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December 10, 2004 HAND DELIVERED

Mr. Steve Tarlton
Hazardous Materials and Waste Management Division
Colorado Department of Public Health and Environment
4300 Cherry Creek Drive South
Denver, CO 80246

Subject: Technical Assessment, Waste Containment and Leak Detection Systems for Cotter Corporation Primary and Secondary Impoundments, Canon City, Colorado

Dear Mr. Tarlton:

Sentinel Consulting Services, LLC (Sentinel) is pleased to provide the following assessment to the Colorado Department of Public Health and Environment (CDPHE) regarding the regulatory conformance and technical viability of the existing waste containment and leak detection systems for the primary and secondary tailings impoundments at the Cotter Corporation (Cotter) facility near Canon City, Colorado. This assessment was conducted in accordance with the scope of work identified in the signed Consultant Agreement between Sentinel and the State of Colorado (Agreement Routing No. FEA-05-00018; Project No. HMWMD-CP-01; October 22, 2004).

1.0 INTRODUCTION

The assessment provided herein has been developed based upon our review of relevant sections of existing project records provided by CDPHE. The documents reviewed by Sentinel include:

(1) *Site and Laboratory Investigation and Definitive Design Report, Cotter Corporation Uranium-Vanadium Tailings Impoundment*, W.A. Wahler & Associates, February 1978.

(2) *First Stage Construction Report, Uranium-Vanadium Tailings Impoundment*, W.A. Wahler & Associates, July 1980.

(3) *Rules and Regulation Pertaining to Solid and Hazardous Wastes, Part 2, Requirements for Siting of Hazardous Waste Disposal Sites*, State of Colorado, applicable to any facility operated after July 1, 1981.

(4) Guidance documents for Uranium Mill Tailings impoundments prepared for DOE and/or NRC, dated 1981, 1983, 1984, and 1986.

(5) *Remedial Investigation, Cotter Corporation Uranium Mill Site*, GeoTrans et al., February 1986.

(6) *Assessment of Potential Seepage Impacts on Groundwater, Cotter Uranium Mill*, Daniel B. Stevens & Associates (3 Volumes):

- **a.** *Volume I – DRAFT Summary of Existing Hydrogeological Data*, January 30, 1993.
- **b.** *Volume II – Performance Assessment of Main and Secondary Impoundments*, March 17, 1993.
- **c.** *Volume III – Evaluation of Long-Term Impacts on Lincoln Park Groundwater Quality*, March 17, 1993.

(7) *Clay Liner Impact Evaluation, Primary Impoundment, Canon City Mill*, Volumes I and II, GEOCHEM Division, Terra Vac, January 17, 1994.

(8) *Technical Review of Clay Liner Impact Evaluation, Primary Impoundment, Canon City Mill*, Daniel B. Stevens & Associates, March 30, 1994.

(9) Canon City Milling Facility, *Total Quality Environmental Management (TQEM) Project Summary Report* (2 Volumes):

- **a.** *Volume 1: Overview*, November 1995.
- **b.** *Volume 2: Details*, November 1995.

(10) *6 CCR 1007-1, Part 18 (RH 18), Licensing Requirements for Uranium and Thorium Processing*, State of Colorado, November 30, 2001.

(11) *Standard Review Plan for the Review of a Reclamation Plan for Mill Tailings Site Under Title II of the Uranium Mill Tailings Radiation Control Act of 1978*, NRC, June 2003, NRC.

(12) *Site Liquids and Solid Materials Management Plan*, Cotter Corporation License No. 369-01 Renewal Application 2003.

(13) *2004 Update of the Mill Decommissioning and Tailings Reclamation Plan for the Cotter Corporation Canon City Mill Facility*, MFG, Inc., September 2004.

(14) *CDPHE Interoffice Communication, Draft Cotter Impoundment Evaluation*, from Larry Bruskin to Phil Egidi and Steve Tarlton, October 15, 2004.

(15) *Cotter Corporation Environmental Report*, Cotter Corporation, April 24, 1996.

In addition, the following documents were consulted to support our assessment:

(16) *Quality Assurance and Quality Control for Waste Containment Facilities*, U.S. EPA Technical Guidance Document EPA/600/R-93/182, September 1993.

(17) Benson, C.H., Daniel, D.E., and Boutwell, G.P. (1999), Field Performance of Compacted Clay Liners. *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, 125(5), 390-403.

(18) Benson, C.H. and Boutwell, G.P. (1992), Compaction Control and Scale-Dependent Hydraulic Conductivity of Clay Liners, *Proceedings of the 15th International Madison Waste Conference*, Madison, WI, September 23-24, 62-83.

(19) Benson, C.H. and Boutwell, G.P. (2000), Compaction Conditions and Scale-Dependent Hydraulic Conductivity of Compacted Clay Liners, *Constructing and Controlling Compaction of Earth Fills*, STP 1384, ASTM.

(20) Benson, C.H. (2000), Liners and Covers for Waste Containment, *Proceedings, Creation of a New Geo-Environment*, Fourth Kansai International Geotechnical Forum, Japanese Geotechnical Society, Kyoto, Japan, 1-40.

(21) Benson, C.H., and Daniel, D.E. (1990), Influence of Clods on Hydraulic Conductivity of Compacted Clay, *Journal of Geotechnical Engineering*, ASCE, 116(8), 1231-1248.

(22) Shackelford, C.D. and Javed, F. (1991), Large Scale Laboratory Permeability Testing of a Compacted Clay Soil, *Geotechnical Testing Journal*, ASTM, 14(2), 171-179.

(23) Day, S.R. and Daniel, D.E. (1985). Hydraulic Conductivity of Two Prototype Clay Liners, *Journal of Geotechnical Engineering*, ASCE, 111(8).

(24) Benson, C.H. and Daniel, D.E. (1994), Minimum Thickness of Compacted Soil Liners: II. Analysis and Case Histories, *Journal of Geotechnical Engineering*, ASCE, 120(1), 153-172.

(25) Shackelford, C.D. (1994), Waste-Soil Interactions That Alter Hydraulic Conductivity, *ASTM STP 1142*, *Hydraulic Conductivity and Waste Contaminant Transport in Soil*, D.E. Daniel and S.J. Trautwein, Eds., 111-168.

All of the documents listed above are cited by number within the text, where appropriate.

Due to the limited time available for our review and the number and size of the documents required for review as part of this assessment, it is possible that we have overlooked some key information in the documents. In addition, it is possible that relevant documents other than those reviewed by Sentinel (see above) may contain information that would influence the outcome of this assessment. Sentinel reserves the right to modify the opinions stated herein upon identification of such information. Our review of the documentation listed above and our subsequent assessment of the waste containment and leak detection system was focused on the geotechnical and hydrologic aspects of the primary and secondary impoundment tailings containment system performance as designed and/or constructed, to the extent possible based on the documentation provided. No independent geotechnical, hydrologic, or contaminant transport calculations or modeling were performed as part of this scope of work. A detailed review of existing information related to geotechnical stability of the tailings and fate and transport of contaminants (including geochemical analysis) also was not performed.

2.0 TECHNICAL ASSESSMENT

As stated above, Sentinel's review was focused on the geotechnical and hydrologic performance of the containment system and leak detection system for primary and secondary impoundments. As such, we have divided our assessment into five sections that address the following critical aspects of a containment system:

1. Siting and Site Characterization
2. Impoundment Lining System
3. Impoundment Leak Detection System
4. Impoundment Cover System
5. Overall Impoundment Performance
6. Site Operations

The documentation reviewed for each of the six aspects listed above was evaluated in relation to the applicable Part 18 criteria ***(10)***. These criteria are summarized in each relevant section. Our conclusions and recommendations are presented at the end of this letter report.

Sentinel recognizes that the design and construction of the primary and secondary impoundments was done in the late 1970's prior to promulgation of the Part 18 regulations and that the state of practice for waste containment design and construction was in it's infancy stage at that time. The impoundments do appear to be designed and constructed to, or even beyond, the state of practice for that time period and Sentinel commends Cotter for doing this. However, technical research, product development, and forensic studies of failed containment systems have led to numerous new technologies and practices being developed over the last 25 years. Sentinel's comments, conclusions, and recommendations presented below have generally been developed using the current state of practice for the design and construction of waste containment systems.

2.1 Siting and Site Characterization

Criterion 1 of Part 18 regulations ***(10)*** describes the various aspects to be considered when siting a tailings disposal facility. The broad objective in siting and design decisions is permanent isolation of tailings and associated contaminants, with specific consideration of (a) remoteness from populated areas; (b) hydrologic and other natural conditions as they contribute to continued immobilization and isolation of contaminants from groundwater sources, and (c) potential for minimizing erosion, disturbance, and dispersion by natural forces over the long term.

Criterion 5G(2) ***(10)*** states that, in support of a tailings disposal system proposal, the applicant/operator shall supply information concerning the characteristics of the underlying soil and geologic formations particularly as they will control transport of contaminants and solutions. Such information includes details regarding the extent, thickness, uniformity, shape, and orientation of underlying strata. Hydraulic gradients and conductivities of the various formations must be determined. Information must be gathered from borings and field survey methods taken within the proposed impoundment area and in surrounding areas where contaminants might migrate to groundwater. Borehole information must include geological and geophysical logs in sufficient number and degree of sophistication to allow determination of significant discontinuities, fractures, and channeled deposits of high hydraulic conductivity.

A substantial amount of information related to siting criteria and site characterization is available for the Cotter facility. The overall geology and hydrogeology underlying the Cotter facility appear to be relatively well characterized. However, the hydrogeology immediately beneath the impoundments is not as well characterized. For example, the site investigation and design report ***(1)*** acknowledged that the hydrogeology beneath the impoundments was very complex and difficult to fully understand. Groundwater flow beneath the impoundments is characterized by both alluvial saturated flow and unsaturated flow through bedrock. Numerous springs and bedrock fractures were encountered during the impoundment construction. Drawing B-2 of the First Stage Construction Report ***(2)*** indicates that approximately 90 percent of the impoundments are underlain by highly permeable/fractured conglomerate and sandstone, suggesting that pathways may exist for any seepage from the impoundments to migrate to alluvial and deeper bedrock aquifers. According to the First Stage Construction Report ***(2)***, Cotter installed "subdrains" to collect spring flow encountered beneath the impoundments and grouted any fractures encountered. The likelihood that all bedrock fractures were identified during construction is unknown. More importantly, based on the drawings provided in ***(2)***, the subdrain system does not appear to be sufficient to collect all seepage that may be released from the impoundments (as discussed further in Section 2.3 of this document).

2.2 Lining System

As stipulated by Part 18 Criterion 5A ***(10)***, surface impoundments shall have a liner that is designed, constructed, and installed to prevent any migration of wastes out of the impoundment to the adjacent subsurface soil, groundwater, or surface water at any time during the active life (including the closure period) of the impoundment. Exemptions from this requirement can be obtained based on sufficient demonstration that an alternative design together with site characteristics will prevent the migration of any hazardous constituents into groundwater or surface water at any future time.

Based on data in the Definitive Design Report ***(1)***, Remedial Investigation ***(5)***, First Stage Construction Report ***(2)***, and the Clay Liner Impact Evaluation ***(7)***, Sentinel provides the following observations on the impoundment lining system:

2.2.1 Clay Subliner

Material and Compaction Properties

The clay material in the borrow area utilized for the subliner appears to contain a high silt content in the fines fraction (i.e., passing the #200 [0.074 mm] sieve) as indicated by plasticity index (PI) values for eight samples (6 samples from placed soil and 2 samples from borrow area) ranging between 6.39 to 11.5 ***(7)***. This range of PI values indicates that the subliner material would be considered marginally acceptable based on the current standard of practice, considering that a minimum PI of 7 typically is required for compacted clay liners designed to achieve a saturated hydraulic conductivity of 10^{-7} cm/s. Based on a total in-place volume of approximately 375,000 cy of subliner material placed, the testing frequency for Atterberg limits was 1 per ~46,000 cy. Current EPA guidance ***(16)*** recommends Atterberg limits testing during placement at a frequency of 1 per 800 m^3 (or 1,040 cy). Given the relatively low range of PI values measured in the eight tests performed, a greater frequency of testing would have been desirable in order to provide more confidence that the plasticity of the clay was adequate.

Based on construction documentation ***(2)***, a total of 59 field moisture/density tests were performed at 50 locations during construction of the clay subliner. Based on a subliner surface area of 154 acres ***(2)*** and construction of the subliner in three lifts, field moisture/density testing was performed at a frequency much less than 1 test per acre per lift. By contrast, current EPA guidance ***(16)*** recommends field moisture/density testing at a frequency of 5 tests per acre per lift. Sand cone tests (ASTM D1556) were used exclusively for field density evaluation. In addition, there appeared to be a total of 9 modified Proctor compaction tests performed after placement, indicating a testing frequency of ~1/42,000 cy (based on a total of ~375,000 cy of soil placed). Current EPA guidance ***(16)*** recommends a frequency of one test per 4,000 m^3 (or ~5,200 cy) of material placed.

Construction specifications for the clay subliner were not available for review. However, the Definitive Design Report ***(1)*** recommends that the subliner be compacted to a relative density greater than 95 percent (based on Modified Proctor) and a moisture content wet of optimum. Upon our review of the field moisture density test results ***(2)***, it appears that approximately 35 percent of the tests (21 of 59) failed to meet the design recommendations, and only 7 of the failed areas were retested (i.e., 14 failed areas were not retested). Moreover, it appears that four of the retested samples were compared against a different reference compaction curve than the initial failed sample. Finally, it is not clear from the documentation in the First Stage Construction Report ***(2)*** if all of the failed areas were reworked.

The low soil testing frequencies, high percentage of initial failures, unexplained changes in the reference compaction curve during retesting, and lack of retesting at several failed locations raises serious questions regarding (a) what fraction of the clay subliner actually met placement requirements at completion of construction, and (b) whether or not clay liner construction was conducive to achieving a low as-built hydraulic conductivity.

Hydraulic Conductivity

With respect to as-built hydraulic conductivity, Part 18 Licensing Requirements ***(10)*** do not specify a maximum prescriptive hydraulic conductivity for the lining system of an impoundment. However, it has generally been assumed by Cotter representatives that the clay subliner exhibits an as-built saturated hydraulic conductivity of 10^{-7} cm/s ***(6b, 9b)***. However, this assumption is almost certainly unconservative based on three primary considerations. First, the thickness of the clay subliner itself (18 inches) is less than that currently recommended to achieve a low hydraulic conductivity. For example, Benson and Daniel ***(23)*** indicate that liners with a thickness of one foot (e.g., two lifts) tend to be much more permeable than liners with a thickness of two to three feet (e.g., 4 to 6 lifts) based on both field data and models. Higher hydraulic conductivity in liners with fewer lifts is attributed to construction deficiencies such as poorly compacted lifts and imperfect bonding between lifts. These deficiencies are less likely to dominate the hydraulic performance of a compacted clay liner as the number of lifts is increased. Benson and Daniel ***(24)*** recommend a liner thickness of at least two feet (4 lifts) to achieve a low field hydraulic conductivity.

Second, even if all of the clay was placed in accordance with compaction conditions recommended in the design report ***(1)***, these conditions are not conducive to achieving a saturated hydraulic conductivity of 10^{-7} cm/s since a substantial amount of the clay subliner likely was placed beneath the line of optimums. Research has shown that the compaction conditions relative to the line of optimums is a critical factor influencing the field hydraulic conductivity of a compacted clay liner ***(17, 18, 19, 20, and 21)***. Generally, soils compacted wet of the line of optimums contain fewer large clods and, thus, fewer interclod macropores that govern the overall hydraulic conductivity of the soil. The line of optimums compaction approach is supported by evaluations conducted at more than 50 sites ***(17, 18, and 19)***.

Third, compaction beneath the line of optimums also has been shown to result in field hydraulic conductivity values that deviate considerably from laboratory samples, whereas compaction wet of the line of optimums typically produces comparable results between the field and the laboratory. As stated previously, clay soils compacted dry of the line of optimums typically contain numerous macropores that may not be captured in small laboratory scale tests ***(21, 22)***. Small scale tests are even less likely to capture representative macrofeatures if the specimens were remolded rather than collected from the as-built liner. Case studies have shown that field hydraulic conductivities can be 10 to 1,000 times greater than predicted from laboratory data ***(18, 19, 23)***, particularly for liners compacted beneath the line of optimum. For example, Benson ***(20)*** illustrates that at least an order of magnitude higher field hydraulic conductivity is expected relative to the laboratory when the percentage of field moisture/density data beneath the line of optimums is greater than 50 percent, and the percentage of field moisture/density data above the line of optimums should exceed 75 percent in order to achieve comparable field and laboratory hydraulic conductivity results. Benson ***(20)*** also indicates that large-diameter test specimens (e.g., 300 mm diameter or more) provide more reliable estimates of field hydraulic conductivity because these specimens are more likely to contain a network of pores that are representative of those existing in the field. For the Cotter impoundments, there is little or no reliable quantitative data to suggest that the as-built hydraulic conductivity of the clay subliner meets the assumed hydraulic conductivity of 10^{-7} cm/s. While some small-scale laboratory test results were reportedly in the 10^{-7} cm/s range ***(7)***, these tests were performed on remolded samples only (see “Compatibility” section below for more discussion on these tests). No large-scale (e.g., block samples or SDRI tests) or even small-scale (e.g., Shelby tube) testing was performed on the constructed liner. Shelby tube samples were taken as part of the Clay Liner Impact Evaluation **(7)** but the samples could not be extruded without disturbance.

Given the absence of measured hydraulic conductivity of the as-built liner, definitive conclusions regarding the actual field hydraulic conductivity cannot be made. However, based on the considerations described above, it is probable that the as-built hydraulic conductivity at the time of construction was on the order of 10^{-5} to 10^{-6} cm/s. The current in-place hydraulic conductivity of the clay subliner is likely in this same range. This statement is based on the recognition that the permeability could have been increased by interaction with tailings solutions (see below) or decreased by the consolidation pressures induced by the weight of the overlying tailings.

Compatibility

Part 18 Criterion 5E ***(10)*** requires that, where clay liners are proposed, tests must be conducted with representative tailings solutions and clay materials to confirm that no significant deterioration of permeability or stability properties will occur with continuous exposure of clay to tailings solutions. Tests must be run for a sufficient period of time to reveal any effects if they are going to occur.

Chemical compatibility of the clay subliner was not performed as part of the design process for the impoundments but was performed subsequently as part of the 1994 Clay Liner Impact Evaluation ***(7)***. Compatibility tests for which data were provided in this report included six fixed-wall hydraulic conductivity tests on relatively small (i.e., 6-inch diameter and 4-inch thick) remolded specimens of clay subliner material removed from the as-built liner system (testing of undisturbed specimens was not performed). Two of these six tests were duplicates. Permeant liquids in these tests consisted of actual free-standing impoundment liquids with a pH of approximately 1.9. Initially, the tests were conducted by permeating under a low, falling head (~ 1 foot of head on average). After several months of operation, the influent head was increased to 23 feet by pressurizing the influent compartment with nitrogen gas at 10 psi. The results of the compatibility tests were reviewed by Sentinel as part of this assessment and also were reviewed in 1994 on behalf of CDPHE by D.B. Stevens ***(8)***.

The Clay Liner Impact Evaluation ***(7)*** provides plots of incremental and cumulative effluent liquid mass from the column as a function of time. Raw data showing the same information, along with the cumulative pore volumes of flow through each specimen, also is provided in tabular form. The total pore volumes of flow passed through the six clay subliner specimens ranged from 2.21 to 3.48. The text states that hydraulic conductivities generally were in the 10^{-7} cm/s range at the start of the tests but decreased into the 10^{-8} to 10^{-9} cm/s range upon continued exposure to the tailings solutions. The apparent decline in hydraulic conductivity with increasing pore volumes of flow was attributed to plugging of seepage pathways by mineral precipitates jarosite ($KFe(SO_4) \cdot H_2O$) and gypsum ($CaSO_4 \cdot H_2O$).

However, upon review of the data, actual calculated hydraulic conductivity values versus pore volumes of flow appear to have been provided for only one of the six specimens (i.e., Specimen B). For this specimen, the hydraulic conductivity at one pore volume of flow was reported as approximately 4×10^{-7} cm/s in Figure 10 ***(7)***. Subsequent values of hydraulic conductivity for this specimen at two, three, and four pore volumes appear to be approximately 10^{-7} cm/s, 4×10^{-8} cm/s, and 2×10^{-9} cm/s, respectively, in Figure 10 ***(7)***. None of these calculations are shown in tabular form. Also, although Figure 10 shows that Cotter representatives measured hydraulic conductivity at four pore volumes of flow, the accompanying raw data indicates that the test was terminated at 3.48 pore volumes. Moreover, it does not appear that all of the test specimens exhibited a decline in permeability. Some specimens show relatively constant or even increasing flow rate with time. Finally, the plots of effluent mass collected over time are provided as histograms with variable time-axis increments. As noted by D.B. Stevens ***(8)***, definitive trends cannot be determined from data illustrated in this manner.

Sentinel generally concurs with the D.B. Stevens review ***(8)*** that, even if such a decrease in hydraulic conductivity was actually realized with increasing pore volumes of flow, it is not clear that such a decrease was due to precipitation of secondary minerals. We agree that several testing artifacts (e.g., loss of nitrogen gas pressure, evaporative losses in the effluent, downward migration of clay particles and subsequent entrapment in lower pores or on the downgradient filter paper or perforated base plate) may have significantly influenced the test results. Sentinel agrees with D.B. Stevens ***(8)*** that a control column using ordinary groundwater would have been beneficial for interpreting the test results.

It is clear from the x-ray diffraction data provided in ***(7)*** that clay minerals (primarily smectite) were either being forced to migrate downward or were being attacked by the acidic permeant. Smectite content in the upper portion (i.e., nearest the influent end) of the specimens were distinctly lower than the smectite content in the lower portion (i.e., nearest the effluent end) of the specimens. Attack of the smectite by the acidic permeant would not be surprising, particularly for influent pH less than 2. Shackelford ***(25)*** notes that a significant change in hydraulic conductivity may result when a strong acid disintegrates the soil into smaller fragments or dissolves the mineral. If the fragments are flushed from the permeameter, an increase in hydraulic conductivity would be expected. However, if the particles are restrained from piping due to a sieving effect (e.g., filter paper, porous stone), the hydraulic conductivity may decrease. Migration of particles may have been further exacerbated in the Cotter compatibility tests when the hydraulic head at the influent end of the specimens was increased from one foot to 23 feet.

Based on the above, the Clay Liner Impact Evaluation ***(7)*** provides incomplete and potentially inaccurate analysis of the compatibility test data. Due to time and budget constraints, Sentinel did not attempt to calculate hydraulic conductivity versus pore volumes from the raw data for any of the clay subliner specimens. However, we recommend that these calculations be performed to provide a complete and accurate analysis of the data.

2.2.2 Hypalon Liner

Sentinel understands that the 18-inch clay subliner for the Cotter impoundments was overlain by a 30- to 60-mil thick Hypalon liner and 12 inches of a “protective” soil cover. In general, a composite liner system that includes a competent geomembrane is expected to exhibit better hydraulic performance than a compacted clay liner alone. However, there are several lines of evidence that suggest the integrity of the Hypalon liner may be significantly compromised. First, the Remedial Investigation (5) states that there were more than 70 documented breaches in the Hypalon liner, including numerous seam failures and dozer tears. Extensive repairs on the Hypalon liner were required, as indicated by the statement in the First Stage Construction Report ***(2)*** that a full-time repair crew was required during construction to repair both installation and factory seams. Quality control of seaming was based on visual observation only. Non-destructive (e.g., air lance, vacuum box) testing of seams apparently was not performed. Also, since liner installation was not completed until December, seaming operations likely were performed under low temperature conditions. Dozer tears in the Hypalon are attributed to the use of a D8 dozer to spread the 12-inch "protective" soil cover above the Hypalon. Also, several of the breaches may have been the result of large rocks in the protective cover soil. Although construction documentation indicates that the protective soil cover consisted of only fine-grained materials ***(2, 7)***, both the Remedial Investigation ***(5)*** and the D.B. Stevens Assessment ***(6)*** assert that cobbles and rocks up to boulder size were present in the "protective" cover soil.

The D.B. Stevens assessment ***(6)*** indicates that the Hypalon liner likely provides little contribution to the overall hydraulic performance of the liner system. Sentinel is inclined to agree with this assessment. Based on the considerations above, it would be reasonable to assume that the Hypalon is not highly functional as a hydraulic barrier.

2.3 Leak Detection System

Criterion 5B(1) ***(10)*** prohibits the migration of hazardous constituents from a licensed impoundment into underlying groundwater above specified concentration limits in the uppermost aquifer beyond the point of compliance during the compliance period. Also, Criterion 5E(1) ***(10)*** states that, where synthetic liners are used, a leakage detection system must be installed immediately below the liner to ensure major failures are detected if they occur. Finally, Criterion 7 ***(10)*** states that the licensee shall establish a detection monitoring program needed for the CDPHE to set the site-specific groundwater protection standards pursuant to Criterion 5B(1). A detection monitoring program has generally two purposes: (1) to detect any releases from the containment system; and (2) if releases are detected, to generate data and information needed to determine what remedial action, if any, is necessary. .

The Total Quality Environmental Management (TQEM) report ***(9)*** states that the three subdrain sumps (Nos. 710, 711, and 712) and a monitoring well (Well 003) installed at the toe of the primary impoundment comprise the seepage detection system. No discussion is provided as to the ability of this system to detect all leaks from the containment system.

Table VII-1 of the First Stage Construction Completion Report ***(2)*** states that 13,063 linear feet of subdrains and 154 acres of Hypalon were installed. The drawings in this report illustrate that the subdrain trenches were constructed into the impoundment subgrade at a width of two feet, with the clay liner constructed immediately above it. Based on these findings and the statements made in the design and construction reports ***(1, 2)***, the subdrains clearly were designed and constructed only to drain groundwater from the springs encountered during the foundation excavation and not as a leak detection system. The only seepage from the impoundments that would be collected by the subdrain system is seepage that passes through the clay liner in the area immediately above the subdrains (e.g., perhaps only within the two-foot width of the subdrain trenches). The total planar area of the subdrain trench network is approximately one-half an acre. By contrast, the total subliner surface area is approximately 154 acres. Thus, seepage from the 153.5 acres of lined area not located directly above a subdrain trench (99.7 percent of the total) may not be captured by the subdrain systems and may only be detected by Well 003. Moreover, even if the subdrain system were more effective for capturing impoundment seepage than presumed herein, it is likely that any contamination contained in the seepage would be diluted when combined with spring seepage also collected by these same subdrains.

Based on information provided in Volume I of the Assessment of Potential Seepage Impacts on Groundwater ***(6a)***, Well 003 is 36 feet deep and located near the Berm Withdrawal Wells, just outside the northeastern tip of the impoundment. The well was installed in 1988 and monitors water in the Poison Canyon Formation. Numerous groundwater contour maps also included in ***(6a)*** indicate that Well 003 is cross-gradient, not down-gradient, from the impoundments and that groundwater contours beneath the impoundment cannot be fully interpreted. Based on this information, it is doubtful that Well 003 is very effective for detecting all releases from the impoundments.

2.4 Cover System

Criterion 6(1) of the Part 18 Licensing Requirements ***(10)*** states that licensees shall place an earthen (or approved alternative) cover over tailings at the end of milling operations and shall close the waste disposal area in accordance with a design which provides reasonable assurance of control of radiological hazards to (i) be effective for 1,000 years, to the extent reasonably achievable, and in any case, for at least 200 years, and (ii) limit releases of radon-222 or radon-220 to the atmosphere so as not to exceed 20 picocuries per square meter per second, to the extent practicable throughout the effective design life of the cover system.

The cover design for the tailings impoundments is described in the 2004 update of the tailings reclamation plan ***(13)***. Design criteria listed in this plan include isolation of waste from biointrusion and minimizing infiltration from precipitation. The current cover design cross-section consists of the following layers, from top to bottom: topsoil (0.5 ft); sandy clay (1.0 ft); sand (2.0 ft); and compacted clay (1.0 ft).

As a means to minimize infiltration through the cover system, the design objective for the compacted clay layer is to achieve a saturated hydraulic conductivity less than 10^{-7} cm/s ***(13)***. Infiltration modeling for the current cover design cross-section was performed using the finite-element saturated/unsaturated flow model VADOSE/W. A saturated hydraulic conductivity of 10^{-7} cm/s was assumed for the compacted clay layer in the model simulations. The modeled cover system also included 1.5 feet of random fill below the compacted clay layer. The results of this modeling exercise indicated that, over a 20-year simulation period, the average flux rate at the base of the cover generally is low and may be upward (from the underlying fill/tailings into the cover) rather than downward (into the underlying fill/tailings) under most circumstances. However, the compacted clay layer thickness and the technical specifications for construction of the compacted clay layer may not be adequate to achieve a hydraulic conductivity of 10^{-7} cm/s.

As stated previously (Section 2.2.1), a minimum compacted clay thickness of least two feet is recommended to consistently achieve a low hydraulic conductivity. In addition, the current compaction specification allows for the clay to be compacted at a moisture content as low as two percent below the optimum moisture content. At a minimum, revision of the compaction specification to include an acceptable zone for clay compaction in accordance with the line of optimums approach (see Section 2.2.1) is recommended, along with a permeability testing program to verify that the acceptable zone will achieve the design objective of 10^{-7} cm/s. Otherwise, it is more likely that the compacted clay layer could exhibit a hydraulic conductivity as high as 10^{-5} cm/s, and the infiltration modeling evaluation should be revised to incorporate this more conservative value of saturated hydraulic conductivity.

It also should be noted that upward flux values reported in the existing infiltration model results appear to be an artifact of including the underlying random fill in the modeled cover system and allowing any water contained in this fill to migrate into the cover. As noted in ***(13)***, the random fill is not part of the engineered cover system. Also, there is no material specification associated with this random fill. As such, spatial variability of the material properties and, thus, the hydraulic properties of the random fill layer may be considerable. While the VADOSE/W analysis includes a model simulation with an assumed hydraulic conductivity of 10^{-2} cm/s for the random fill, this assumption likely creates a significant capillary barrier effect at the interface between the compacted clay and the random fill that would result in an unconservative estimate of infiltration through the cover system. A more appropriate modeling approach would be to exclude the random fill from the modeled cover cross section such that any migration of water at the base of the cover system would be downward only.

Other concerns regarding the current cover design include the extremely flat cover slope (i.e., 0.5 percent or less) as illustrated in Figure 4.2 of ***(13)***. Such a shallow slope may be advantageous for minimizing erosion but would be nearly impossible to construct without creating significant flat areas or depressions that would promote ponding of water on the cover surface, notwithstanding any settlement after cover placement that would further promote ponding. Current EPA guidance for soil covers indicates that a cover slope of three to five percent is necessary to promote runoff and minimize ponding while also minimizing erosion. In addition, while the cover design criteria include isolation from biointrusion, the current cover design does not include a biota barrier layer to prevent intrusion into the cover and underlying waste by burrowing animals. Typical biota barrier layers to prevent animal biointrusion consist of large (e.g., up to 10-inch) rocks or similar (e.g., crushed concrete), in accordance with specific requirements for particle size distribution. This type of biota barrier layer is included in the design of over 400 acres of soil cover systems to be constructed at the Rocky Mountain Arsenal (RMA) in Commerce City, Colorado. Finally, it is noted that all soil layers in the cover, with the exception of the topsoil layer, are to be compacted above a relative density of 90 percent. This minimum relative density likely would result in actual bulk density values that exceed the growth limiting bulk density for most, if not all, native grassland species, as indicated by recent efforts for evapotranspirative covers at RMA. Although the current cover design does not rely on evapotranspiration for successful cover performance, the 2004 reclamation plan update ***(13)*** indicates that there is a requirement to establish a total vegetative cover of at least 70 percent of the total vegetative cover of a nearby background area. This requirement likely will be more easily met by limiting compaction of the upper 18 inches of the soil cover (i.e., the topsoil and underlying sandy clay layer) to less than 90 percent relative density.

It is noted that, although Cotter representatives performed infiltration model simulations for an alternative monolithic (evapotranspirative) cover system to be considered in lieu of the current cover design, this proposal has been withdrawn ***(13)***. As such, this technical assessment does not address the alternative cover design. An independent technical assessment of the alternative cover design is recommended in the event that an alternative cover is pursued in the future.

2.5 Overall performance

Part 18 Criterion 5E(1) ***(10)*** states that applicants and licensees should consider dewatering of tailings by process devices and/or in-situ drainage systems, and neutralization to promote immobilization of hazardous constituents. Based on the documents reviewed, it is apparent that Cotter has been and/or will be dewatering the tailings prior to closure and that they are adjusting the pH to within 4 to 11. It is unclear from the documents how thoroughly the tailings will be dewatered or how the verification will be performed. The degree to which the existing tailings will be dewatered prior to closure will have a critical effect on the post-closure performance of the impoundment containment system.

No specific criterion is given for the allowable amount of seepage from the impoundments. However, as stated above, Criterion 5A(1) ***(10)*** states that surface impoundments shall have a liner that is designed, constructed, and installed to prevent any migration of wastes out of the impoundment to the adjacent subsurface soil, groundwater, or surface water at any time during the active life (including the closure period) of the impoundment.

The hydrologic performance (i.e., the amount of seepage through the bottom of the clay subliner) of the impoundments was evaluated using the Hydrologic Evaluation of Landfill Performance (HELP) model by two entities in the documents reviewed ***(6b, 9b)***. The results of these evaluations indicate that the predicted long-term steady state seepage (after 200 to 300 years) from the impoundment is 10^{-8} cm/s (or 450 cubic feet/acre/year) ***(6b)*** and 10 to 100 times more (roughly 23,000 cubic feet/acre/year on the average) during the initial 200 to 300 years. Appendix E of Earth Sciences Consultants' Decommissioning and Reclamation Plan ***(9b)*** reported an average of approximately 1,230 cubic feet/acre/year in years 20 to 80. Multiplying these values by the 132-acre closed impoundment area reported in ***(15)*** and converting units results in a current annual infiltration ranging from approximately 1.2 to 22.7 *million* gallons per year (gpy) into the environment. This range reflects the fact that D.B Stevens assumed the tailings wouldn't be dewatered during the first 20 years of the simulation whereas the Earth Sciences scenario assumed the tailings were dewatered. Additionally, the HELP model evaluations were performed by different professionals using different versions of the HELP model and different variables and/or containment scenarios. It is also important to note, however, that both model evaluations assumed that the as-built hydraulic conductivity of the clay liner is 10^{-7} cm/s. As stated previously (see Section 2.2 above), it is more likely that the as-built saturated hydraulic conductivity of the clay subliner is on the order of 10^{-5} to 10^{-6} cm/s. The influence of an increase in hydraulic conductivity of up to two orders of magnitude on the HELP model infiltration results is unknown but should be investigated. The HELP model results should be considered very approximate.

2.6 Site Operations

Cotter's operational situation is unique in that their containment system has been active for roughly 25 years and will continue to be active for the foreseeable future. According to (9) and (15), Cotter developed operational constraints during the TQEM process to further enhance the operational performance of the impoundments. The constraints of particular interest are the requirements to maintain the primary impoundment's pool elevation to 5587.5 feet mean sea level (msl) or less and to adjust the pH in the primary impoundment to between 4 and 11 by June 30, 1998. Furthermore, based on discussions with CDPHE an operational constraint of 4 million tons of tailings below the 5580 msl was agreed to at this time. These constraints were implemented to: allow enough freeboard beneath the top of liner elevation (5603 msl), decrease the mobility of constituents of concern, and limit the amount of seepage from the impoundments. Also, the decision to not build the second stage of the impoundment described in ***(1)*** was apparently made as part of the TQEM process.

Sentinel has significant performance concerns with allowing this much hydrostatic head to remain on the impoundment liner. According to ***(9)***, the lowest top of liner elevation is approximately 5545 feet msl. Allowing standing water at the 5580 foot msl elevation results in a maximum of 35 feet and an approximate average of 20 feet of hydrostatic head on the liner system. Again according to ***(9)***, the flux through the clay liner at 20 feet of head is 2.5 gallons per minute (gpm), or 1.3 million gpy, for a 29-acre area assuming a non-conservative hydraulic conductivity of 10^{-8} cm/s. This indicates that a large amount of seepage will likely occur as long as the water elevation is maintained at this level. Using the same methodology and assumptions, at an average head of 10 feet, the seepage will decrease to approximately 0.6 gpm (300,000 gpy). It will further decrease to 0.005 gpm (3,000 gpy) if it's reduced to 1 foot.

3.0 CONCLUSIONS AND RECOMMENDATIONS

The primary objective of this assessment was to evaluate the technical viability of the waste containment and leak detection systems for the primary and secondary tailings impoundments at the Cotter facility, relative to 6 CCR 1007-1, Part 18 Licensing Requirements. The assessment was based upon review of the documents cited above addressing the design, construction, and field condition of these systems. Our conclusions are as follows:

- The Cotter facility property as a whole has been characterized reasonably well but the hydrogeology immediately beneath the impoundments is not as well understood. Underlying bedrock consists primarily of conglomerate and sandstone formations that may be highly permeable, and numerous springs and open bedrock fractures were encountered during impoundment construction. These conditions suggest that pathways exist for migration of impoundment seepage into both shallow and deep aquifers.

- The leak detection system (three subdrain sumps and Well 003) will not detect all releases from the primary and secondary impoundments. The subdrains were designed and constructed to collect groundwater spring flow, not for detection of leaks from the impoundments. This system may only be capable of collecting seepage over 0.5 acres of the 154-acre impoundment area. Moreover, any impoundment seepage collected by the subdrains would commingle with groundwater spring flow also collected by these same subdrains. As a result, flow from the subdrain system likely is a poor indicator of the actual volume and water quality of seepage from the impoundments. Additionally, Well 003 appears to be cross-gradient, rather than downgradient, from the impoundments and will likely not detect all releases from the impoundments.

- Multiple lines of evidence contained in design, construction, and post-construction documentation strongly suggest that the current effectiveness of the Hypalon liner is severely limited and that the as-built saturated hydraulic conductivity of the 18-inch thick clay subliner may be 10 to 100 times greater than the value of 10^{-7} cm/s assumed in previous water balance (infiltration) model simulations. Thus, although the results of this previous modeling already suggest that the impoundments are releasing millions gallons of leachate to the environment each year, these estimates may be low.

- The current cover design appears inadequate for meeting design objectives and criteria described in the 2004 reclamation plan update. The current design is not conducive to minimizing infiltration due primarily to insufficient compacted clay thickness and inappropriate compaction specifications. The design objective to achieve a hydraulic conductivity of 10^{-7} cm/s or less in the compacted clay layer probably will not be realized by the current design. Other concerns regarding the cover design are the extremely flat slope (i.e., less than 0.5 percent), absence of an animal biointrusion layer, and compaction requirements that generally will result in cover soil density above the growth-limiting bulk density for native grasses.

- The current operational practice of maintaining the pool elevation in the primary impoundment in the range of the 5580 msl elevation is causing a large amount of seepage to be released beyond the limits of impoundment's lining system. The amount of seepage will be reduced substantially with a reduction in the hydrostatic head.

Based on the above conclusions, Sentinel provides the following recommendations:

1. Infiltration modeling should be revised to reflect more conservative as-built lining system conditions. Revised model simulations should account for the possibility that (a) the 18-inch clay subliner exhibits a hydraulic conductivity as high as 10^{-5} cm/s and (b) the Hypalon geomembrane is no longer functional as a hydraulic barrier. Additionally, computer models other than HELP should be evaluated for use in the evaluation.

2. Independent quantitative analysis of the compatibility test results reported in Cotter's 1994 Clay Liner Impact Evaluation is recommended to evaluate hydraulic conductivity values and trends over time. Given the numerous concerns identified in this assessment and the prior review by D.B. Stevens, the conclusions in the 1994 evaluation regarding

the influence of acidic tailing solutions on the hydraulic conductivity of the clay subliner should not be considered credible at this time.

3. If possible, measurement of the actual hydraulic conductivity of the clay subliner to the existing impoundment liquid should be considered in order to refine model estimates of infiltration. Such testing could be performed in situ (i.e., SDRI testing) and/or in the laboratory. Laboratory specimens should be prepared from block samples collected from the clay subliner and should be a minimum of 30 cm (1 foot) in diameter. .

4. Dewatering of the tailings should be performed in the near term, rather than the long term, as an operational measure to reduce the current hydraulic head above the liner system and, thus, reduce the potential for release of liquid and associated contaminants through the lining system. A maximum pool elevation significantly below 5580 msl should be strongly considered. It is noted in ***(13)*** that fluid containment for the impoundments includes the capability to reduce the hydraulic gradient across the liner by pumping from the drainage system installed above the liner and within the tailings. It is not clear, based on the documentation reviewed for this assessment, that these drainage systems have been, or will be, effective in substantially reducing the hydraulic gradient.

5. If additional tailings are to be disposed in the impoundments, placement of such tailings in a dewatered condition is preferable. Also, use of soil cover or tackifiers should be considered in lieu of water for dust control. These modifications, in combination with expedited dewatering of the existing tailings, will further reduce the potential for seepage through the impoundments.

6. The current soil cover design should be modified to reflect conditions more amenable to minimizing infiltration and to provide better assurance that the target hydraulic conductivity of 10^{-7} cm/s for the compacted clay layer will be achieved in the field. At a minimum, these modifications include (a) increasing the compacted clay thickness to at least two feet, (b) development of a soil compaction "acceptable zone" based on the line of optimums approach (see Section 2.4), and (c) development and implementation of a hydraulic conductivity testing program to verify that the acceptable zone is sufficient to achieve the target hydraulic conductivity. Otherwise, incorporation of a low-permeability geosynthetic barrier (i.e., geomembrane or geosynthetic clay liner [GCL]) into the current cover design should be considered. A properly designed and constructed alternative (evapotranspirative) cover system also would be effective for minimizing infiltration and should be considered. Regardless of the cross-section, an increase in the cover surface slope to at least three percent should be considered in order to minimize the potential for ponding, and addition of an animal biointrusion layer to the cover cross-section should be considered in order to meet the design criteria of isolating the tailings from biointrusion. Finally, infiltration modeling performed for the cover system should be revised to include only the compacted clay and overlying layers. The random fill is not part of the engineered cover system and should not be included in the modeled cross-section.

7. A comprehensive groundwater monitoring program should be designed and implemented for the impoundments' perimeter to define and monitor the potentiometric surface(s) beneath the impoundments. The program should also be designed such that a well network is installed to detect potential releases from all areas of the impoundments and in both shallow and deep aquifers.

We appreciate the opportunity to provide these services and look forward to discussing this assessment with you. If you have any questions regarding this letter report, please contact Brad Coleman at (303) 883-4408 (bcoleman@sentinelteam.com) or Mike Malusis at (303) 250-4416 (mmalusis@sentinelteam.com).

Sincerely,

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