APPENDIX G

SETTLEMENT

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G.1 INTRODUCTION

This appendix outlines the evaluation of the disposal cell settlement and its effect on cover system performance. This appendix is an update of responses to the NRC in October 2004 and September 2006, reflecting current plans for disposal cell construction and disposed material placement.

G.2 MATERIAL PLACEMENT AND COMPACTION

The plans for disposed material placement and compaction have been revised for phased construction and to minimize potential settlement, and are outlined in the updated Technical Specifications (Reclamation Plan Attachment A). The material placement strategy is to minimize void spaces around the incompressible materials in the cell (using soils) and to minimize void spaces within the compressible materials in the cell. This strategy is outlined below for incompressible materials, compressible materials, and soils.

G.2.1 Incompressible Materials

Structural materials will be broken or cut to manageable size using typical equipment for demotion work, such as hydraulic excavators with specialized attachments for shearing and grasping. These materials will be hauled with trucks to the disposal cell for placement. The material placement strategy for incompressible structural materials is to minimize void spaces around these materials in the cell by spreading or laying out these materials in lifts. Materials of large size will be cut for loading and transport to the designated area of the disposal cell, with a maximum dimension 20 feet (unless loading or handling conditions dictate a smaller dimension). Large or odd-shaped materials will be laid flat in the disposal cell, or (in other words) placed with longest dimension oriented horizontally. Each lift of material will be covered with soil and compacted to minimize void spaces within the incompressible materials in the cell.

Large incompressible materials exceeding two feet in vertical dimension (such as thick-walled tanks or vessels) will be placed in the cell, with interior void spaces filled with sand or grout. Soil will be placed outside of the large materials and compacted with standard compaction equipment (where possible) or hand-operated equipment.

G.2.2 Compressible Materials

There are two types of compressible materials that will be disposed in the cell: structural material and sludge. The material placement strategy for compressible materials is to make them incompressible by cutting, crushing, solidifying, or compacting these materials. Compressible structural material (such as thin-walled piping and tanks) will be flattened or crushed at the disposal cell with hydraulic excavator attachments, or with a dozer or other steel-tracked equipment. Compressible sludge material (such as calcium fluoride sludge) will be amended with fly ash, placed in lifts in the disposal cell, and compacted.

G.2.3 Soil Placement

Material type D consists of soils and weathered sedimentary rock from contaminated soil cleanup that is placed with and on top of structural materials (material type C). The soils will be used to minimize void spaces around the structural material and provide bedding for subsequent lift of structural material.

Checking soil compaction with standard field density testing methods (such as with a nuclear density gauge) is not recommended because of interference with structural debris. As a result, a method specification for compaction of this material is outlined in the Technical Specifications (Reclamation Plan Attachment A). The method would be a minimum of six passes over a two-foot maximum thickness lift of soil with a vibratory tamping-foot compactor. The number of passes would be confirmed on a field test section of soils to establish a correlation between the compaction method and 95 percent of the maximum dry density for the material, as determined by the Standard Proctor test.

G.3 DISPOSAL CELL SETTLEMENT

Settlement calculations were conducted in response to NRC requests for estimates of settlement in the disposal cell and evaluation of cover performance. The background, strategy, and calculations are outlined below.

G.3.1 Applicable Settlement Data

Related experience with settlement of disposed materials and cover performance is in three general areas: (1) uranium tailings impoundment reclamation, (2) uranium mill demolition and disposal, and (3) municipal landfill performance. Experience at uranium tailings impoundments has shown settlement values on the order of 10 to 20 percent of tailings thickness. However, these values are for slurry-deposited tailings undergoing decreasing porewater pressures and increasing loading. From experience with uranium mill demolition, settlement has been limited to areas with residual void spaces between structural materials.

Municipal landfill settlement data include values ranging from 5 to 25 percent of the waste thickness. Because the disposal cell will not include biodegradable materials, the amount of settlement in the disposal cell was estimated to be 5 to 10 percent of waste material height (consistent with the amount of short-term landfill settlement).

Compressibility properties for the materials placed in the disposal cell were estimated based upon a review of published performance summaries for municipal solid waste landfills. In their review of final covers for solid waste landfills, Koerner and Daniel (1997) estimated the typical amount of surface settlement at landfills to be approximately 10 percent of the total height. The City of New York has found that surface settlements at their Fresh Kill landfill ranged from 10 to 15 percent of the waste height, with half of the settlement occurring in the first 5 to 10 years and the remainder occurring within the next 20 years (City of New York, 2004). The United States Environmental Protection Agency indicates landfill settlement can range from 5 to 25 percent of the original waste thickness (EPA, 2004).

The material placed in the SFC disposal cell will consist of inorganic, non-biodegradable demolition debris and soils from cleanup of the surrounding area. Therefore, decomposition of biodegradable material is not expected to be a factor contributing to settlement of the disposal cell. Consequently, the settlement of the SFC disposal cell is expected to be at the low end of the range cited for typical municipal solid waste landfills. The methods of material placement and compaction (described above) should further limit settlement.

G.3.2 Settlement Estimate Strategy

The anticipated settlement of materials in the disposal cell is based on analysis of both total and differential settlement. Since the amount of differential settlement, rather than total settlement, is a critical factor when evaluating the potential for disruption and cracking of the cover system, settlement estimates were made for areas of maximum anticipated differential settlement. Differential settlement can result from both varying thicknesses of compressible materials, with greater thicknesses resulting in greater settlement, and varying material properties. As a result, the area of maximum differential settlement for each cell is expected to occur at the location of maximum cell material thickness along the interior berms (where material properties are likely to vary most significantly).

Differential settlement analyses were made by calculating the settlement in vertical profiles representing the least and the most compressible profiles over a short distance. The closest lateral distance for these profiles is represented by the length of the internal berm slopes (35 feet).

NRC stated that 35 feet could underestimate the strain across a stiff inclusion from a beam in material type C, or the concrete slab in the foundation. Stiff inclusions such as beams within a compacted soil matrix are not likely to have significant effects on the top surface of the disposal cell. If such materials were close to the surface, such stiff inclusions could impact settlement at the surface such that cracking may be of concern. The concrete slab will be covered by a minimum of ten feet of material prior to placement of the cover, as will be non-compressible structural materials. Therefore, the effects of any locally high strains across stiff inclusions will be reduced by the overlying compacted materials.

A more detailed evaluation of settlement, based on the specific materials to be placed in the disposal cell is outlined below. The general characteristics of materials to be placed in the interior of the three phases of cell construction are summarized in the table below.

Phase	Area (sq. ft)	Primary Material	Volume (cu. ft)	Average Thickness (ft) for 70% of Area	Total Cell Thickness (ft)*
I	160,000	Subsoils and liner soils Buried solid wastes	306,356 51,250	2.7 0.4	15-30
II	250,000	Building debris Concrete and asphalt	568,660 511,795	3.3 2.9	30-40
III	220,000	Calcium fluoride sludge Fly ash	625,280 625,280	8.1 (mixed)	20-30

*Including cover thickness

This table indicates that the soft materials and structural debris are a relatively small proportion of the materials to be placed in the cell. The larger proportion of material will be contaminated soils and sedimentary rock.

G.3.3 Settlement Calculations

As outlined in the Cell Construction Plan, a layer of treated calcium fluoride sludge, will be placed in the bottom of the disposal cell. The gypsum in the treated sludge (mixed with fly ash) will allow sulfate to be used as a tracer for cell seepage leak detection. The estimated thickness of the treated sludge placed across the bottom of the entire cell is approximately two feet (based on a ratio by volume of two parts sludge to one part fly ash). The settlement of this layer is estimated using the standard settlement equation from Holz and Kovacs (1981):

$$S = C_c/(1+e_0)\, H_0 \log(\sigma_1/\sigma_0)$$

S = calculated settlement (feet)
C_c = compression index, ranging from 0.01 to 0.10 for compacted to compressible materials
e_0 = initial void ratio (1.1) for a sludge/fly ash mixture with a dry density of 80 pcf
H_0 = initial layer thickness (2 feet)
σ_1 = final vertical stress, in psf
σ_0 = initial vertical stress, in psf

Lifts of material placed in the disposal cell will be compacted with a conventional vibratory, wedge-foot (tamping-foot) compactor. Based on manufacturer's data, the vertical stress beneath the compactor wheels would be approximately 5,000 psf (Caterpillar, Inc., 1996). This loading of the compaction equipment is generally greater than the loading of subsequent disposed materials and cover.

for σ_0 = 50 percent of compaction loading = 2,500 psf
σ_1 = 3500 psf (20 feet of contaminated soils and debris at 120 pcf and 10 feet of cover at 110 pcf)

$$S = \frac{0.01}{2.1} 2 \log\left(\frac{3500}{2500}\right) = 0.0014\ feet$$

For a conservatively high compression index of 0.1, the estimated settlement of the two-foot thick layer is 0.014 feet.

For comparison, a 10-foot thick zone of contaminated soils or treated sludge compacted to approximately 112 pcf (equivalent to a void ratio of 0.50) at the bottom of the cell would have an estimated settlement of approximately 0.07 feet (for a compression index of 0.1). These calculations indicate that total settlement of materials in the cell will be relatively low.

G.3.4 Evaluation of Cover Cracking Potential

Differential settlement values were calculated for settlement between two materials occurring over a distance of 35 feet (representing the internal berm slopes in the disposal cell). These values were compared with allowable tensile strain values developed for covers over uranium mill tailings. The estimated tensile strain values were less than allowable values, indicating that the estimated differential settlement would not adversely affect cover performance.

The calculations for allowable tensile strain were based on the relationship from Caldwell and Reith (1993):

$$e_f = 0.05 + 0.003\ PI$$

e_f = soil strain at failure (or cracking) in percent
PI = plasticity index of cover soil

For a plasticity index value of 10, the soil strain at failure is 0.08 percent.

For differential settlement to reach the allowable strain value above, this would be equivalent to 0.17 feet of differential settlement over a lateral distance 35 feet. This would occur if a thick zone of calcium fluoride sludge was disposed adjacent to an internal soil berm. The effects of changing foundation conditions (from concrete pad left in place to compacted subsoil) would be masked by compaction of subsequent lifts of material and would not be reflected to the top of fill.

The lateral distance of 35 feet was used in the original differential settlement calculations to represent the distance between the top and bottom of slope for an internal embankment of compacted soils within the cell. If a soft material (such as calcium fluoride sludge) was placed on the inside of this internal embankment, differential settlement would be based on no settlement at the top of the embankment slope and some amount of settlement of soft materials at the toe of the embankment slope.

Based on differential settlement occurring over a distance of 35 feet (representing the compacted internal berm in the disposal cell), differential settlement values were calculated. For a 10-foot thick zone of treated calcium fluoride sludge adjacent to an internal berm, the estimated differential settlement (from the calculations above) would be approximately 0.07 feet. The allowable tensile strain calculated aove is equivalent to a differential settlement of approximately 0.17 feet. These calculations indicate that differential settlement in the disposal cell would not adversely affect cover performance.

Two additional methods were used to evaluate the potential effects of differential settlement on cover performance. The first method, proposed by Koerner and Daniel (1992) and cited by the EPA (2004), states that the center of a 20-foot diameter, circular area can settle 0.5 to 1.5 feet before cover cracking of a composite clay cover could be expected. In other words, 0.5 to 1.5 feet of differential settlement over a 10-foot horizontal distance can be accommodated by a clay cover without cracking. Comparing this criterion with the differential settlement estimates above indicates the anticipated level of differential settlement at the disposal cell would not be expected to cause cracking of the cover system.

The second method was proposed by Morrison-Knudsen Environmental Corporation for evaluation of the potential for cover cracking at the Naturita-UMTRA site (M-K/UMTRA, 1993). This procedure compares allowable tensile strains for the cover soils with tensile strains resulting from calculated differential settlement of the underlying materials to estimate the potential for crack development. The allowable tensile strains within the cover are based upon the plasticity index of the cover soils. This is essentially the same procedure as the equation cited in Caldwell and Reith (1993). For a minimum plasticity index of 5, the calculated allowable tensile strains are 0.065 percent. When converted to differential settlement, the allowable differential settlement is greater than the estimated differential settlement, so that cover cracking is not likely.

It should be noted that M-K/UMTRA method described above does not take into account the effect of overburden in a relatively thick cover. The overlying cover soils will result in the lower portion of the cover remaining in compression even under some elongation due to differential settlement. The M-K/UMTRA procedure implicitly assumes no overburden stress on the cover. As a result the cover cracking analyses (based upon the M-K/UMTRA method) are expected to provide conservative estimates of cover cracking potential, with the disposal cell cover being able to withstand larger differential movements without experiencing settlement-related cracking. Therefore, disruption of the disposal cell cover due to settlement cracking is not likely under the planned method of cell operation.

G.4 REFERENCES

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