer placed below tailings; 18 in (45.7 cm) infiltration clay barrier; 10 ft (3 m) of high permeability drainage layer; backfill; and vegetated

surface. Very thick backfill/deep burial could eliminate degradation of infiltration barrier. Groundwater monitoring not required because upper aquifer is naturally contaminated.

d) Other:

● "Liner" under tailings might not result in bathtub effect due to overlying 10 ft (3 m) drainage layer and overlying thick backfill.

e) Recommendations:

● None

Tuba City, AZ

a) Potential for increased radon release – Moderate/High

● 42 in (1.07 m) radon barrier with thin 1 ft (30.5 cm) overburden consisting of 6 in (15.2 cm) bedding layer and 6 in (15.2 cm) rock cover. Calculated radon flux with no frost impact was 9.3 pCi/m^2/s. Frost protection analyses documented and assumed a 1.5 ft (45.7 cm) frost penetration and 11% porosity increase that resulted in an increased calculated radon flux of 14 pCi/m^2/s but under the 20 pCi/m^2/s criterion.

b) Quality and usability of nearest aquifer – Contaminated

● Terrace deposits under the cell overly the Navajo aquifer, a vast regional aquifer; depth of groundwater ranges from 60-75 ft (18 – 22.9 m) below land surface. Limited and highly variable supply of surface water makes groundwater an important resource in the area. Historical milling operations contaminated groundwater in the terrace deposits and the Navajo aquifer. Groundwater remediation and extensive monitoring (38 wells) of the effectiveness of remediation are ongoing. Navajos and Hopis near the site use surface water from the Moenkope Wash for stock watering and agriculture; disposal site is 300-400 ft (91 – 122 m) above the wash, an intermittent stream.

c) Potential for increased groundwater contamination from tailings seepage – Moderate

● 42 in (1.07 m) infiltration layer with overlying 6 in (15.2 cm) capillary break/drain layer; 6 in (15.2 cm) rip rap and no vegetation layer. Low average annual precipitation of 10-15 in (25.4 – 38.1 cm) and potential evapotranspiration of 70 in/yr (1.8 m/yr).

d) Other:

● Transient drainage from the tailings is contributing to the pre cell contamination
DOE notes that groundwater monitoring for disposal cell performance will be done after completion of groundwater restoration of preexisting contamination. DOE has developed performance measures and criteria for cell performance.

e) Recommendation:

● Continue groundwater monitoring. Discuss with DOE lessons learned from extensive groundwater monitoring and development of cell performance criteria.

12.2 Title II Sites

12.2.1 General Background

Uranium processing sites addressed by Title II of the Uranium Mill Tailings Radiation Control Act (UMTRCA) were active when the act was passed in 1978. These sites were commercially owned and regulated under a NRC license. For license termination, the owner conducts an NRC-approved reclamation of any on-site radioactive waste remaining from uranium ore-processing operations. The site owner also ensures full funding for inspections and, if necessary, ongoing maintenance. The DOE then accepts title to a site for long-term custody and care. DOE administers Title II sites under the provisions of a general NRC license granted under Title 10 *Code of Federal Regulations* Part 40.28, "General License for Custody and Long-Term Care of Uranium or Thorium Byproduct Materials Disposal Sites." The number of UMTRCA Title II sites will increase as ongoing site reclamations are completed. Ultimately, DOE may manage as many as 27 UMTRCA Title II sites.

12.2.2 Tables (including Decommissioning site)

Table 12.2a: Characteristics of Title II Disposal Site and Decommissioning Site Covers Associated with Radon Release

Characteristics of Title II Disposal Site and Decommissioning Site Covers Associated with Radon Release	Cover Vegetation (Yes or No)	Cover Type - Compacted soil/clay If yes, thickness (ft)	Overburden Thickness on top of compacted soil/clay (ft)	Cover Type - Drainage/bedding/ filter/capillary layer	Cover Type - Geomembrane	Year Cover Built	Waste Type/ Source Term (Curies [Ci] or volume [yd^3])	Calculated Radon Flux ($pCi/m^2/s$)	Measured Radon Flux at Conpletion (pCi/m2/s)	Population Type near Site (no population or rural or near urban)	Public Interest (H, M, or L)	Precipitation Rate (in/yr)	Potentail ET Rate (in/yr)	POTENTIAL for Increased Radon Release due Processes Documented in NUREG/CR-7028 (High, Moderate, or Low)	
		[1 ft = 0.305 m]	[1 ft = 0.305 m]				[1 Ci = 37000 MBq]	[1 $pCi/m^2/s$ = 0.037 Bq/m2/s]				[1 in/yr = 2.54 cm/yr]			
TITLE II SITES *DOE Licensed under 40.28; 40 CFR 192(C)(D)*							[1 yd^3 = 0.765 m^3]								*TITLE I SITES* *DOE Licensed under 40.28; 40 CFR 192(C)(D)*
Bluewater, NM - main disposal cell	No	Yes- 2.0 to 2.5 ft	4 to 12 in of riprap	No	No	1995	11,200 Curies of Ra-226	NA	2.8	rural, <5 miles from town with more than 5,000 residents	H	11	50 (estimated)	H	Bluewater, NM - main disposal cell
Bluewater, NM - carbonate tailings cell	No	Yes- 2.0 to 2.5 ft	4 to 12 in of riprap	No	No	1995	1,130 Curies of Ra-226	NA	1.3	rural, <5 miles from town with more than 5,000 residents	H	11	50 (estimated)	H	Bluewater, NM - carbonate tailings cell
Bluewater, NM - PCB disposal cell	No	Yes- 2.0 to 2.5 ft	6 in of riprap	No	No	1995	NA	NA	NA	rural, <5 miles from town with more than 5,000 residents	H	11	50 (estimated)	M	Bluewater, NM - PCB disposal cell
Edgemont, SD	Yes	Yes - 3.0 ft	72 in	No	No	1989 (decommisisoning activities completed)	527 Curies of Ra-226	17.5	unknown	rural	M	14	50 (estimated)	L	Edgemont, SD
L-Bar, NM	Yes, vegetated	Yes, 4.1 ft clay	2-6' of vegetated soil	Yes	No	2000	205 Ci Ra-226 (2.1 million tons of ore was processed, producing 700,000 yd^3 of tailings distributed over 100ac)	7.3	3.7	rural - several nearby villages	M	8-10	50 (estimated)	L	L-Bar, NM
Maybell West, CO	No	Yes; 1.5 ft	1 ft rip-rap plus 4.5 ft	Yes (.5')	No	2005	96 curies Ra-226; 1.975m tons of tailings	NA	NA	rural	L	12	50 (estimated)	L	Maybell West, CO
Sherwood, WA	Yes, vegetated	No, 12.6-20 ft of uncompacted local soil	12.6-20' uncompacted sandy soil, 6" vegetated soil	No	No	1996	2.9 million tons of tailings (equates to 2.4 million cubic yards of tailings)	0.13	0.51	limited population nearby but immediately adjacent to Spokane River	M	16-18	NA	L	Sherwood, WA
Shirley Basin South, WY	Yes, vegetated	Yes, 2' of compacted clay	2' compacted sandy soil 10" topsoil	Yes	No	2001	6.3 million tons of tailings or 4.5 million yd^3 + 14.7 million tons of acidic mill liquids	NA	1.3	Rural	M	10	50 (estimated)	L	Shirley Basin South, WY
Decommissioning Sites not yet Released *10 CFR 20, Subpart E*															***Decommissioning Sites not yet Released*** *10 CFR 20, Subpart E*
Kerr-McGee - Cimarron, OK (complex materials)	No	No	NA	No	No	2002	0.98 ci U/Th contaminated soils	NA	NA	no population	L	27-30	60	None	Kerr-McGee - Cimarron, OK (complex materials)

Table 12.2b: Characteristics of Title II Disposal Site and Decommissioning Site Covers Associated with Seepage from Mill Tailings

Characteristics of Title II Disposal Site and Decommissioning Site Covers Associated with Seepage from Mill Tailings														
	Precipitation Rate (in/yr)	Potentail ET Rate (in/yr)	Depth to Aquifer (ft)	Unsaturated Zone Hydrogeological Characterisitcs (qualitative)	Disposal Site on Processing Site (Y or N)	Quality of Dis-posal Site Groundwater (Good, Limited Use, Contaminated)	Groundwater Status Corrective Action (Y or N) Standards (NA, Background, MCLs, or ACLs/Suppl.Stnd)	Disposal Site GW Monitoring Program Ongoing (Y or N)	Groundwater Contaminants from Post-Operational Disposal Cell Detected (Y, Potentially, or N)	Existing Liner below Waste (Y or N)	Leachate Collection System (Y o N)	Intensity of Aquifer Use Nearby Use (H, M, L, or None)	POTENTIAL for Increased GW Contamination due Processes Documented in NUREG/CR-7028 (High, Moderate, or Low)	
	[1 in/yr =	2.54 cm/yr]	[1 ft = 0.305 m]											
TITLE II SITES *DOE Licensed under 40.28; 40 CFR 192(C)(D)*														***TITLE II SITES*** *DOE Licensed under 40.28; 40 CFR 192(C)(D)*
Bluewater, NM - main disposal cell	11	50 (estimated)	25-50 ft (estimate)	unknown	Y	Contaminated	Y; ACLs	N	N	N	N	M	M	Bluewater, NM - main disposal cell
Bluewater, NM - carbonate tailings cell	11	50 (estimated)	25-50 ft (estimate)	unknown	Y	Contaminated	Y; ACLs	N	N	N	N	M	M	Bluewater, NM - carbonate tailings cell
Bluewater, NM - PCB disposal cell	11	50 (estimated)	25-50 ft (estimate)	unknown	Y	Contaminated	Y; ACLs	N	N	N	N	M	M	Bluewater, NM - PCB disposal cell
Edgemont, SD	14	50 (estimated)	300-700 ft	unknown	N (2 miles away)	unknown	N	NA	N	N	N	unknown	L	Edgemont, SD
L-Bar, NM	8-10	50 (estimated)	60-80 (estimate)	alluvium, shale, sandstone	Y	Cotaminated	N	Y	N	N	N	None	L	L-Bar, NM
Maybell West, CO	12	50 (estimated)	200ft	silty sandstone	Y	Limited Use	N	N	N	Y	N	L	L	Maybell West, CO
Sherwood, WA	16-18	unknown	58 ft (at one point)	alluvium and conductive bedrock	Y	unknown	N	Y	N	Y	N	unknown	L/M	Sherwood, WA
Shirley Basin South, WY	10	50 (estimated)	60	sandstone, conglomerates, claystones	Y	Cotaminated	N	Y	N	N	N	L	M	Shirley Basin South, WY
Decommissioning Sites not yet Released *10 CFR 20, Subpart E*														***Decommissioning Sites not yet Released*** *10 CFR 20, Subpart E*
Kerr-McGee - Cimarron, OK (complex materials)	30	60	10-30	sandstone	N	Good	N	Y	N	N	N	I	L	Kerr-McGee - Cimarron, OK (complex materials)

12.2.3 Qualitative Assessments

Bluewater, NM

a) Potential for increased radon release – High

● Main Tailings Disposal Cell, the Acid Tailings Disposal Area, and the South Bench Disposal Area are contiguous, and together they constitute one large disposal area of approximately 354 acres. The main tailings disposal cell is covered with basalt riprap and slopes northward. The top slope grade is 3 to 4 percent at the south end and decreases to less than 0.5 percent at the north end. The top slopes of the acid tailings and the south bench disposal areas are essentially flat and covered by healthy grass. Basalt riprap protects the side slopes of the three disposal areas. No frost protection layers exist.

● Main Tailings Pile:

The main disposal cell total radioactivity is 11,200 Ci of ^{226}Ra. The main tailings pile has a northerly trending top slope that ranges from 0.5 to 4% grade. The average thickness of the radon cover ranges from 2.4 to 3.4 ft (73 to 102 cm). The mixed tailings area and the slimes area of the main tailings pile have a minimum thickness of 1.0 and 0.5 ft, respectively. The rock erosion protection cover on the top surface of the pile is 4.5 in (11 cm) thick of D50 = 1.5 in (4 cm) rock. The cover rock on the outslopes is 7.5 in (19 cm) thick of D50 = 2.5 in (6 cm) rock and on the spillways is 12 in (30 cm) thick of D50 = 5 in (13 cm) rock.

● Acid Tailings Pile

The final top slope of the acid pile slopes northward at 0.15 percent and is covered by 8 in (20 cm) of topsoil, which has been seeded with native grasses. The topsoil is underlain by an 8 in (20 cm) average thickness of radon cover material. The short outslope along the north side of the acid pile is covered by rip-rap about 7.5 in (19 cm) thick of D50 = 2.5 in (6 cm).

● Carbonate Tailings Pile

Basalt riprap covers the top and side slopes of the 54-acre carbonate tailings disposal cell. The top, for the most part, slopes gently eastward. The small northwest and southeast extensions slope in their respective directions. The carbonate disposal cell total radioactivity is 1,130 Ci of ^{226}Ra. The carbonate tailings have a top slope with a maximum grade of 3%.

b) Quality and usability of nearest aquifer – Contaminated

● Near surface alluvial aquifer (between 25 and 50 ft deep [7.6 and 15.2 m]), contamination detected prior to final cover system installation, ACLs established for site. San Andres-Glorieta aquifer is a principal drinking water aquifer. The San Andres-Glorieta aquifer outcrops beneath the main tailings pile and is the uppermost bedrock aquifer at the site.

c) Potential for increased groundwater contamination from tailings seepage – Moderate

● Low precipitation, high evaporation area, cover on thinner side, shallow depth to first aquifer, need to check ACL application for discussion of seepage rate. Several shallow depressions exist on the relatively flat north end of the top slope of the main tailings disposal cell and along the east and northwest edges of the cover. Standing water from a recent rainfall event was present in several of the depressions. Given that evaporation greatly exceeds precipitation in this area, ponding is believed to be infrequent and brief and, therefore, has not been considered to be a concern. However, the cell cover in the area of the depressions will be evaluated to determine if additional monitoring or corrective action is necessary.

d) Other:

- The uranium concentration in alluvium point-of-compliance (POC) well T(M) exceeded the alternate concentration limit (ACL) of 0.44 milligrams per liter (mg/L). The uranium concentration for a sample collected on November 9, 2010, was 0.557 mg/L.
- Plant encroachment (annual weeds and scattered perennial shrubs) continues on the cell cover and side slopes. Several saplings of Siberian elm were present on the cell cover and east side slope and subsequently were cut and treated with herbicide.
- Site is located near the Homestake site.

e) Recommendations:

- Continue groundwater monitoring.

Edgemont, SD

a) Potential for increased radon release – Low

- The disposal cell encompasses about 100 acres and contains about 4 million tons (3 million cubic yards) of contaminated material with a total activity of 527 curies of radium-226.
- The cover of the disposal cell is a multicomponent system designed to encapsulate and protect the contaminated materials. The 9-ft-thick disposal cell cover comprises (1) a low-permeability radon barrier (first layer placed over compacted tailings) consisting of compacted clay (3 ft [0.91 m]), (2) clean, compacted fill (5 ft [1.5 m]), and (3) a layer of topsoil material (1 ft [0.30 m]). The top of the cell and surrounding disturbed areas were seeded with native grasses. An existing gully northwest of the cell and the containment dam face were armored with rock (riprap) for erosion protection. Additional riprap- and grass-protected diversion ditches were installed to channel runoff water away from the disposal cell. The NRC staff estimate of flux was 17.5 $pCi/m^2/s$.

b) Quality and usability of nearest aquifer – Unknown

- The site overlies a 300- to 700-ft-thick (91 – 210 m) layer of shale of sufficiently low permeability that NRC granted an exemption from the requirement of a liner beneath the disposal cell. The uppermost aquifer in the area is beneath the shale layer. Because contaminants from the disposal cell are not expected to ever come into contact with the aquifer, there is no groundwater monitoring system at the disposal site, and groundwater monitoring is not a part of the long-term surveillance requirements for the site.

c) Potential for increased groundwater contamination from tailings seepage – Low

- Relatively low precipitation, high potential evaporation site, depth to first aquifer is more than 300 ft (91.4 m). Note there is apparently no groundwater monitoring network at site. Placing the disposal cell at the head of an ephemeral drainage required construction of a containment dam of compacted clay at the down-gradient face of the disposal basin. The base of the cell is below ground surface; compacted clay perimeter walls averaging 13 ft (4.0 m) in thickness are keyed into shale at the base of the cell and extend up the sides of the cell. The clay walls were designed to physically separate the contaminated tailings material from surrounding soils and any perched water zones that may be present.

d) Other:

- None

e) Recommendations:

- Based on site characteristics and location, no future activities related to cover performance are recommended.

L-Bar, NM

a) Potential for increased radon release – Low

- The 100 acre cover cell consists of 4.1 ft (1.25 m) of compacted clay and 2 – 6 ft (0.61 – 1.8 m) of a vegetated cover soil (DOE Disposal Fact Sheet). As of 2004, L-Bar, NM contained 205 Ci of radium (LTSP DOE, 2004). After the radon flux barrier was completed in 1991, the average radon flux measurement was 3.7 pCi/m^2/s and the estimated long-term radon flux was calculated to be 7.3 pCi/m^2/s (ML0126803971; ML0101202831).

b) Quality and usability of nearest aquifer – Contaminated

- Ground water from the impacted aquifers is not currently being used as a drinking water source and is unlikely to be used in the future as (i) the volume of available water is low, (ii) the original ambient -groundwater quality is poor, and (iii) a higher quality and more dependable water source is located in a deeper aquifer (ML0924002890).

c) Potential for increased groundwater contamination from tailings seepage – Low

- Thick clay layer (4.1 ft [1.25 m]) with a 2-6 ft (0.61 – 1.8 m) cover soil; arid climate (8-10 in [20.3 – 25.4 cm] of precipitation); natural attenuation likely due to a large neutralization capacity within the aquifer.

d) Other:

- None

e) Recommendations:

- None

Maybell West, CO

a) Potential for increased radon release: Low

- Although the climate is semiarid with an annual precipitation of 12 in (30.5 cm) and a potential ET rate of approximately 50 in (1.27 m), actual transpiration is low since the cover is not vegetated and root systems causing increased connectivity among pores are kept at a minimum. The most important feature contributing to a low estimate of potential radon release

is the 4.0 ft (1.2 m) thickness of frost protection layer to prevent desiccation cracking and freeze-thaw cracking and the relative small total radioactivity of the waste: 96 Ci.

● The cover consists of a minimum 18 in (46 cm) thick clayey soil layer (radon barrier material) placed over the reshaped heap materials. Frost and erosion protection materials, along with a drainage/filter bed layer designed to shed precipitation-related water, were in turn placed over the radon barrier material. On top of the clayey soil layer is a 42 to 48 in (107 – 122 cm) thick layer of random fill that is covered by a 6 in (15 cm) thick layer of riprap/bedding material having a median diameter (D50) of 3/8 to 1 1/2 in (1 – 4 cm). A 12 in (31 cm) thick layer of 5 to 8 –in (13 – 20 cm) D50 riprap covers the 5:1 side slopes of the reclaimed heap leach pile.

● The ancillary cell was an existing heap drainage storage pond. Synthetic pond liner material, evaporation pond material, and other contaminated debris that remained on site when reclamation activities were closed are isolated in this cell. The ancillary cell was covered with a minimum of 5.5 ft (1.7 m) of cover, including radon barrier clay, random fill, and erosion protection material.

● Additional facts: 1.975 m tons tailings; 96 Ci Ra-226;

● Cover layers: 1.0 ft (30.5 cm) riprap; 1 ft (30.5 cm) bedding; 3.5 ft (1.1 m) overburden; 1.5 ft (45.7 cm) radon barrier

b) Quality and usability of the nearest aquifer – Limited Use

● Limited use groundwater determination.

c) Potential for increased groundwater contamination from tailings seepage - Low

● Overburden is relatively thick; climate semiarid; potential pathway through the unsaturated zone is 200 ft (61 m); and a 1-ft (30.5 cm) thick clay liner below the heap.

d) Other:

● Contains a bottom clay liner to inhibit contaminant discharge to the subsurface. The cover of the disposal cell is designed to shed precipitation to an armored outlet channel, which is further protected from head-cutting by a launch rock basin.

e) Recommendations:

● Leachate should be analyzed to indicate changing cover properties.

Sherwood, WA

a) Potential for increased radon release – Low

● The model predictions and measurements for Sherwood, WA are well below the regulatory limit of 20 pCi/m^2/s. The cover system at Sherwood, WA does not contain a compacted clay layer but consists of 12.6 ft – 20 ft (3.8 – 6.1 m) of uncompacted sandy and clayey-sandy soil to control radon flux. The cover includes 6 inches of topsoil that was vegetated with native grasses, forbs, shrubs, and trees. A drainage channel along the perimeter of the disposal cell is designed to intercept overland flow and convey storm water around and away from the cell. The perimeter drainage channel is lined with riprap to control erosion. The site contains approximately 470 Ci of radium (LTSP DOE, 2001). The modeled radon emanation was

calculated to be 0.13 pCi/m^2/s. The mean radon flux was measured to be 0.51 pCi/m^2/s and the maximum value was 0.7 pCi/m^2/s in 1996 (ML0036914490).

b) Quality and usability of nearest aquifer – Unknown

● The groundwater flow rate in the alluvium was calculated to be 218 gpm (0.9 m^3/min) and the conductive bedrock layer to be 1.5 gpm (0.006 m^3/min). Data was not readily available for pre-existing contamination.

c) Potential for increased groundwater contamination from tailings seepage– Low/Moderate

● The cover system was designed with 12.6 ft – 20 ft (3.8 – 6.1 m) of uncompacted local sandy soils and 6 in (15.2 cm) of vegetated topsoil. The acid-leached tailings were neutralized prior to emplacement and underlain by a synthetic liner. The groundwater could be impacted by the tailings due to leakage through the impoundment liner or overtopping of the liner. A containment dam was constructed at the down- gradient end of the disposal cell to enclose the disposal cell drainage area, and a 6 in (15 cm) layer of riprap (rocks) was placed on the downslope face of the containment dam to control erosion.

d) Other:

● The performance of a store-and-release cover system is more dependent on vegetation, settlement, and erosion than on a resistive layer. The short-term changes in hydraulic properties for this cover system from as-built conditions can be expected to be less than for conventional clay covers, due to the lack of soil compaction and the lower proportion of clay (Benson, et al., 2010). Ongoing monitoring by the DOE will facilitate understanding of the changes in the long-term performance of this system.
● As of 2009, ponding was present on top of the cover due to settlement and the resultant change in surface contouring.

e) Recommendations:

● The uniqueness of this Title II site may warrant additional measurements to verify continuing performance and serve as a reference for alternative design for radon release.

Shirley Basin South, WY

a) Potential for increased radon release – Low

● The mill tailings have 2 ft (61 cm) of compacted clay that is overlain by 2 ft (61 cm) of compacted sandy soil and 10 in (25.4 cm) of topsoil. There are 974 Ci of Radium within the disposal cell with an aerial extent of 142 ac. (Draft LTSP, 2009). The cover was completed and tested in 1997, 1999, and 2000 (different areas were completed at different times and the measured radon flux for the entire pile was 1.3 pCi/m^2/s (ML0136204672).

b) Quality and usability of nearest aquifer – Contaminated (Moderate)

● The upper two aquifers (Upper Sand and Main Sand) have been impacted by tailings fluids and institutional controls do not exist for the potential extent of the plume; the Lower Sand

aquifer has not been affected by site-derived contamination. Site-derived contamination is flowing towards surface water bodies (Lakes 2/8) and may be impacting the lakes.

c) Potential for increased groundwater contamination from tailings seepage – Moderate

● To be conservative, Petrotomic's modeled the long term tailings seepage rate to be equal to the areal groundwater recharge rate i.e., no credit was taken for reduced infiltration due to the cover system. The NRC-approved transport model for Shirley Basin South assumes that the groundwater will reverse directions and site-derived contamination will remain within the site boundary. In addition, exposure scenarios are based on livestock consumption or 10 days of groundwater consumption at the point of exposure (POE). If both of these assumptions remain valid, then there is no increased risk from degradation of cover performance. However, the groundwater flow direction is dependent on Lakes 2/8 recharging and remaining stable and the potential exists for the land use scenarios at the POE to change.

d) Other:

● Ra-226 concentrations are exceeding the ACL value at the POE; the DOE is planning on submitting an evaluative monitoring program to determine the source of the contamination. Radium-228 continued to exceed the ACL in both MW–5–DC and MW–54–SC in 2010.

e) Recommendations:

● Upon determination of a path forward with the State of Wyoming, the DOE, and the NRC regarding the elevated Ra-226 concentrations at the POE and the land use scenarios, reevaluation of the increased risk from cover degradation should be conducted.

12.3 Title II Sites in Closure

12.3.1 General Background

Uranium recovery facilities are currently licensed by the NRC under its regulations (10 CFR Part 40), including conventional uranium mills and in situ leach (ISL) facilities. Conventional mill site licenses have been terminated and the reclaimed tailings areas transferred to DOE for long-term care under the general license provisions of 10 CFR 40.28. A conventional mill uses uranium ore extracted by either open pit or deep mining. The ore is then crushed and sent through the mill, where extraction processes concentrate the uranium into uranium-oxygen compounds called yellowcake. The remainder of the crushed rock, in a processing fluid slurry, is placed in a tailings pile/cell. The "pile"; is actually a constructed impoundment or a former uranium mine pit that must meet criteria in 10 CFR Part 40, Appendix A. These criteria include requirements for siting and design of the pile, cover performance, and financial surety for decommissioning, reclamation, and long-term surveillance.

With the ISL uranium extraction process, wells are drilled into rock formations containing uranium ore. Water, with added oxygen and sodium bicarbonate, is injected down the wells to mobilize the uranium in the rock so that it dissolves in the groundwater. The water is pumped to the surface, where a processing plant separates the uranium. Waste from this process is disposed in a tailings pile at a mill site.

No NRC-licensed conventional uranium mills are operating. The NRC-licensed sites are located in Nebraska, New Mexico, and Wyoming. There also are eight conventional uranium mills in Agreement States that have similar non-operational tailings impoundments. One mill in Colorado is operating. Texas also has ISL facilities, but most are in, or have completed, decommissioning. Three uranium mill sites are located in Utah, with one being active, one in reclamation, and one returning to active status. An active mill tailings disposal facility is also located in Utah. This mill tailings disposal facility was licensed by NRC as a commercial facility in November 1993 to receive and dispose of 11e.(2) byproduct material. In 2004, Utah became an Agreement State for 11e.(2) byproduct material and regulatory authority over the site transferred to the state. The site also has disposal cells licensed under Utah Agreement State authority for the disposal of low-level radioactive waste and mixed waste.

12.3.2 Tables

Table 12.3a: Characteristics of Title II in Closure Disposal Site Covers Associated with Radon Release

Characteristics of Title II in Closure Disposal Site Covers Associated with Radon Release	Cover Vegetation (Yes or No)	Cover Type - Compacted soil/clay If yes, thickness (ft)	Overburden Thickness on top of compacted soil/clay (ft)	Cover Type - Drainage/bedding/ filter/capillary layer	Cover Type - Geomembrane	Year Cover Built	Waste Type/ Source Term (Curies [Ci] or volume [yd^3])	Calculated Radon Flux ($pCi/m^2/s$)	Measured Radon Flux at Conpletion (pCi/m2/s)	Population Type near Site (no population or rural or near urban)	Public Interest (H, M, or L)	Precipitation Rate (in/yr)	Potentail ET Rate (in/yr)	POTENTIAL for Increased Radon Release due Processes Documented in NUREG/CR-7028 (High, Moderate, or Low)	
		[1 ft = 0.305 m]	[1 ft = 0.305 m]				[1 Ci = 37000 MBq] [1 yd^3 = 0.765 m^3]	[1 $pCi/m^2/s$ =	0.037 Bq/m2/s]			[1 in/yr =	2.54 cm/yr]		
TITLE II SITES IN CLOSURE *NRC Licensees; 10 CFR 40, App. A*															***TITLE I SITES*** *NRC Licensees; 10 CFR 40, App. A*
Ambrosia Lake West (Rio Algom), NM	No	Yes - 1.5 ft	24 in (12 in soil, 6 in bedding, 6 in riprap)	Yes	No	started 1986	33 million tons of tailings	19.7	could not locate numbers, reclamation still in progress	rural	M	9	50 (estimated)	M	Ambrosia Lake West (Rio Algom), NM
Bear Creek (Anadarko), WY	Yes	Yes - 3 ft	12 in (min, may be more in places)	No	No	1997	860 Curies of Ra-226	8.5 (sands) 9.4 (slimes)	0.73	no population	L	12	45 (estimated)	M	Bear Creek (Anadarko), WY
Church Rock (UNC), NM	Yes	Yes - 1.5 ft	6 in	No	No	1996	3.5 million tons of tailings over 100 acre area	NA	5.7	rural, native americans living near site	H	12	50 (estimated)	H	Church Rock (UNC), NM
Gas Hills East (Umetco), WY	Rock	Yes (variable, 1-1.5 ft clay)	4.5-8.5'	Yes/No (a portion of the cover contains a bedding layer - % NA)	No	2003	~20 million tons of tailings and 465,000 tons of tailings slurry per year from late 1950s to 1979 (Umetco, 2001 - ML0200201330)	NA	1.1-6.8	No population - nearest residence is 5 miles to the northeast	M (due to recent cover issue)	9	46 (derived from nearby lake measurements)	L/M	Gas Hills East (Umetco), WY
Gas Hills North/Lucky Mc (Pathfinder), WY	Mostly No	Yes (variable, 1 -3 ft of clay)	0-0.7' soil	Yes	No	2004	12 million tons of ore were mined at this site	NA	0.8	No population - nearest residence is 4 miles to the NW and is upgradient, nearest downgradient residence is 11 miles (ML0225200650)	M	9	46 (derived from nearby lake measurements)	L	Gas Hills North/Lucky Mc (Pathfinder), WY
Gas Hills West (ANC), WY	No	No - radon barrier (not clay) 30-36"	2.5' - 3' borrow soil	No	No	1997	~1 million cubic yards of mill tailings	17 or 19.9	0.5	No population	M/H (due to state involvement)	9	46 (derived from nearby lake measurements)	M/H	Gas Hills West (ANC), WY
Grants (Homestake), NM	No	Yes - variable, 2 ft minimum	15.6 in (6 in bedding, 9.6 in rip-rap)	Yes	No	fall 1994	22 million tons of tailings	NA	close to 20, site not completely covered yet	rural, <5 miles from town with more than 5,000 residents	H	11	50 (estimated)	M/H	Grants (Homestake), NM
Highland (Exxon), WY	Yes	Yes - 3.5 ft	6 in	No	No	August 1989	11.3 million tons of ore processed	NA	2.52	no population	L	12	45 (estimated pan evaporation)	L	Highland (Exxon), WY
Sequoyah (Sequoyah Fuels), OK [design only]	Yes	Yes - 2.0 ft	96 in	Yes	Yes	pending	cell has design capacity of about 350,000 cubic yards	2.0 (licensee number) 5.9 (NRC number)	NA	rural	M	44	48 (estimated lake evaporation)	L	Sequoyah (Sequoyah Fuels), OK [design only]
Shirley Basin North (Pathfinder), WY	Yes	Yes - 6" of sandy soil on top of 6" of compacted clay	0.5" sandy soil (proposed in 2004)	No?	No	2004?	8.5 million tons of ore mined	14.6, 18.9 or 22.9	4.9	no population - nearest downgradient resident is 6 miles away	M	11	47 (estimated from annual lake evaporation)	H	Shirley Basin North (Pathfinder), WY
Split Rock (Western Nuclear), WY	Yes	Yes (0.5-3.7 ft)	0.7-1" soil	No	No	2000	7.7 million tons of ore were processed and a 5-to-1 ratio of effluent to tailings was placed into the impoundment	1.7 or 2.1	0.88	rural but the town of Jeffrey City is near the plume	M	10	36	M	Split Rock (Western Nuclear), WY

Table 12.3b: Characteristics of Title II in Closure Disposal Site Covers Associated with Seepage from Mill Tailings

Characteristics of Title II in Closure Disposal Site Covers Associated with Seepage from Mill Tailings	Precipitation Rate (in/yr)	Potentail ET Rate (in/yr)	Depth to Aquifer (ft)	Unsaturated Zone Hydrogeological Characterisitcs (qualitative)	Disposal Site on Processing Site (Y or N)	Quality of Dis-posal Site Groundwater (Good, Limited Use, Contaminated)	Groundwater Status Corrective Action (Y or N) Standards (NA, Background, MCLs, or ACLs/Suppl.Stnd)	Disposal Site GW Monitoring Program Ongoing (Y or N)	Groundwater Contaminants from Post-Operational Disposal Cell Detected (Y, Potentially, or N)	Existing Liner below Waste (Y or N)	Leachate Collection System (Y o N)	Intensity of Aquifer Use Nearby Use (H, M, L, or None)	POTENTIAL for Increased GW Contamination due Processes Documented in NUREG/CR-7028 (High, Moderate, or Low)	
	[1 in/yr =	2.54 cm/yr]	[1 ft = 0.305 m]											
TITLE II SITES IN CLOSURE														*TITLE II SITES IN CLOSURE*
NRC Licensees; 10 CFR 40, App. A														*NRC Licensees; 10 CFR 40, App. A*
Ambrosia Lake West (Rio Algom), NM	9	50 (estimated)	150 ft (estimate)	alluvium	Y	Contaminated	Y; ACLs	N	N	N	N	L	M	Ambrosia Lake West (Rio Algom), NM
Bear Creek (Anadarko), WY	12	45 (estimated)	50 ft (?)	discontinuous sand lenses	Y	Contaminated	Y; ACLs	N	N	N	N	L	L	Bear Creek (Anadarko), WY
Church Rock (UNC), NM	12	50 (estimated)	60 ft (estimate)	alluvium	Y	Contaminated	Y; MCLs	Y	N	N	N	L	M	Church Rock (UNC), NM
Gas Hills East (Umetco), WY	9	46 (derived from nearby lake measurements)	100-150	Interbedded sands, silts, and clays	Y	Contaminated	N	Y	N	N	N	L	L/M	Gas Hills East (Umetco), WY
Gas Hills North/Lucky Mc (Pathfinder), WY	9	46 (derived from nearby lake measurements)	100-150 (estimate)	Interbedded sands, silts, and clays	Y	Contaminated	N	Y	N	N	N	L	L	Gas Hills North/Lucky Mc (Pathfinder), WY
Gas Hills West (ANC), WY	9	46 (derived from nearby lake measurements)	100-150 (estimate)	alluvium and weathered bedrock	Y	Contaminated	Y; Background	Y	N	N	N	L	M/H	Gas Hills West (ANC), WY
Grants (Homestake), NM	11	50 (estimated)	25-50 ft (estimate)	unknown	Y	Contaminated	Y; ACLs	Y	N	N	N	M	M	Grants (Homestake), NM
Highland (Exxon), WY	12	45 (estimated pan evaporation)	110 ft (estimate)	discontinuous sand-stones and shales	Y	Contaminated	Y; ACLs	N	N	N	N	H	L	Highland (Exxon), WY
Sequoyah (Sequoyah Fuels), OK [design only]	44	48 (estimated lake evaporation)	100 ft (estimate)	loamy soil, terrace deposits and alluvium	Y	Unknown	Y; MCLs	Y	N	Y	Y	L	L	Sequoyah (Sequoyah Fuels), OK [design only]
Shirley Basin North (Pathfinder), WY	11	47 (estimated from annual lake evaporation)	60 ft (estimate)	interbedded claystone, siltstone, and sandstone	Y	Contaminated	N	Y	N	N	N	L	M/H	Shirley Basin North (Pathfinder), WY
Split Rock (Western Nuclear), WY	10	36	5-50	eolian deposits and alluvium	Y	Contaminated	N	Y	N	N	N	M	L/M	Split Rock (Western Nuclear), WY

12.3.3 Qualitative Assessments

Ambrosia Lake West (Rio Algom), NM

a) Potential for increased radon release – Moderate

● Thinner radon barrier (1.5 ft [45.7 cm]), at least 1.5 ft (45.7 cm) of overburden (soil and bedding layer) plus 0.5 ft (15.2 cm) of riprap, no vegetation.

b) Quality and usability of nearest aquifer – Contaminated

● ACL's established for site, nearest aquifer estimated to be 150 ft (45 m) deep, contaminants detected prior to cover system installation, ACLs established for site.

c) Potential for increased groundwater contamination from tailings seepage – Moderate

● Low precipitation, high evaporation rate location, cover system on thinner side, no vegetation on cover, contaminants detected at site before cover was built, need to check ACL application for tailings seepage.

d) Other:

● None

e) Recommendations:

● Continue oversight of reclamation process, continue groundwater monitoring, staff could pursue verification of radon flux measurements prior to site transfer to DOE.

Bear Creek (Anadarko), WY

a) Potential for increased radon release – Moderate

● Thicker radon barrier (3 ft [91 cm]), only 1 ft (30.5 cm) min of soil cover on top of radon barrier, relatively low source term (860 Curies of Ra-226), cover is vegetated, so there is potential for root penetration. Design calculated radon flux rate was 8.5 $pCi/m^2/s$ in sands, 9.4 $pCi/m^2/s$ in slimes, actual measurements on as-built cover was 0.73 $pCi/m^2/s$.

b) Quality and usability of nearest aquifer – Contaminated

● ACL's established for the site, note near surface aquifer is encountered at relatively shallow depth.

c) Potential for increased groundwater contamination from tailings seepage – Low

● Low precipitation, high evaporation rate location, thicker cover, vegetated cover, contaminants detected at site before cover was built, probably related to mill process water. Need to check ACL application to identify tailings seepage rate.

d) Other:

● None

e) Recommendations:

● Based on site characteristics and location, no future activities related to cover performance are recommended.

Church Rock (UNC), NM

a) Potential for increased radon release – High

● Thinner radon barrier (18 in [45.7 cm]), low overburden/frost protection (only 6 in [15.2 cm]), and a vegetated cover, which provides possibility for root penetration. Measured radon flux rate on as-built cover system was 5.7 pCi/m^2/s.

b) Quality and usability of nearest aquifer – Contaminated

● Currently undergoing active groundwater remediation, contaminants detected prior to construction of cover system.

c) Potential for increased groundwater contamination from tailings seepage – Moderate

● Low precipitation, high evaporation rate location, thinner cover system, vegetated cover, contaminants detected at site before cover was built.

d) Other:

● None

e) Recommendations:

● Continue to monitor groundwater and progress of EPA activities in area. It is possible that the final cover system would be re-designed and re-constructed to accommodate mine waste from the northeast church rock mine. If the cover is re-designed, the staff should carefully review the radon flux calculations as well as the erosion protection aspects of the design. If the cover remains in current configuration, confirmation radon flux measurements prior to transfer to DOE would be recommended.

Gas Hills East (Umetco), WY

a) Potential for increased radon release – Low/Moderate

● The Gas Hills East site consists of a series of different cover areas (see below) with average radon fluxes ranging from 1.1 to 6.8 pCi/m^2/s. The nearest residence is 5 miles (7.5 km) to the northeast (ML0037707450) and the radon flux measurements were significantly below the regulatory 20 pCi/m^2/s; however, the radon barriers are relatively thin. (ML011450405 – 2001 ACL Application).

- A-9 Repository
  Radon barrier = 1.5 ft (45.7 cm) (ML0721905640)
  Frost protection layer = 4.5 ft (1.4 m)
  Riprap = 6-12 in (15.2 – 30.5 cm)
  Total average of radon flux for 2002 and 2003 for the A-9 repository was 3.5 pCi/m^2/s (ML033650364)
  Ra-226 concentration = 342pCi/g (ML0721905641)
- AGTI (Above Ground Tailings Impoundment)
  Radon barrier = 1 ft (30.5 cm) (ML0722000561 Table 3.3)
  Frost protection 8.5 ft (2.6 m)
  Radon Flux for AGTI was 1.4 pCi/m^2/s (2000) ML072200056
  Ra-226 concentration = 310pCi/g
- Heap Leach Repository
  Radon barrier = 1 ft (30.5 cm) (ML072190016 Table 3.3)
  Frost protection = 5 ft (1.5 m)
  Radon Flux was 1.1 pCi/m^2/s ML072200056
- GHP-2 Repository
  Radon barrier = 1.00 – 1.80 ft (30.5 – 54.9 cm) (ML0722105770)
  Radon Flux was 6.8 pCi/m^2/s (2006) ML070110059

b) <u>Quality and usability of nearest aquifer – Contaminated (Moderate)</u>

● Umetco's comparison of background concentrations to the Wyoming Department of Environmental Quality groundwater quality standards are compatible with a Class III (livestock) designation. Widespread groundwater contamination from mining and milling has resulted in a groundwater quality that is not compatible with domestic or agricultural groundwater use, however it has been used for livestock watering.

c) <u>Potential for increased groundwater contamination from tailings seepage– Low/Moderate</u>

● The site is located in an arid region; the radon barriers are typically 1 ft (30.5 cm), however the frost protections layers are at least 4.5 ft (1.4 m) thick for the AGTI, A-9 and Heap Leach Repositories.

d) <u>Other:</u>

● The Gas Hills area is sparsely populated and expected to remain stable with the most likely use of groundwater to be mining-related and livestock and wildlife watering. In 2010, portions of the cover system were discovered to be rapidly eroding. Preliminary indications are that the erosion is due to the lack of a bedding layer.

e) <u>Recommendations:</u>

● Continue to monitor the cover erosion and the potential impact to radon release and groundwater contamination.

Gas Hills North/Lucky Mc (Pathfinder), WY

a) Potential for increased radon release – Low

● The radon barrier and overburden at Gas Hills North (Pathfinder Lucky Mc) was variable in design (see below), depending on the underlying source term (ML051720392; ML053250478). The average radon flux measurement was 0.8 pCi/m^2/s, however this value was likely to be significantly less as many of the radon flux values were less than the detection limit of 0.5 pCi/m^2/s but were conservatively averaged in at 0.5 pCi/m^2/s (ML051720392; ML053260287). Total radium activity was 1808 Ci in December of 2004 (ML090400197).

Ore pad – 1 ft (30.5 cm) of clay; 1-2 in (2.5 – 5.1 cm) of rock mulch
Mill site – 2 ft (61 cm) of clay; 1-2 in 92.5 – 5.1 cm) of rock mulch
Mill site (adjacent to) – 1.5 ft (45.7 cm) of clay; 1-2 in (2.5 – 5.1 cm) of rock mulch
Ponds 1 and 2 – 3 ft (61 – 91.4 cm) of clay; 8 in (20.3 cm) of topsoil
Pond 2A – 2 ft (61 cm) of clay; 8 in (20.3 cm) of topsoil
Regraded dam outslopes – 1.5 ft (45.7 cm) of clay (typically); 1-2 in (2.5 – 5.1 cm) of rock mulch
Solution ponds – 13 in (33 cm) of clay; 1-2 in of rock 92.5 – 5.1 cm) mulch
Ponds 3, 3A, and 4 13 – 26 in (33 – 66 cm) of clay

b) Quality and usability of nearest aquifer – Contaminated

● The WDEQ classified the adjacent, downstream aquifer as Class III groundwater, suitable for livestock use. The area is sparsely populated, stable, and there are no downgradient residences within 20 miles (32.2 km); the first groundwater use is 11 miles (17.7 km) from the site and used for livestock watering.

c) Potential for increased groundwater contamination from tailings seepage – Low

● The ponds have 2 – 3 ft (61 – 91.4 cm) of clay and the site is located in an arid region averaging 6 – 9 in (15.2 – 22.8 cm) of precipitation annually.

d) Other:

● None

e) Recommendations:

● None

Gas Hills West (ANC), WY

a) Potential for increased radon release – Moderate/High

● Although the measured average radon flux is relatively low for Tailings Pond 2, the calculated values indicate a potential for higher values. The cover for Tailings Pond 1 was never finalized.

● Tailings Pond 2 (80 ac [0.32 km^2]):
The cover consists of 2.7 ft (82 cm) of a previous interim (mine spoil) cover, 3 ft (91.4 cm) of compacted mine spoil material, 3 ft (91.4 cm) of compacted clean borrow material, and a rock mulch layer. The average radon flux measurement for Tailings Pile No. 2 was 0.5 pCi/m^2/s (ML092390096) in June 1997. WDEQ calculated the radon flux to be 17.0 pCi/m^2/s or 19.1 pCi/m^2/s, depending on parameterization. Ra-226 level was 232 pCi/g (samples varied from 11-556 pCi/g)
● Tailings Pond 1 (40 ac [0.16 km^2]):
The existing cover has not been approved by the NRC and consists of 5.1 ft (1.55 m) of a previous interim (mine spoil) cover, 2.5 ft (76.2 cm) of compacted mine spoils and 2.5 ft (76.2 cm) of clean borrow material; (ML042080344; Accession Number 9802260220). Ra-226 level was 474 pCi/g

b) <u>Quality and usability of nearest aquifer – Contaminated (Low)</u>

● WDEQ stated that groundwater contamination exists primarily in the shallow alluvial aquifer; contamination extends northward at least 0.5 miles (805 m); Willow Spring is impacted by site-derived contamination; as of 2002 Willow Springs and most of the wells met the Wyoming livestock water quality standards (ML0420803440).

c) <u>Potential for increased groundwater contamination from tailings seepage- Moderate/High</u>

● The cover for Tailings Pond 1 has not been finalized or evaluated; further information is required from WDEQ-LQD.

d) <u>Other:</u>

● The cover for Tailings Pond 2 was approved by URFO, but would not meet current standards for erosion. The relatively thick cover does not have a clay layer and may become the final cover. The final plan for Tailings Pond 1 has not been submitted. In addition, there is some vegetation growing on the covers. Gas Hills West, Wyoming (ANC) went out of business in 1994 (ML0115103120) and the Wyoming Department of Environmental Quality assumed responsibility and activities at the site are currently on hold.

e) <u>Recommendations:</u>

● Current and future cover performance is difficult to ascertain without further information from WDEQ-LQD. Any final cover for Tailings Pond 1 should address potential degradation in light of the RES Benson Report.

Grants (Homestake), NM

a) <u>Potential for increased radon release – Moderate/High</u>

● Thicker cover (3 ft [0.9 m]), thinner frost protection/overburden layer, no vegetation, the staff notes that only an interim cover has been installed on the top of the tailings pile. The final cover on the top slope of tailings has not been constructed yet.
● Large Tailings Pile (LTP)
An extensive tailings coring program was undertaken to accurately characterize the Ra-226 concentrations and the moisture in the tailings down to a depth of 10 ft (3 m) in order to define

the source term. Previous measurements of the tailings emanating fraction and diffusion coefficients by Rogers and Associates were accepted for use in the final design.

● Side slopes are constructed to a 5 to 1 grade. The tailings are covered with native, locally sourced soil materials to a depth of 4-plus ft (1-plus m) compacted to a minimum 95 to 100 percent maximum dry density (MDD). This compacted native soil cover acts as a radon barrier to control and minimize radon emissions to the atmosphere from the tailings. The compacted soil cover radon barrier is then covered with a layer of D50 12 in (0.30 m) basalt riprap to minimize and control potential erosion from wind and storm water.

● The top perimeter of the LTP is graded and a berm erected to prevent storm water from flowing from the top and down the sides to minimize the potential for erosion of the side slope radon barrier layer. The storm water contained on the top of the pile by the berm is transported down the side slopes of the tailing pile through 12 in (0.30 m) diameter pipe downdrains.

● The top of the LTP currently has an interim cover. Once groundwater restoration is complete borrow materials from the North Borrow Area will used to complete the radon barrier. The borrow material will have a long-term moisture content of 15.5 percent. The top six inches of interim cover will be recompacted to 95 percent MDD (Maximum Dry Density) to serve as a base for the additional radon barrier. The additional radon barrier will consist of a 24 in (0.61 m) layer of North Borrow material compacted to 100 percent MDD followed by a 21 in (0.53 m) layer compacted to 95 percent MDD."

● Small Tailings Pile (STP)

The design for the final radon barrier has been prepared on the basis of assumed conditions at the time of pond decommissioning and using methodologies and cover materials previously approved for the large tailing pile radon barrier design.

● The radon barrier will be constructed of clay soil from the North Borrow Area. The barrier will consist of a lower layer of clay placed at 100% maximum Standard Proctor dry density, from 0.5 ft (0.15 m) thick over the southern part of the pile to 1.7 ft (0.52 m) thick over the EPI area and 3.0 ft (0.91 m) thick over the outslopes. The upper layer will be the same clay soil compacted to 95% maximum dry density and 1.5 ft (0.46 m) thick over all pile surfaces. Freeze-thaw action is expected to expand the 1.5 ft (0.46 m) top layer to 1.6 ft (0.49 m). The two-layer barrier is designed to limit radon flux to about 8.5 pCi/m^{2}s from the radon barrier on the southern part of the pile and about 20 pCi/m^{2}s from all other radon barrier surfaces.

● The Ra-226 concentration averaged 408 pCi/g for the sand tailings and 732 pCi/g for the slime tailings. The measured radon emanation coefficients are somewhat troubling in that three out of the ten measurements exceed the theoretical maximum of 0.5 with the averages higher than typical default values. (ML080030071).

b) <u>Quality and usability of nearest aquifer – Contaminated</u>

● Nearby residents are using groundwater and depth to aquifer estimated to be 25 to 50 ft (7.6 to 15 m) below ground surface, contaminants detected prior to cover system construction, need to understand groundwater remediation system.

c) <u>Potential for increased groundwater contamination from tailings seepage – Moderate</u>

● Low precipitation, high evaporation location, thicker cover, thinner overburden, not planned as a vegetative cover, shallow depth to first aquifer.

d) <u>Other:</u>

● Located near Arco Bluewater site.

e) Recommendations:

● Continue to monitor groundwater and progress of reclamation activities. The staff may need to re-evaluate final cover system design for top slope. Recommend confirmation radon flux measurements on sideslopes of final cover system.

Highland (Exxon), WY

a) Potential for increased radon release – Low.

● Thicker radon barrier (3.5 ft [1.07 m]), thinner overburden (0.5 ft [15.2 cm]), vegetated cover, measured radon flux rate of 2.52 pCi/m^2s, low precipitation, high evaporation rate location.

b) Quality and usability of nearest aquifer – Contaminated

● Contaminants detected prior to cover system installation.

c) Potential for increased groundwater contamination from tailings seepage – Low

● Low precipitation, high evaporation rate location, vegetated cover, estimated depth to first aquifer is 110 ft (33.6 m), thicker cover system. An amendment request for constituent-specific ACLs, including the establishment of a new point of compliance (POC) and POE for 11e.(2) byproduct material constituents seeping into site groundwater from ExxonMobil's reclaimed uranium mill tailings was submitted for review on May 12, 2011.

d) Other:

● Located near Cameco Smith Ranch Highland ISR facility.

e) Recommendations:

● Based on site characteristics and location, no future activities related to cover performance are recommended.

Sequoyah (Sequoyah Fuels), OK [design only]

a) Potential for increased radon release – Low

● Roughly average radon barrier thickness (2 ft [61 cm]), high overburden thickness (96 in [2.4 m]) vegetated cover

b) Quality and usability of nearest aquifer – Unknown

● Need to check design review for presence of contamination at site

c) Potential for increased groundwater contamination from tailings seepage – Low

● Composite liner system, much wetter environment, thick cover system, leak detection system, estimated depth to first aquifer is 100 ft (30.5 m).

d) Other:

- None

e) Recommendations:

- Continue oversight of reclamation process.

Shirley Basin North (Pathfinder), WY

a) Potential for increased radon release – High

- As of 2004, the proposed radon barrier was to be composed of at least 6 in (15.2 cm) of clay and 6 in (15.2 cm) of sandy soil. (Note: Tailings reclamation was scheduled to be completed by the end of 2005 – ML052270503). Pathfinder's radon flux calculation using RADON predicted a radon flux of 14.6 pCi/m^2/s. An independent analysis by the NRC calculated a flux of 18.9 and 22.9 pCi/m^2/s depending on parameterization (ML041840182). Six radon-flux test plots were evaluated to provide model support; the average radon flux was 4.9 pCi/m^2/s (ML042660065).

b) Quality and usability of nearest aquifer – Contaminated (Low)

- The aquifer of primary concern, the surficial aquifer, discharges into Spring Creek. The Wyoming Department of Environmental Quality classified Spring Creek as a Class 2C surface water (non-drinking water, known to or has potential to support non-game fish populations). The limited extent of the surficial aquifer; the unlikelihood of future foreseeable uses; and the accessibility of deeper and more productive aquifers should limit potential usage of the surficial aquifer.

c) Potential for increased groundwater contamination from tailings seepage -Moderate/High

- Depending on the final design of the cover, a 6 in (15.2 cm) clay layer might be susceptible to increased infiltration upon cover degradation.

d) Other:

- The nearest downgradient residence is located 6 miles (9.7 km) from the site. A small portion of the Shirley Basin tailings area remains open to receive, for disposal, byproduct from in-situ leach uranium projects. Once that activity has concluded, reclamation of the tailings area will be completed, and transferred to DOE.

e) Recommendations:

- Further consideration of additional radon flux testing at Shirley Basin South may be warranted due to (i) a relatively thin radon barrier, (ii) radon flux calculations that approached the regulatory limit of 20 pCi/m^2/s, (iii) the uncertainty and sensitivity of their model parameters, (iv) and a lack of documentation regarding the final construction. Additional reports (e.g., Final Completion Construction Report) that document the measured radon flux from the finished cover would be helpful.

Split Rock (Western Nuclear), WY

a) Potential for increased radon release – Moderate

- The measured and calculated radon fluxes were relatively low.
- Tailings disposal area:

The radon barrier consists of 6 – 44 in (0.15 – 1.1 m)of compacted Cody Shale clay, 8-12 in (20.3 – 30.5 cm) of borrow soil, and at least 4 in (10.2 cm) of rock mulch (WNI, April 21, 1999). The average measured radon flux after construction was 0.88 pCi/m^2/s (ML0101601870).

- Groundwater Corrective Action Program ponds:

The compacted clay layer was designed to be a minimum of 6 in (15.2 cm) with a 12 in (30.5 cm) borrow soil layer and a 4 in (10.2 cm) thick rock mulch layer (ML072840542; ML010160187). The cover is not required for radon flux requirements, but to isolate the waste from the environment; the calculated average radon emission from the sludge alone is below the regulatory 20 pCi/m^2/s at 2.37 pCi/m^2/s. WNI calculated the flux to be 1.71 pCi/m^2/s and an independent NRC estimate was 2.1 pCi/m^2/s (ML072050150).

b) Quality and usability of nearest aquifer – Contaminated (Moderate)

- There are two aquifers at the site, the flood-plain aquifer and the Split Rock aquifer. The flood-plain aquifer is located within the long-term surveillance boundary (LTSB) for which institutional controls were established to restrict domestic groundwater use (ML072840542). Contaminated groundwater from the flood-plain aquifer is discharging to the Sweetwater River, however concentrations are expected to remain insufficient to impact human health and the environment (ML072840542). The Split Rock aquifer extends beyond the LTSB and the potential exists for contamination to migrate beyond the boundary. License conditions require certain actions be taken in the event that groundwater concentrations of ACL parameters exceed the trigger values at the downstream LTSB.

c) Potential for increased groundwater contamination from tailings seepage -Low/Moderate

- Precipitation is low and the radon barrier is relatively thick, however the overburden layer is relatively thin.

d) Other:

- Runoff from the surrounding environment may result in contaminant transport times that are shorter than may otherwise be expected. As groundwater is used for drinking and livestock watering in close proximity to the LTSB and the addition of runoff to the aquifer, this site has an additional sensitivity to increased infiltration rates.

e) Recommendations:

- Continue to monitor groundwater contamination.

12.4 <u>Decommissioning Site</u>

12.4.1 General Background

The NRC's Office of Federal and State Materials and Environmental Management Programs (FSME) has project management responsibility for decommissioning complex materials facilities. Currently, 63 complex materials sites are undergoing decommissioning in the United States, as illustrated below.

Under certain conditions, the NRC enters into agreements with State governors. Those agreements authorize individual States to regulate the decommissioning of complex materials facilities within their borders. Currently, 11 of the 37 Agreement States are regulating the decommissioning of 49 complex materials sites, with technical support from the NRC's regional offices, as needed. In States that do not have agreements with the NRC, FSME and the NRC's regional offices exercise regulatory authority over the decommissioning of complex materials facilities. In addition, the NRC retains regulatory authority over decommissioning in certain portions of Agreement States that are subject to "exclusive Federal jurisdiction," including most American Indian reservations and certain areas of military bases. Currently, only one of the NRC-regulated complex materials sites in has a cover: the Cimarron (Kerr-McGee) Decommissioning Site. The ECTG has performed the following qualitative assessment.

For tables on decommissioning site, see Section 12.2.2.

12.4.2 Qualitative Assessments

Cimarron, Oklahoma (decommissioning site not yet released)

a) <u>Potential for increased radon release – None</u>

● Residual contamination in the on-site disposal cell in Area N only includes enriched uranium (2.5 to 3% uranium-235) and some thorium. Therefore, radon release as a result of decay is not expected until beyond the 1000 year compliance period. The residual contamination in the disposal cell is buried under a 4-ft (1.2 m) soil cover for the purpose of limiting intrusion and was not engineered to limit radon release or infiltration.

b) <u>Quality and usability of nearest aquifer – Usable</u>

● The underlying Garber/Wellington aquifer generally has potable water. The Garber Sandstone is the principal source of groundwater near the Cimarron Facility, but the deeper Wellington Fm is of poor quality in and around the facility because of its salinity. The shallow water table is about 20 ft (61 m) under the disposal cell.

c) <u>Potential for increased groundwater contamination – Low</u>

● The potential for groundwater contamination from the disposal cell was modeled and reviewed by NRC in 1987. The TRANSS code predicted that: 1) no measurable increase in uranium will appear in the groundwater for many thousands of years and 2) after 1,000 years, the uranium concentration in the intruder well would still be at natural background levels, even using the conservative distribution coefficient. Annual precipitation is between 27 and 30 in

(68.6 and 76.2 cm) and 4.8 in (12.2 cm) of water was assumed to infiltrate through the cell cover every year in the dose assessment. A 1999 NRC EA also modeled the site with a resident farmer scenario and the assumption of both a cover and without a cover over the disposal cell. The predicted doses for both scenarios were less than 9 mrem/yr, well below the public dose of 100 mrem/yr. The disposal cell consists of three pits with both uranium and thorium. The total activity estimated to be present is 0.98 curies of total uranium. After the contamination in each lift was compacted to 95% Proctor density the material was covered with four feet of clean fill and the top contoured to achieve a slope ranging from 1.4-2.5 %. Both the soil placed in the disposal cell and the cover material was compacted in 1 ft (30.5 cm) lifts to reasonably minimize subsidence. Although the dose assessment included analyses of different and more conservative K_d, no sensitivity analyses were preformed for the infiltration assumption.

d) Other:

- This is a decommissioning site currently under the SDMP criteria rather than the License Termination Rule. The on-site disposal cell was approved under NRC's Branch Technical Position Option 2 (30 -100 pCi/g). The license for this site has not been terminated and the licensee is in bankruptcy. The dose modeling also concluded that the 4 ft (1.2 m) clean soil cover provides shielding and would not expose any member of the public to direct radiation. The cover would also essentially eliminate the uptake of uranium by food or pasture crops.

e) Recommendations:

- None.

Appendixes

Appendix A: Characteristics of Disposal Site Covers Associated with Radon Release

Characteristics of Disposal Site Covers Associated with Radon Release

	Cover Vegetation (Yes or No)	Cover Type - Compacted soil/clay If yes, thickness (ft)	Overburden Thickness on top of compacted soil/clay (ft)	Cover Type - Drainage/bedding/ filter/capillary layer	Cover Type - Geomembrane	Year Cover Built	Waste Type/ Source Term (Curies [Ci] or volume [yd^3])	Calculated Radon Flux (pCi/m^2/s)	Measured Radon Flux at Conpletion (pCi/m2/s)	Population Type near Site (no population or rural or near urban)	Public Interest (H, M, or L)	Precipitation Rate (in/yr)	Potentail ET Rate (in/yr)	POTENTIAL for Increased Radon Release due Processes Documented in NUREG/CR-7028 (High, Moderate, or Low)	
		[1 ft = 0.305 m]	[1 ft = 0.305 m]				[1 Ci = 37000 MBq] [1 yd^3 = 0.765 m^3]	[1 pCi/m^2/s =	0.037 Bq/m2/s]			[1 in/yr =	2.54 cm/yr]		
TITLE I SITES															***TITLE I SITES***
DOE Licensed under 40.27; 40 CFR 192(A)(B)															*DOE Licensed under 40.27; 40 CFR 192(A)(B)*
NRC Staff: annual review of inspection reports; occassional site visit															*NRC Staff: annual review of inspection reports; occassional site visit*
Ambrosia Lake, NM	No (rip rap)	Yes; 2.5 ft	rip-rap 1ft on side slope; 0.5 ft on top slope	Yes; 0.5 ft	No	1995	5.3E+6 yd^3; 1,850 Ci Ra-226	< 20	NA	Rural	L	9	46.1 (Calculated, Hargreaves Model)	M/L	Ambrosia Lake, NM
Burrell, PA	No	Yes; 3 ft	1 ft rip-rap	Yes; 1 ft	No	1987	73000 yd^3; 4 Ci of Ra-226	< 20	NA	Rural	M	40	43.3 (Calculated, Hargreaves Model)	M/L	Burrell, PA
Canonsburg, PA	Yes - Some rock	Yes - clay 3 ft	rock 1.5 ft, top soil 1 ft	Yes	No	1985	100 Ci Ra-226	1.6 area A cell, 7.0 average	NA	Very near urban area	M	38	39.6	M	Canonsburg, PA
Crescent Junction, UT [design only]	No	Yes; compacted clay 4 ft	4 ft	Yes	No	Under construction	12myd^3, Average activity 565 pCi/g	<20	NA	Rural	H	8	50	M	Crescent Junction, UT [design only]
Durango, CO	Yes - Rock/soil matrix	bentonite/sand/2 geotextiles; 2 ft	4.5	Yes	Yes	1991	436 pCi/g; vol 2.53 mcy	NA	0.2	Rural	NA	15-20	>50	L	Durango, CO
Falls City, TX	Yes - Rock on sides	Yes - clay 3 ft	3.5 ft soil	Yes	No	1994	1277 Ci Ra-226	17.8 assume 3ft barrier	NA	Rural	L	30	59	M	Falls City, TX
Grand Junction, CO	No	Yes, 2 ft	5	Yes	No	1994	340 pC/g; vol 4.43 mcy	NA	0.33	Rural	NA	5-10	65	L	Grand Junction, CO
Green River, UT	No	Yes; 3 ft	1 ft rip-rap plus 0.5 ft	Yes	No	1990	30 Ci of Ra-226	need only 2.4 in.	NA	near urban	M	6	50 (estimated)	L	Green River, UT
Gunnison, CO	No	Yes; 1.5 ft	0.5 ft rip-rap plus 7 ft	Yes	No	1996	175 Ci of Ra-226	9 - 14	NA	Rural	L	11	50 (estimated)	L	Gunnison, CO
Lakeview, OR	Yes - Some rock	Yes - 18 inches	24 inches	Yes	No	1988	42 curies of radium 226	< 20	Background	Rural	M	15-25	52	M	Lakeview, OR
Lowman, ID	Yes	Yes; 1.5 ft	1 ft rip-rap plus 0.5 ft	Yes	No	1992	12 Ci of Ra-226	NA	0.18	Rural	L	20-25	37 (estimated)	L	Lowman, ID
Maybell, CO	No	Yes; 1.5 ft	0.67 ft rip-rap plus 4.5 ft	Yes	No	1997	455 Ci of Ra-226	14.7	0.26	Rural	L	13	50 (estimated)	L	Maybell, CO
Mexican Hat, UT	No	Yes, 2 ft (silty sand; 10% clay)	2 ft rip-rap plus 0.5 ft	Yes	No	1995	1800 Ci of Ra-226	>13	0.05	Rural	L	6	84	M/H	Mexican Hat, UT
Naturita, CO	No	Yes; 3 ft	2 ft rip-rap plus 6 ft	Yes	No	1997	79 Ci of Ra-226	11.8	0.2	Near urban	M	13	50 (estimated)	L	Naturita, CO
Rifle, CO	No	Yes - 18 in (6 in compacted clay 12 in bentonite amended clay)	9.5-20	Yes	No	1996	600 pC/g; vol 3.76 mcy	NA	3.4	Rural	NA	11	55	L	Rifle, CO
Salt Lake City - Clive, UT	No	Yes; 7 ft	2 ft rip-rap plus 0.5 ft	Yes	No	1989	1550 Ci of Ra-226	14	0.3	rural	L	5	>25	L	Salt Lake City - Clive, UT
Shiprock, NM	No	Yes - 6.4 ft top; 7.0 ft sides	1.5	Yes	No	1987	404 pC/g; vol 2.8 mcy	NA	NA	Very near urban area	VH	< 10	58	M	Shiprock, NM
Slick Rock, CO	No, all rock	yes, 18 in	3	Yes	No	1996	140 pC/g; vol 0.86 mcy	NA	0.1	sparce, 10 within 10mi	NA	10-15	58	L	Slick Rock, CO
Spook, WY	Yes	Yes, 18 in	35	Yes	No	1989	310 pC/g; vol 0.32 mcy	NA	NA	sparce, cattle ranches	L	10-15	50	L	Spook, WY
Tuba City, AZ	No, all rock	Yes, 42 in	1.5	Yes	No	1990	470 pC/g; vol 1.4 mcy	9.3	NA	sparce; town within 5 mi	H	5-10	70	M/H	Tuba City, AZ
TITLE II SITES															***TITLE II SITES***
DOE Licensed under 40.28; 40 CFR 192(C)(D)															*DOE Licensed under 40.28; 40 CFR 192(C)(D)*
NRC Staff: annual review of inspection reports; occassional site visit															*NRC Staff: annual review of inspection reports; occassional site visit*
Bluewater, NM - main disposal cell	No	Yes- 2.0 to 2.5 ft	4 to 12 in of riprap	No	No	1995	11,200 Curies of Ra-226	NA	2.8	rural, <5 miles from town with more than 5,000 residents	H	11	50 (estimated)	H	Bluewater, NM - main disposal cell
Bluewater, NM - carbonate tailings cell	No	Yes- 2.0 to 2.5 ft	4 to 12 in of riprap	No	No	1995	1,130 Curies of Ra-226	NA	1.3	rural, <5 miles from town with more than 5,000 residents	H	11	50 (estimated)	H	Bluewater, NM - carbonate tailings cell
Bluewater, NM - PCB disposal cell	No	Yes- 2.0 to 2.5 ft	6 in of riprap	No	No	1995	NA	NA	NA	rural, <5 miles from town with more than 5,000 residents	H	11	50 (estimated)	M	Bluewater, NM - PCB disposal cell
Edgemont, SD	Yes	Yes - 3.0 ft	72 in	No	No	1989 (decommisisoning activities completed)	527 Curies of Ra-226	17.5	unknown	rural	M	14	50 (estimated)	L	Edgemont, SD
L-Bar, NM	Yes, vegetated	Yes, 4.1 ft clay	2-6' of vegetated soil	Yes	No	2000	205 Ci Ra-226 (2.1 million tons of ore was processed, producing 700,000 yd^3 of tailings distributed over 100ac)	7.3	3.7	rural - several nearby villages	M	8-10	50 (estimated)	L	L-Bar, NM
Maybell West, CO	No	Yes; 1.5 ft	1 ft rip-rap plus 4.5 ft	Yes (.5')	No	2005	96 curies Ra-226; 1.975m tons of tailings	NA	NA	rural	L	12	50 (estimated)	L	Maybell West, CO
Sherwood, WA	Yes, vegetated	No, 12.6-20 ft of uncompacted local soil	12.6-20' uncompacted sandy soil, 6" vegetated soil	No	No	1996	2.9 million tons of tailings (equates to 2.4 million cubic yards of tailings)	0.13	0.51	limited population nearby but immediately adjacent to Spokane River	M	16-18	NA	L	Sherwood, WA
Shirley Basin South, WY	Yes, vegetated	Yes, 2' of compacted clay	2' compacted sandy soil 10" topsoil	Yes	No	2001	6.3 million tons of tailings or 4.5 million yd^3 + 14.7 million tons of acidic mill liquids	NA	1.3	Rural	M	10	50 (estimated)	L	Shirley Basin South, WY
TITLE II SITES IN CLOSURE															***TITLE II SITES IN CLOSURE***
NRC Licensees; 10 CFR 40, App. A															*NRC Licensees; 10 CFR 40, App. A*
NRC Staff: Review documentation; inspections; develop TER															*NRC Staff: Review documentation; inspections; develop TER*
Ambrosia Lake West (Rio Algom), NM	No	Yes - 1.5 ft	24 in (12 in soil, 6 in bedding, 6 in riprap)	Yes	No	started 1986	33 million tons of tailings	19.7	could not locate numbers, reclamation still in progress	rural	M	9	50 (estimated)	M	Ambrosia Lake West (Rio Algom), NM
Bear Creek (Anadarko), WY	Yes	Yes - 3 ft	12 in (min, may be more in places)	No	No	1997	860 Curies of Ra-226	8.5 (sands) 9.4 (slimes)	0.73	no population	L	12	45 (estimated)	M	Bear Creek (Anadarko), WY
Church Rock (UNC), NM	Yes	Yes - 1.5 ft	6 in	No	No	1996	3.5 million tons of tailings over 100 acre area	NA	5.7	rural, native americans living near site	H	12	50 (estimated)	H	Church Rock (UNC), NM
Gas Hills East (Umetco), WY	Rock	Yes (variable, 1-1.5 ft clay)	4.5-8.5'	Yes/No (a portion of the cover contains a bedding layer - % NA)	No	2003	~20 million tons of tailings and 465,000 tons of tailings slurry per year from late 1950s to 1979 (Umetco, 2001 - ML0200201330)	NA	1.1-6.8	No population - nearest residence is 5 miles to the northeast	M (due to recent cover issue)	9	46 (derived from nearby lake measurements)	L/M	Gas Hills East (Umetco), WY
Gas Hills North/Lucky Mc (Pathfinder), WY	Mostly No	Yes (variable, 1 -3 ft of clay)	0-0.7' soil	Yes	No	2004	12 million tons of ore were mined at this site	NA	0.8	No population - nearest residence is 4 miles to the NW and is upgradient, nearest downgradient residence is 11 miles (ML0225200650)	M	9	46 (derived from nearby lake measurements)	L	Gas Hills North/Lucky Mc (Pathfinder), WY
Gas Hills West (ANC), WY	No	No - radon barrier (not clay) 30-36"	2.5' - 3' borrow soil	No	No	1997	~1 million cubic yards of mill tailings	17 or 19.9	0.5	No population	M/H (due to state involvement)	9	46 (derived from nearby lake measurements)	M/H	Gas Hills West (ANC), WY
Grants (Homestake), NM	No	Yes - variable, 2 ft minimum	15.6 in (6 in bedding, 9.6 in rip-rap)	Yes	No	fall 1994	22 million tons of tailings	NA	close to 20, site not completely covered	rural, <5 miles from town with more than 5,000 residents	H	11	50 (estimated)	M/H	Grants (Homestake), NM
Highland (Exxon), WY	Yes	Yes - 3.5 ft	6 in	No	No	August 1989	11.3 million tons of ore processed	NA	2.52	no population	L	12	45 (estimated pan evaporation)	L	Highland (Exxon), WY
Sequoyah (Sequoyah Fuels), OK [design only]	Yes	Yes - 2.0 ft	96 in	Yes	Yes	pending	cell has design capacity of about 350,000 cubic yards	2.0 (licensee number) 5.9 (NRC number)	NA	rural	M	44	48 (estimated lake evaporation)	L	Sequoyah (Sequoyah Fuels), OK [design only]
Shirley Basin North (Pathfinder), WY	Yes	Yes - 6" of sandy soil on top of 6" of compacted clay	0.5" sandy soil (proposed in 2004)	No?	No	2004?	8.5 million tons of ore mined	14.6, 18.9 or 22.9	4.9	no population - nearest downgradient resident is 6 miles away	M	11	47 (estimated from annual lake evaporation)	H	Shirley Basin North (Pathfinder), WY
Split Rock (Western Nuclear), WY	Yes	Yes (0.5-3.7 ft)	0.7-1" soil	No	No	2000	7.7 million tons of ore were processed and a 5-to-1 ratio of effluent to tailings was placed into the impoundment	1.7 or 2.1	0.88	rural but the town of Jeffrey City is near the plume	M	10	36	M	Split Rock (Western Nuclear), WY
Decommissioning Sites not yet Released															***Decommissioning Sites not yet Released***
10 CFR 20, Subpart E															*10 CFR 20, Subpart E*
Kerr-McGee - Cimarron, OK (complex materials)	No	No	NA	No	No	2002	0.98 ci U/Th contaminated soils	NA	NA	no population	L	27-30	60	None	Kerr-McGee - Cimarron, OK (complex materials)

Appendix B: Characteristics of Disposal Site Covers Associated with Seepage from Mill Tailings

Characteristics of Disposal Site Covers Associated with Seepage from Mill Tailings	Precipitation Rate (in/yr)	Potentail ET Rate (in/yr)	Depth to Aquifer (ft)	Unsaturated Zone Hydrogeological Characterisitcs (qualitative)	Disposal Site on Processing Site (Y or N)	Quality of Dis-posal Site Groundwater (Good, Limited Use, Contaminated)	Groundwater Status Corrective Action (Y or N) Standards (NA, Background, MCLs, or ACLs/Suppl.Stnd)	Disposal Site GW Monitoring Program Ongoing (Y or N)	Groundwater Contaminants from Post-Operational Disposal Cell Detected (Y, Potentially, or N)	Existing Liner below Waste (Y or N)	Leachate Collection System (Y o N)	Intensity of Aquifer Use Nearby Use (H, M, L, or None)	POTENTIAL for Increased GW Contamination due Processes Documented in NUREG/CR-7028 (High, Moderate, or Low)	
	[1 in/yr =	2.54 cm/yr]	[1 ft = 0.305 m]											
TITLE I SITES														***TITLE I SITES***
DOE Licensed under 40.27; 40 CFR 192(A)(B)														*DOE Licensed under 40.27; 40 CFR 192(A)(B)*
NRC Staff: annual review of inspection reports; occassional site visit														*NRC Staff: annual review of inspection reports; occassional site visit*
Ambrosia Lake, NM	9	46.1 (Calculated, Hargreaves Model)	300-800ft (shallow aquifer not potable)	alluvium	Y	Contaminated, Limited Use	N	Y	N	N	N	L	L	Ambrosia Lake, NM
Burrell, PA	40	43.3 (Calculated, Hargreaves Model)	>30	alluvium	N	Contaminated, Limited Use	N	Y	N	N	N	L	L	Burrell, PA
Canonsburg, PA	40	39.6	<10	alluvium/fill	Y	Limited use/Contaminated	N, ACL for U, MCL for Mo	Y	Y	Y	N	L to None	M	Canonsburg, PA
Crescent Junction, UT [design only]	8	50	>2400 ft	alluvium/rock	N	Limited Use	N	Y	N/A	N	N	None	L	Crescent Junction, UT [design only]
Durango, CO	15-20	>50	100?	relatively imperm	N	Limited Use	N	Y	Y	Y	Y	M	L	Durango, CO
Falls City, TX	>40	59	10	alluvium	Y	Contaminated	N	Y	Y	N	N	L	M	Falls City, TX
Grand Junction, CO	10-15	>50	50?	permeable	N	Limited Use	N	Y	N	N	N	L	L	Grand Junction, CO
Green River, UT	6	50 (estimated)	60	alluvium&sandstone	Y	Contaminated	Y; ACLs	Y	N	N	N	M	L	Green River, UT
Gunnison, CO	11	50 (estimated)	100	alluvium	N	Good	N	N	N	N	N	L	L	Gunnison, CO
Lakeview, OR	15-25	52	100	sand, silt, clay	N	Good	N	Y	N	N (Clay liner along hillside under waste)	N	L	M/H	Lakeview, OR
Lowman, ID	20-25	37 (estimated)	27-78	alluvium&igneous	Y	Good	N	N	N	N	N	L	L	Lowman, ID
Maybell, CO	13	50 (estimated)	35-300	alluvium&sandstone	Y	Limited Use	N	N	N	N	N	L	L/M	Maybell, CO
Mexican Hat, UT	6	84	74?	siltstone [artesian]	Y	Limited Use	N	N	N	N	N	None	L	Mexican Hat, UT
Naturita, CO	13	50 (estimated)	600	Sandstone and Shale	N	Good	N	Y (from TER)	N	N	N	None	L	Naturita, CO
Rifle, CO	11	55	50?	relatively imperm	N	Limited Use	N	N	N	Y	Y	L	L	Rifle, CO
Salt Lake City - Clive, UT	5	>25	250?	silty sand	N	Limited Use	N	N	N	N	N	L	L	Salt Lake City - Clive, UT
Shiprock, NM	< 10	58	100?	permeable	Y	Contaminated	Y; ACL/SS	Y	N	N	N	None	L	Shiprock, NM
Slick Rock, CO	15-Oct	58	0	alluvial aquifer below	N	Limited Use	N	N	N	N	N	None, low yield	L	Slick Rock, CO
Spook, WY	15-Oct	50	? 2 ss aquifers	Sandstone	Y	Limited Use	N	N	N	Y	N	None, low yield	L	Spook, WY
Tuba City, AZ	6.5	67-80	60-75 ft	uncon sand gravel	Y	Contaminated	Y; MCLs	Y	N	N	N	L	M	Tuba City, AZ
TITLE II SITES														***TITLE II SITES***
DOE Licensed under 40.28; 40 CFR 192(C)(D)														*DOE Licensed under 40.28; 40 CFR 192(C)(D)*
NRC Staff: annual review of inspection reports; occassional site visit														*NRC Staff: annual review of inspection reports; occassional site visit*
Bluewater, NM - main disposal cell	11	50 (estimated)	25-50 ft (estimate)	unknown	Y	Contaminated	Y; ACLs	N	N	N	N	M	M	Bluewater, NM - main disposal cell
Bluewater, NM - carbonate tailings cell	11	50 (estimated)	25-50 ft (estimate)	unknown	Y	Contaminated	Y; ACLs	N	N	N	N	M	M	Bluewater, NM - carbonate tailings cell
Bluewater, NM - PCB disposal cell	11	50 (estimated)	25-50 ft (estimate)	unknown	Y	Contaminated	Y; ACLs	N	N	N	N	M	M	Bluewater, NM - PCB disposal cell
Edgemont, SD	14	50 (estimated)	300-700 ft	unknown	N (2 miles away)	unknown	N	NA	N	N	N	unknown	L	Edgemont, SD
L-Bar, NM	8-10	50 (estimated)	60-80 (estimate)	alluvium, shale, sandstone	Y	Contaminated	N	Y	N	N	N	None	L	L-Bar, NM
Maybell West, CO	12	50 (estimated)	200ft	silty sandstone	Y	Limited Use	N	N	N	Y	N	L	L	Maybell West, CO
Sherwood, WA	16-18	unknown	58 ft (at one point)	alluvium and conductive bedrock	Y	unknown	N	Y	N	Y	N	unknown	L/M	Sherwood, WA
Shirley Basin South, WY	10	50 (estimated)	60	sandstone, conglomerates,	Y	Contaminated	N	Y	N	N	N	L	M	Shirley Basin South, WY
TITLE II SITES IN CLOSURE														***TITLE II SITES IN CLOSURE***
NRC Licensees; 10 CFR 40, App. A														*NRC Licensees; 10 CFR 40, App. A*
NRC Staff: Review documentation; inspections; develop TER														*NRC Staff: Review documentation; inspections; develop TER*
Ambrosia Lake West (Rio Algom), NM	9	50 (estimated)	150 ft (estimate)	alluvium	Y	Contaminated	Y; ACLs	N	N	N	N	L	M	Ambrosia Lake West (Rio Algom), NM
Bear Creek (Anadarko), WY	12	45 (estimated)	50 ft (?)	discontinuous sand lenses	Y	Contaminated	Y; ACLs	N	N	N	N	L	L	Bear Creek (Anadarko), WY
Church Rock (UNC), NM	12	50 (estimated)	60 ft (estimate)	alluvium	Y	Contaminated	Y; MCLs	Y	N	N	N	L	M	Church Rock (UNC), NM
Gas Hills East (Umetco), WY	9	46 (derived from nearby lake measurements)	100-150	Interbedded sands, silts, and clays	Y	Contaminated	N	Y	N	N	N	L	L/M	Gas Hills East (Umetco), WY
Gas Hills North/Lucky Mc (Pathfinder), WY	9	46 (derived from nearby lake measurements)	100-150 (estimate)	Interbedded sands, silts, and clays	Y	Contaminated	N	Y	N	N	N	L	L	Gas Hills North/Lucky Mc (Pathfinder), WY
Gas Hills West (ANC), WY	9	46 (derived from nearby lake measurements)	100-150 (estimate)	alluvium and weathered bedrock	Y	Contaminated	Y; Background	Y	N	N	N	L	M/H	Gas Hills West (ANC), WY
Grants (Homestake), NM	11	50 (estimated)	25-50 ft (estimate)	unknown	Y	Contaminated	Y; ACLs	Y	N	N	N	M	M	Grants (Homestake), NM
Highland (Exxon), WY	12	45 (estimated pan evaporation)	110 ft (estimate)	discontinuous sand-stones and shales	Y	Contaminated	Y; ACLs	N	N	N	N	H	L	Highland (Exxon), WY
Sequoyah (Sequoyah Fuels), OK [design only]	44	48 (estimated lake evaporation)	100 ft (estimate)	loamy soil, terrace deposits and alluvium	Y	Unknown	Y; MCLs	Y	N	Y	Y	L	L	Sequoyah (Sequoyah Fuels), OK [design only]
Shirley Basin North (Pathfinder), WY	11	47 (estimated from annual lake evaporation)	60 ft (estimate)	interbedded claystone, siltstone, and sandstone	Y	Contaminated	N	Y	N	N	N	L	M/H	Shirley Basin North (Pathfinder), WY
Split Rock (Western Nuclear), WY	10	36	5-50	eolian deposits and alluvium	Y	Contaminated	N	Y	N	N	N	M	L/M	Split Rock (Western Nuclear), WY
Decommissioning Sites not yet Released														***Decommissioning Sites not yet Released***
10 CFR 20, Subpart E														*10 CFR 20, Subpart E*
Kerr-McGee - Cimarron, OK (complex materials)	30	60	10-30	sandstone	N	Good	N	Y	N	N	N	l	L	Kerr-McGee - Cimarron, OK (complex materials)

Appendix C: Recommendations from the RES Benson Report

Recommendations from the RES Benson Report

Report Recommendation 1:

a) The saturated hydraulic conductivity of fine-textured earthen storage and barrier layers can be assumed to range between $1x10^{-7}$ m/s and $5x10^{-6}$ m/s. This relatively narrow range of saturated hydraulic conductivities was obtained from a very broad range of as-built saturated hydraulic conductivities, which suggests that the saturated hydraulic conductivity reached an equilibrium condition during the study. Moreover, given that storage and barrier layers are constructed with fine-textured soils, saturated hydraulic conductivities much higher than $5x10^{-6}$ m/s are unlikely unless a fundamental change in texture or mineralogy occurs during the service life of the cover. Typical conditions can be predicted using a saturated hydraulic conductivity of $5x10^{-7}$ m/s. However, sensitivity analyses should be conducted using the aforementioned upper and lower bounds to assess the range of performance that may be encountered.
b) Designers should acknowledge that these changes in properties will occur, e.g., saturated hydraulic conductivity of increasing to a range between $1x10^{-7}$ m/s and $5x10^{-6}$ m/s) and select materials and placement conditions that result in earthen barrier and storage layers that have as-built saturated hydraulic conductivities within this range.

ECTG: Current research indicates this may be sensible and help minimize efforts and expenses at some point in the future. However, due to the differences between the many of the mill tailings sites and the sites studied in the Report, this recommendation should be put on hold until further research results are evaluated.

Report Recommendation 2:

When practical, earthen storage and barrier layers should be constructed using fine-textured soils containing a broad range of particles (coarse and fine) with a modest amount of clay-size particles. Soils classifying as SC, SM, ML, and SC-CL in the Unified Soil Classification System (USCS) are likely to be more resistant to changes in hydraulic properties over time compared to soils classifying as CL, CH, CL-CH, or CL-ML. Compaction water content is less important, and compaction near optimum water content is recommended.
ECTG: Current research indicates this may be sensible and help minimize efforts and expenses at some point in the future. However, due to the differences between the many of the mill tailings sites and the sites studied in the Report, this recommendation should be put on hold until further research results are evaluated.

Report Recommendation 3:

GCLs should be covered with a geomembrane and placed on a subgrade having an initial water content exceeding 10% and total cation charge per mass (TCM) less than 0.8 cmol+/kg. Under these conditions, the bentonite will undergo osmotic swell and retain low saturated hydraulic conductivity (< $5x10^{-11}$ m/s) even if divalent cations replace the native Na. GCLs not covered by a geomembrane or placed on drier subgrades have the potential to become much more permeable, with saturated hydraulic conductivities on the order of 10^{-8} to 10^{-6} m/s.
ECTG: Agrees with recommendation.

Report Recommendation 4:

Periodic inspection and replacement of geosynthetics may be necessary once the service-life timeframe have been reached.
ECTG: Agrees with recommendation.

Report Recommendation 5:

The saturated hydraulic conductivity of fine-textured earthen storage and barrier layers can be assumed to range between $1x10^{-7}$ m/s and $5x10^{-6}$ m/s. This relatively narrow range of saturated hydraulic conductivities was obtained from a very broad range of as-built saturated hydraulic conductivities, which suggests that the saturated hydraulic conductivity reached an equilibrium condition during the study. Moreover, given that storage and barrier layers are constructed with fine-textured soils, saturated hydraulic conductivities much higher than $5x10^{-6}$ m/s are unlikely unless a fundamental change in texture or mineralogy occurs during the service life of the cover. Typical conditions can be predicted using a saturated hydraulic conductivity of $5x10^{-7}$ m/s. However, sensitivity analyses should be conducted using the aforementioned upper and lower bounds to assess the range of performance that may be encountered.
ECTG: Due to the differences between the many of the mill tailings sites and the sites studied in the Report, this recommendation should be put on hold until further research results are evaluated.

Report Recommendation 6:

The permittivity and transmissivity of geosynthetic drainage layers can be assumed to be 6 times lower than the minimum average role value (MARV) after approximately one decade of service. The rate of reduction for longer times remains unknown. A linear reduction in permittivity and transmissivity over time should be conservative, given that natural filter layers will develop and provide greater protection of the drainage layer over time.
ECTG: Due to the differences between the many of the mill tailings sites and the sites studied in the Report, this recommendation should be put on hold until further research results are evaluated.

Report Recommendation 7:

The tensile strength of geomembranes can be assumed to decrease by a factor of 1.5 over the first decade. Given that installation damage contributes to the initial reduction in tensile strength, a similar rate of reduction in tensile strength over the lifespan of the geomembrane should be very conservative.
ECTG: Agrees with recommendation

Report Recommendation 8:

a) Given the important role that a final cover plays in long-term isolation of wastes and the changes in engineering properties that have been observed in cover materials, direct performance monitoring of final covers is prudent for facilities containing long-lived wastes (e.g., LLW, mine wastes, etc.). At a minimum, at least one pan lysimeter having a minimum dimension of 10 m should be installed for performance monitoring.
b) The lysimeter should be supplemented with other performance and interpretive monitoring devices when practical. Spatial variability in flux can be evaluated by installing a distributed network of flux meters in the cover to assess the impact of

microclimates induced by slopes oriented in different directions and top deck vs. slope. A flux meter can also be installed within or adjacent to the lysimeter to ascertain the bias between the percolation measurements made with both devices, thereby permitting assessment of data from flux meters in the context of data from large-scale lysimeters.

c) Sensors should also be installed to collect direct interpretive data, most importantly water content and temperature. At least one nest of sensors should be installed within the periphery of the lysimeter. A wide range of sensors can be used to sense water content and temperature. Robust sensors that require little or no maintenance should be selected, and site-specific calibrations should be performed. Because sensor technology is changing rapidly, specific sensors were not recommended in this report.

ECTG: Agrees with recommendation.

Report Recommendation 9:

Periodic vegetation and reconnaissance surveys should also be conducted, particularly for store-and-release covers that rely strongly on vegetation to manage the water balance. Vegetation surveys should evaluate the relative distribution of plant species on the cover as well as the percent coverage to ensure that a diverse and desirable plant community has been established and that succession towards a complex plant community is occurring. Surveys conducted in undistributed reference areas can be used as natural analogs to assess whether the plant community is on a trajectory commensurate with surrounding ecological conditions.
ECTG: Agrees with recommendation.

Report Recommendation 10:

Additional research investments are needed to more accurately and completely define these very long-term properties of earthen and geosynthetic cover materials. These research activities should include analog studies of natural environments where earthen and natural polymeric materials exist as well as accelerated laboratory experiments that can be used to develop predictive degradation models. Research investments are also needed in remote monitoring methods that will permit long-term and low-cost reconnaissance from remote locations. These technologies likely would employ surface and airborne remote sensing methods to scan the condition of the cover non-intrusively. While some of these technologies exist today, they have not been coupled to cover performance. Research investments should explore appropriate remote sensing technologies and to develop relationships between remotely sensed information and direct performance data for final covers.
ECTG: Agrees with recommendation.

Appendix D: Questions and Answers

Questions and Answers
[as of December 11, 2010]

The Office of Nuclear Regulatory Research (RES) has completed the research project, “Effectiveness of Engineered Covers: From Modeling to Performance Monitoring,” conducted by the University of Wisconsin under a NRC contract with the US Geological Survey. A draft report, "Engineered Covers for Waste Containment: Changes in Engineering Properties & Implications for Long-Term Performance Assessment," on the project (hereafter referred to as the Report) has been submitted to the NRC. The research project involved assessments of the performance of engineered soil/composite cover materials with regard to changes in the engineered properties of cover soils/composites over a period of approximately 10 years after construction. An important conclusion of the Report is that compacted soil materials used in cover materials do not retain “as built” properties over the period of regulatory interest as assumed in most performance assessments. Within 5 to about 10 years after installation, the properties of these materials change to property values typical of surrounding soils. For some properties the change may be several orders of magnitude. The performance of geosynthetic materials, sometimes used in conjunction with the soil materials in the cover, is also addressed in the RES Benson report. Their short-term performance (up to about 10 years) and conditions under which these materials may perform satisfactorily are documented.

Currently, there is no monitoring data indicating that NRC regulated facilities with engineered covers are a threat to public health and safety or do not meet regulatory criteria based on the findings and degradation processes discussed in the Report. NRC staff is aware that the engineered surface cover may be only one component of the entire disposal system, i.e., other components besides the engineered surface cover are being relied upon to isolate the waste and minimize contaminate release. However, for some disposal facilities, engineered surface covers are significant to performance. Although there are some differences in design and construction between the covers exhumed in the Report and engineered surface covers at NRC regulated sites, the Report clearly shows that if some engineered soil barriers are exposed to the natural environment, the properties of the engineered soil may change. Based on this increased uncertainty, NRC staff needs to be reasonably reassured that the degradation processes at NRC regulated disposal sites will not led to releases of contaminants that would endanger public health and safety. ECTG evaluated available information for each site, compared the specific results of the Report to the specific condition of the existing sites, and is considered future actions to obtain data for selected sites. The results of these efforts are contained in this Report.

[1]
Q: Why was research on the performance and effectiveness of covers conducted by RES?

A: In the mid 1990’s EPA funded the Alternate Cover Assessment Program (ACAP) to compare evapotranspiration cover systems, where the soil and plants absorb moisture from precipitation, store it in the plant and soil structure, with conventional covers that exclude water from an underlying waste mass by the use of low permeability clay soils in the cover. Measurements from the conventional cover systems indicated that infiltration of water through those covers exceeded that assumed in the design of the covers. Results from the research were reported in the technical journals.

In FY 2006 RES contracted the USGS to investigate the reasons for the increased infiltration. The research involved exhuming the constructed covers and conducting field and laboratory testing to determine field properties of the cover materials and whether there were changes in these properties from the as built conditions. The low permeability of the clay soils (less than 10^{-7} cm/sec) can be important in mitigating gaseous releases (e.g. radon) and blocking infiltration of water through the cover.

[2]
Q: What are the major findings from the research that was conducted and as stated in the Report?

A: An important conclusion of the Report is that compacted cover soils examined in this Report do not retain “as built” properties over the period of regulatory interest as assumed in most performance assessments. The Report has demonstrated that the saturated hydraulic conductivities of engineered barriers at each site investigated have increased from that of the original as-built conditions. These increases are variable in magnitude due to differences in (i) compaction conditions, (ii) soil composition, (iii) climate, and (iv) service life. The more compact the soils, the greater the potential increase in saturated hydraulic conductivity. The field permeability properties of the clay soils change over time, increasing by three to four orders of magnitude within the cover study period. The increases in the saturated hydraulic conductivity of the soils are attributed to changes in the soil structure due to the reestablishment of structural features between soil clods, root penetration, desiccation cracking from wet-dry cycles and processes involving freezing and thawing. For nearly all sites, saturated volumetric water content and porosity increased while dry unit weight decreased due to formation of soil structure. The results of the Report suggest that changes in the soil structure consisted primarily of the formation of large pores without altering the distribution of smaller pores. The performance of geosynthetic materials, sometimes used in conjunction with the soil materials in the cover, is also addressed in the Report. Their short-term performance (up to about 10 years), and conditions under which these materials may perform satisfactorily, are noted in the Report.

[3]
Q: Based on the research findings, will existing nuclear waste facilities be able to meet regulatory criteria on gaseous (e.g. radon) and surface/groundwater release of radionuclides?

A: Currently, there is no monitoring data indicating that these facilities are a threat to public health and safety or do not meet regulatory criteria based on the findings and degradation processes discussed in the Report. In general, a monitoring program is recommended that is based on confirming main assumptions and performance. This could include periodic radon flux measurements, direct or indirect sampling or monitoring of additional seepage from the tailings, and confirming groundwater and vadose water quality.

[4]
Q: What are the implications of the research findings for the performance and effectiveness of existing waste covers?

A: NRC staff is aware that the engineered surface cover may only be one component of the entire disposal system, i.e., other components besides the surface cover are being relied upon to isolate the waste and minimize contaminant release. However, for some disposal facilities,

engineered surface covers are significant to performance. Although there are differences in design between the covers exhumed in the Report and engineered surface covers at NRC regulated sites (see no. 3), the Report clearly shows that engineered barriers exposed to the natural environment will be stressed and properties may change. Based on this increased uncertainty, NRC staff needs to be reasonably reassured that the degradation processes at NRC regulated disposal sites will not led to releases of contaminants that would endanger public health and safety. ECTG evaluated available information for each site, compared the specific results of the Report to the specific condition of the existing sites, and is considered future actions to obtain data for selected sites. The results of these efforts are contained in this Report.

[5]
Q: Does this report suggest that there are significant health and safety impacts to people living near sites that currently have these covers? Will groundwater be contaminated near these sites?

A: No. This report summarizes the observed field conditions and provides recommendations for long-term performance. It is possible that radon emissions may increase and infiltration of water through the cover system may increase if the covers do degrade as suggested and are left unattended. However, typically there are numerous features at each site that contribute to protection of health and safety, with the cover being one of these features within the total barrier system. Currently, there are no indications that NRC regulated facilities do not meet regulatory criteria. In general, a monitoring program is recommended that is based on confirming main assumptions and performance. This could include periodic radon flux measurements, direct or indirect sampling or monitoring of additional seepage from the tailings, and confirming groundwater and vadose water quality.

[6]
Q: What steps need to be taken if information suggests that regulatory criteria are not met?

A: NRC staff obtains and reviews the relevant data to determine if regulatory criteria are being met, in addition to physically inspecting the engineered barriers of the disposal sites. Based on the results of NRC's staff evaluation, mitigating actions may be considered as will potential revisions to existing regulatory guidance. If it is determined that there are impacts on public health and safety, the licensee will be required to undertake activities to meet the regulatory criteria. The activities will depend on the immediacy of the dangers and the type and scale of the problem.

[7]
Q: What is NRC doing to ensure health and safety is protected? What are some of the future actions that will be taken by NRC in their regulation of nuclear waste facilities that employ covers to isolate waste, in the light of the findings from the report?

A:
a. NRC has established a joint FSME/RES Engineered Cover Technical Group (ECTG) to identify and prioritize by risk those existing and future NRC regulated sites that may be impacted by the findings from the Report and determine if sites need additional monitoring.
b. Increased information from these sites will be obtained in addition to discussions with the licensees, particularly DOE-EM/LM, with regard to ongoing and past radon testing, groundwater monitoring activities, and maintenance and repair. NRC plans to continue exchanging

information on cover performance with DOE, EPA, and others involved with covers to further understand the potential for degradation, the design and monitoring options, and methods for measuring for various contaminant concentrations and release rates.

c. Findings will be communicated to Agreement States regulating disposal sites with covers. The NRC staff will communicate findings to NRC licensees and stakeholders for these licensees. The public has access to the results through NRC's web site.

d. A workshop organized by DOE was conducted in February 2010. NRC conducted a public Workshop in August 2010 with DOE, EPA, and others. Experts exchanged information and discuss cover performance at nuclear waste facilities. A summary of recommendations and insights from workshop participants can be found at NRC Public Website: http://www.nrc.gov/public-involve/public-meetings/index.cfm?fuseaction=Search.Detail&MC=20100473&NS=0&CFID=500619&CFTOKEN=80528178.

e. Based on the results of NRC's staff evaluation, mitigating actions may be considered at specific sites as will potential revisions to existing regulatory guidance.

f. NRC staff revised its decommissioning guidance in NUREG-1757 due to the findings of published studies similar to the findings of the Report.

g. NRC staff is currently revising NUREG-1620 on reviewing reclamation plans for mill tailings sites under Title II of the Uranium Mill Tailings Radiation Control Act of 1978.

[8]

Q: Doesn't this prove that near surface disposal of these materials can never be proven to be safe?

A: No. This report indicates that NRC staff may need to change our approach to design and regulatory approval of near surface disposal systems. Regulatory criteria may need to be updated and adjusted to accommodate new information and new technology. However, although NRC staff is reevaluating the sites and their covers, there are currently no indications that these facilities do not meet regulatory criteria based on the findings and degradation processes discussed in the Report. In general, a monitoring program is recommended that is based on confirming main assumptions and performance. This could include periodic radon flux measurements, direct or indirect sampling or monitoring of additional seepage from the tailings, and confirming groundwater and vadose water quality.

[9]

Q: What steps are planned to address the issues cited in this report?

A: Many Federal and State agencies are aware of the issues and processes discussed in the Report. Many are actively engaged in plans to better monitor performance and design better covers. For example, at some sites, evapotranspiration covers use the increased water infiltration through the top portion of a cover to sustain vegetation and remove that water from the system through plant transpiration.

[10]

Q: Why has it taken so long for NRC to act on this information?

A: NRC staff has acted on published information:

i.) In FY 2006 RES contracted the USGS to investigate the reasons for the increased infiltration as reported in publications.

ii.) Previous studies of soil cover performance indicated the potential for degradation of compacted soil covers that were designed to limit the infiltration of water into disposal cells.

This information was documented and captured in NRC's decommissioning regulatory guidance NUREG-1757 in 2006.
iii.) The "Workshop on Engineered Barrier Performance" was planned before the findings of the draft Report were circulated and in response to the previous studies of soil cover performance.

[11]
Q: How long will resolution of these issues take?

A: It is an on-going, iterative process and will take years. However, NRC staff obtains and reviews data to determine if regulatory criteria are being met, as well as physically inspects the engineered barriers of the disposal sites. In addition, DOE Legacy Management will be managing and maintaining surveillance of their sites in perpetuity.

[12]
Q: What are the research findings on the performance of geosynthetic materials?

A: Drainage layers generally performed well for the short term period of the Alternative Cover Assessment Program (ACAP) research program (about ten years). The properties of geosynthetic clay liners changed similar to clay soils in some conditions but performed well when underlain by a wet foundation and overlain by an impermeable geosynthetic membrane. Based on antioxidant depletion rates, the minimum life span of geomembranes ranged between 55 and 125 years, close to manufacturer specifications for the product.

[13]
Q: What are important implications for NRC regulated sites?

A:
i.) This Report has important implications for existing sites where NRC has regulatory authority and where covers have already been constructed. Most of these sites are uranium mill tailings sites owned and maintained by DOE/LM under an NRC general license for long-term surveillance and maintenance.
ii.) In general, a monitoring program is recommended that is based on confirming main assumptions and performance. This could include periodic radon flux measurements, direct or indirect sampling or monitoring of additional seepage from the tailings, and confirming groundwater and vadose water quality.
iii.) Most of the existing surface covers over mill tailings have a radon barrier designed to have low permeability to decrease the atmospheric release of radon and decrease the amount of precipitation contacting the buried waste. However, disposal facilities are not identical. Each waste cell location has its own individual climate and particular waste characteristics. Due to other assumed conservatisms with which the mill tailings covers were designed (e.g., many of the design calculations were made assuming a moisture content equivalent to the wilting point), their performance may be within the range of conservatism for which the cover was designed, or compensated for by additional barriers.
iv.) Due to the variability of engineered barrier types, only several sites studied in the Report (Albany, Apple Valley, Cedar Rapids, and Underwood) are closely related to Title I and Title II Uranium mill tailing sites. Most of the other covers exhumed did not have a compacted clay layer and relied instead on evapotranspiration as the main mechanism for keeping water away from the waste. Caution must therefore be exercised in drawing conclusions about sites that are beyond the scope of the Report's sampled barrier population.

v.) Active and growing root systems played a major role in increasing the saturated hydraulic conductivity of the surface cover soils. All of the surface covers exhumed for the Report had vegetation growing on the surface. Almost all of the existing sites where NRC has regulatory authority try to prevent vegetation from growing on the surface and most are covered with rip-rap (layers of rocks).
vi.) Freeze-thaw cycles were identified as one of the possible causes of increased saturated hydraulic conductivity and decreasing dry bulk density. Many of the existing sites where NRC has regulatory authority have a frost protection layer to prevent such an occurrence.
vii.) No relationship was established between the rate of degradation (increasing saturated hydraulic conductivity) within the compacted clay soil and the depth of the clay layer below surface (or the thickness of the overburden). Sufficient depth below grade, i.e., the overburden thickness, may limit the rate of material property change.
Desiccation cracking due to wet-dry cycles has been identified as a possible cause of increased saturated hydraulic conductivity. As previously mentioned, all covers examined for the Report were vegetated. Most uranium mill tailings covers are not, and transpiration does not generally take place, making it more difficult to dry out the cover soil exclusively through evaporation. Therefore, some processes associated with vegetation could cause additional infiltration into the top of the cover.
viii.) The change in cover properties documented in the Report occurred between a time period of 3.8 and 8.9 years and does not document degradation processes or performance over the long-term (greater than 100 years). However, the Report noted that short-term results such as increasing hydraulic conductivity caused by wet-dry and freeze-thaw cycles happened after the initial cycle(s) and the rate of change slowed with increasing cycles. Degradation processes appear to slow exponentially.
ix.) Previous studies of soil cover performance indicated the potential for degradation of compacted soil covers that were designed to limit the infiltration of water into disposal cells. This information is documented in NRC's decommissioning regulatory guidance NUREG-1757 along with the need for analyses of degradation processes and their affects on performance/compliance.

[14]
Q: What should disposal sites currently nearing license termination do to build confidence towards the termination process?

A: These sites could provide NRC staff with information and data within their possession to help maintain confidence in cover performance. Existing licensees could read the report, become familiar with its findings, and juxtapose the findings of the Report with cover construction and monitoring of their disposal facility.

[15]
Q: NRC has approved the cover design for the relocation of the Moab tailings pile to Crescent Junction. What could DOE be doing to build confidence in the cover design?

A: DOE should read the Benson report, understand the findings, and consider the impact of the findings on the current Crescent Junction cover design and characteristics of the site. In light of the findings in the Report, DOE should determine if additional monitoring or an instrumented cover test pad is needed to obtained site specific information related to cover performance.

[16]
Q: What design changes (if any) need to be instituted for regulated waste disposal facilities with covers of facilities that are under construction or soon to be constructed to ensure that regulatory criteria for each federal agency is met?

A: Typically, there are specific, unique features at each site that contribute to protection of health and safety, with the cover being one of these features. A generic recommendation appropriate and beneficial for all sites may be difficult to develop. However, NRC staff is interested in an increase in the quantity and quality of data from the engineered covers. Greater monitoring abilities and better understanding of the processes within the cover will increase confidence in the expected performance. Future covers could be designed to accommodate monitoring systems to better quantify internal and surface runoff, radon emissions, evapotranspiration, and infiltration into the cover and to increase the accuracy of the water budget.

[17]
Q: NRC's regulations require a onetime look at the adequacy of cover design. Isn't NRC in conflict with its own policy by pursuing these studies? Isn't this a backfit?

A: New regulatory criteria may need to be updated and adjusted to accommodate new information and new technology. Current 10 CFR Part 40 regulations are tied to EPA's 40 CFR Part 192 standards that are design based and currently are being revised by EPA. At present, NRC staff is looking at the adequacy of cover performance for any potential public health and safety concerns. However, as previously stated, there are currently no indications that these facilities do not meet regulatory criteria based on the findings and degradation processes discussed in the Report.

[18]
Q: Engineered surface covers are being planned for those disposal sites with waste-incidental-to-reprocessing (WIR). Will the design of these covers be affected by the findings of this Report?

A: The findings from this Report show that the performance of composite material, especially a geosynthetic clay liner when underlain by a wet foundation over a geomembrane, had not degraded. Most of the proposed WIR sites have cover designs with multiple composite layers and drainage layers. Composite layers and drainage layers were not impacted during the relatively short service life of those engineered surface covers exhumed and examined to obtain the findings of the Report.