

DESIGN AND CONSTRUCTION OF A DISPOSAL CELL FOR ABANDONED URANIUM MILL TAILINGS AT MAYBELL, COLORADO

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ABSTRACT

The on-site stabilization of approximately 3.8 million cubic yards (2.9 million cubic meters) of abandoned uranium mill tailings and other residual radioactive materials at Maybell, Colorado began in April 1995 and was completed in September 1998. The Maybell uranium mill tailings site is in Moffat County, in the northwestern corner of Colorado. The site covers approximately 170 ac (69 ha), and before remediation began it consisted of a tailings pile, rubble from the demolition of the mill buildings, and contamination dispersed to surrounding areas by wind and surface water flow. To stabilize and control the tailings, an in-place disposal cell was designed. The demolition debris, windblown and waterborne contaminated materials and contaminated soil and debris from vicinity properties were placed on top of the existing tailings pile. These materials were then covered with a radon/infiltration barrier, a frost barrier layer, and an erosion protection layer consisting of bedding and riprap. The radon/infiltration barrier was designed to reduce the radon emission from contaminated materials and to limit surface water infiltration into the contaminated material. Permanent drainage features were constructed to divert flow away from the disposal embankment.

The performance criteria established by the U.S. Environmental Protection Agency (EPA) requires that the remedial design will provide reasonable assurance that the tailings will be controlled for 1000 years to an extent reasonably achievable and, in any case, for at least 200 years. The project performance criteria also require that maintenance after construction must be minimized. These very conservative criteria, particularly the 1000-year design life criteria, require the use of natural earthen materials only, sound engineering practice, and exacting construction methods requiring stringent quality control procedures. This paper discusses the design considerations and construction methods involved for the remedial action at the Maybell site.

INTRODUCTION

Regulatory Background

The Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA), Public Law 95-604, authorized the U.S. Department of Energy (DOE) to perform remedial action at the abandoned

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Maybell tailings site (as well as at 23 other sites) to reduce potential public health impacts from the residual radioactivity remaining in the pile (1). The U.S. Environmental Protection Agency

(EPA) promulgated standards (40 CFR part 192) in January 1983, for this remedial action (2). Isolation and stabilization of tailings in order to prevent misuse by man and dispersal by natural forces are the primary objective of the EPA standards. EPA standards requires that : 1) to the extent reasonably achievable, stability and control of the tailings to be effective for up to 1000 years, and in any case , for at least 200 years; and 2) the remedial actions shall be conducted so as to provide reasonable assurance that releases of radon-222 from residual radioactive materials to the atmosphere will not exceed an average release rate of 20 picocuries per square meter per second. The standards also call for protection of surface waters and usable groundwater aquifers. The Act establishes the U.S. Nuclear Regulatory Commission (NRC) as the regulatory agency for the project. In this capacity, the NRC must concur in all major remedial action design and construction before they will issue a license for the long term maintenance and monitoring of the disposal site.

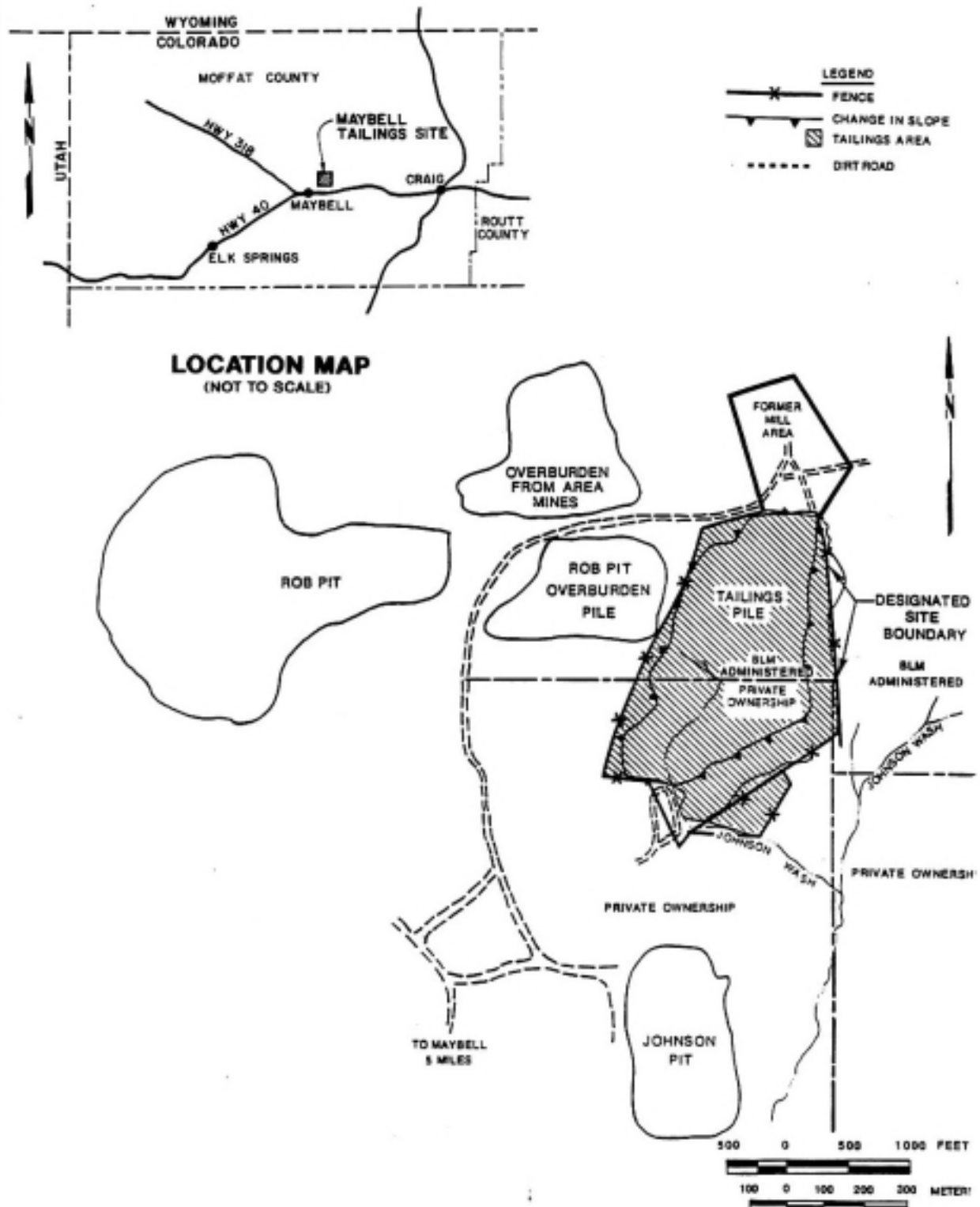
Site History

The mining claims and mill site at Maybell were established by the Trace Elements Corporation in 1955. In 1957, the Union Carbide Corporation (now Umetco) assumed control of the site and began operation of the mill to produce uranium concentrate. Uranium ore was obtained from nearby open pit mines. Operations ceased at the mill in 1964 after approximately 2.6 million tons of ore had been processed. All concentrate produced was sold to the U.S. Atomic Energy Commission. The mill was dismantled by Umetco sometime after 1964, and the following features remained on the site: tailings pile, building demolition debris, contaminated soils and foundation materials, and overburden piles (3).

Site Description

The Maybell uranium mill tailings site is located 25 miles (40 km) west of Craig, Colorado, in Moffat County, in the northwestern corner of the state (Figure 1). The tailings site is 2.5 miles (4 km) northeast of the Yampa River at an elevation of approximately 6200 feet (1890 m) above mean sea level. The site is drained by Johnson Wash, an ephemeral arroyo which is a tributary to Lay Creek. Lay Creek is a tributary to the Yampa River; its confluence with the river is about 5 miles (8 km) southwest of the Maybell tailings pile. No residents inhabit the area surrounding the tailings pile. The climate of the area is semiarid with an average precipitation of 13 inches (33 cm) per year. The area has warm summers and cold winters. The natural vegetation is dominated by sagebrush with the surrounding hills covered by junipers.

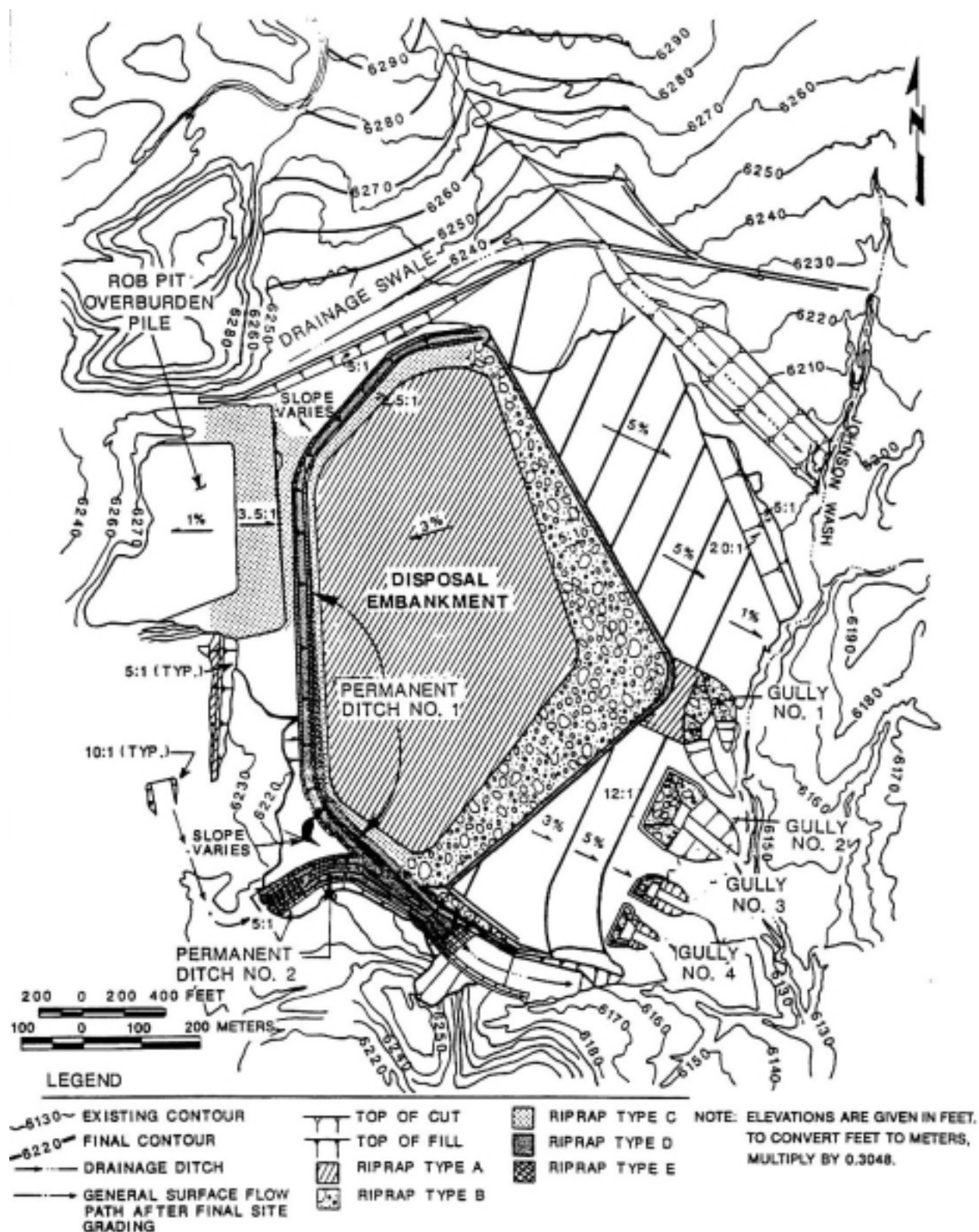
Contaminated areas at the Maybell site included the tailings pile and former mill yard area, the windblown area adjacent to the pile, and waterborne areas along Johnson Wash and Lay Creek (Figure 1). The former mill operators covered the tailings pile with 6 inches (15 cm) of clean soil in accordance with the State of Colorado regulations in placed at the time. However, by the start of the site remediation in April 1995 this soil cover had been eroded and approximately 20 percent of the pile had exposed tailings.



SITE CHARACTERIZATION

Site Geology

The Maybell site rests upon the Browns Park formation of Miocene age. This formation consists of unconsolidated medium to fine grained sand. Within the site area, the Browns Park formation is a 600-foot-thick (183 m) unconfined aquifer, which is underlain by the relatively impermeable Mangos Shale of Cretaceous age. Groundwater levels vary from a few feet below land surface within Johnson wash to over 300 feet (91 m) below land surface north and west of the tailings pile.



Tailings Pile Characterization

The tailings and foundation materials at Maybell were characterized by 135 borings and 79 piezocone soundings on the existing tailings pile . During the field drilling program, soil

samples were obtained for laboratory testing. The borings were advanced with 6.5-inch (16.5 cm) hollow stem augers and samples were taken at nearly continuous intervals. Additionally, undisturbed thin-walled Shelby-tube sampling was performed at intervals specified by the project engineer. Piezocone soundings were performed next to the geotechnical borings to enable correlation between the piezocone data and the borings and laboratory test data. The tailings were differentiated based on the percentage of material having an effective diameter of less than 0.074 millimeters (No. 200 sieve). The three categories are shown in Table I.

Table I - Categories Used to Differentiate Tailings

<u>Designation</u>	<u>Percent Passing #200 sieve</u>
Sand	Less than 30
Sand-Slime Mixture	30-70
Slime	Greater than 70

The tailings pile consists of interlayered sands and slimes overlying alluvial soils. Slime layers up to 24 feet thick (7.3 m) were identified in the south central portion of the pile, with thinner zones occurring along the pile's western edge. The slimes generally grade to sand-slimes and then sands in the northern portion of the pile. Starter dikes used in the construction of the pile on the south and east sides consist of silty sands. Consistencies of the in-place sand tailings are loose to medium dense, and the slimes are generally soft. These consistencies are based on correlations with the blow counts and piezocone point stresses.

Groundwater was not encountered within the tailings pile; however, there are saturated zones in the slimes. Groundwater occurs in the sandstone of the Browns Park formation approximately 35 feet beneath the tailings.

The underlying foundation soils generally consist of silty sands less than 10 feet (3 m) in thickness. These soils are medium dense to dense and exhibit good strength characteristics. Beneath the foundation soils at the site is the sandstone of the Browns Park formation. Properties of the tailings are summarized in Table II.

Radiological Site Characterization

Extensive field sampling and radiological surveys were conducted to determine the extent and degree of contamination at the Maybell site. Approximately 3.8 million cubic yards (2.9 million m³) of residual radioactive materials exists at the site. The pre-existing tailings pile contained 2.8 million cubic yards (2.1 million m³) of tailings with an average Ra-226 concentration of 156 pCi/g. The former mill processing area, located at the north side of the site, had an estimated 20,000 cubic yards (15000 m³) of contaminated demolition debris with an average Ra-226 concentration of 168 pCi/g. The off-pile contaminated materials (materials removed from the north, west, and south side of the tailings pile, and windblown and waterborne contaminated materials) were estimated at approximately one million cubic yards (0.8 million m³) with an average Ra-226 concentration of 36 pCi/g. The background Ra-226 concentration for the Maybell site is 1.5 pCi/g.

REMEDIAL ACTION

Contaminated Material Excavation

Surface remedial action was performed for all contaminated areas, except Johnson Wash and Lay Creek, in compliance with the EPA cleanup standards contained in Subpart B of 40 CFR 192. The cleanup standards require that the residual radioactive materials be removed such that the Ra-226 concentration in land not part of the disposal cell when averaged over any area of 100 square meters does not exceed the background level by more than 5 pCi/g averaged over the first 6 inches of soil below the surface, and 15 pCi/g averaged over subsequent 6-inch layers of soil. Supplemental surface cleanup standards (Subpart C of 40 CFR 192) allow certain areas containing residual radioactive materials to be left in place if it can be demonstrated that impacts of remediations outweigh the benefits. Such supplemental standards were applied to most of Johnson Wash and Lay Creek. Contamination in these areas was left in place because of the relative low risk associated with these materials, the potential environmental harm to riparian and wetland areas, the cost of excavating and diverting of Lay Creek, and the potential detrimental effects on geomorphic stability in Johnson Wash that would result from the cleanup of these areas.

TABLE II - Properties of Tailings at the Maybell Site

Tailings Type	Percent Passing No. 200 Sieve	Specific Gravity	In-Situ Moisture Content (Percent)	In-Situ Dry Unit Weight (lb/ft ³)	Degree of Saturation (Percent)	Compression Index C _c	Coefficient of consolidation C _v (cm ² /s)	Shear Strength Parameters			
								C (lb/ft ²)	(Deg)	C' (lb/ft ²)	' (Deg)
Compacted Tailings	12	2.68	--	--	49	0.072	7.2 x 10 ⁻⁴	0	28	0	28
In-Situ Slime	90	2.86	101	46	100	0.90	7.8 x 10 ⁻⁴ (NC) 4.3 x 10 ⁻³ (OC)	550	0	0	25
In-Situ Sand-Slime	51	2.78	32	85	88	0.20	1.1 x 10 ⁻² (NC) 3.5 x 10 ⁻³ (OC)	0	25	0	28
In-Situ Sand	18	2.64	16	94	56	0.04	1.4 x 10 ⁻²	0	32	0	32

Disposal Cell Design

The Maybell remedial action involved stabilizing the tailings pile and the areas of nearby contamination. Demolition debris from the former mill processing yard, windblown areas containing contaminated soils, waterborne contamination from surface water runoff from the area around the tailings pile and from releases of tailings effluents, and vicinity property contamination were placed with the tailings on the existing pile (Figure 3). Stabilization-in-place was selected as the remedial action because it presented the fewest potential negative impacts on the environment and was the least costly option that satisfied the EPA standards. The general elevation of the Maybell site is approximately 200 feet (61 m) higher than the Lay Creek floodplain at its confluence with Johnson Wash. Therefore, flooding in either Lay Creek or the Yampa River will not impact the disposal site. The disposal cell contains approximately 3.8 million cubic yards (2.9 million m³) of contaminated materials on approximately 66 acres (27 ha) and is somewhat triangular in plan view, with a maximum length of 2650 feet (808 m) and a maximum width of 1750 feet (533 m). The disposal embankment stands about 40 feet (12 m) above the surrounding topography. The disposal embankment was constructed with a top slope of 3 percent and side slopes of 20 percent (Figure 2). The surface water runoff on the cell drains into diversion ditches along the north, west, and south toe of the embankment. Two permanent diversion ditches also divert runoff from the upstream drainage area west and south of the disposal embankment and drain into Johnson Wash on the southeast side of the site. The west ditch is 4350 feet (1325 m) long with maximum flow depth of 6 feet (1.8 m) and maximum peak flow velocity of 12.4 ft/sec (3.8 m/sec). The south ditch is 350 feet (107 m) long with maximum flow depth of 5 feet (1.5 m) and peak flow velocity of 15.7 ft/sec (4.8 m/sec). Both ditches have 5:1 side slopes. Two swales were constructed north of the disposal cell to divert storm runoff from the embankment and into Johnson Wash on the northeast side of the site (Figure 2). All the diversion ditches and swales were designed to carry the runoff resulting from the maximum probable precipitation (PMP) storm. The riprap erosion protection in the existing gullies along Johnson Wash near the east side of the disposal cell and at the outlet of the diversion ditch also was designed to protect from local scouring and prevent headcutting toward the embankment. The areas around the disposal cell were graded such that runoff from the embankment as well as the surrounding areas will be directed away from the embankment and into Johnson Wash. A rock apron 20 feet (6.1 m) wide was placed along the east side of the embankment to prevent headwater erosion of gullies into the disposal embankment.

Perhaps the most important and challenging part of the remedial action was the design of the protective cover for the disposal cell (Figure 3). The function of the cover is to protect the cell from erosion, minimize infiltration, and reduce the radon flux to the required limit. The Maybell disposal cell cover consists of four layers; from bottom to top, these are: 1) radon/infiltration barrier, 2) frost barrier, 3) bedding layer, and 4) erosion protection (riprap) layer.

Radon/Infiltration Barrier: Contaminated materials were covered with 1.5 feet (46 cm) of compacted fine grained material consisting of silty sand amended with 7 percent Wyoming bentonite. This low permeability layer will limit infiltration of precipitation through the tailings and will reduce radon releases to below EPA standards. EPA radon design standards limit the average radon emissions from a tailings disposal embankment to 20 picocuries per square meter per second (pCi/m²s). The computer code RAECOM (4) was used to calculate the required

thickness of the radon/infiltration barrier. The required input parameters are dry bulk density, porosity, long term moisture content, radium concentration, radon emanation, and radon diffusion coefficients of the tailings and radon barrier, and the layer thicknesses of the tailing materials. The long-term moisture content of the radon barrier is of particular concern, since the thickness of this layer is very sensitive to moisture variances. Estimates of long-term moisture contents of the radon/infiltration barrier and other contaminated materials were made using laboratory tests (ASTM D2325 and ASTM D3152) and empirical correlation (5). The predicted amount of water infiltration into the disposal cell is related to the permeability of the radon/infiltration barrier. A permeability of less than 1×10^{-7} cm/sec was required for the cell cover. Since the Maybell disposal site is located in an area where there is a lack of locally available clayey materials, a sand-bentonite mixture was used for the radon/infiltration barrier. Based on laboratory test results, radon/infiltration barrier design parameters were established for sand mixed with various percentage of bentonite. It was determined that a permeability of less than 1×10^{-7} cm/sec could be achieved by mixing the locally available sand with a 7 percent by weight of sodium bentonite from Wyoming.

Frost Barrier : Test results have shown that the repeated cycles of freezing and thawing cause the permeability of compacted fine grained soils to increase (6,7). The increases are about one to three orders of magnitude. In order to protect the radon/infiltration barrier from the deleterious effects of repeated freezing and thawing, the barrier was covered with sufficient amount of material to prevent frost from penetrating it. The required thickness of the protective frost barrier depends on local climatic conditions and geotechnical properties of the soil and rock layers used in the cover. Soil properties such as dry density, moisture content and soil type were determined from laboratory tests. The weather parameters used in the frost depth calculation are the design freezing index, mean annual temperature, and the duration of freeze. The climatic data are based on 45 years of historical climatic records in Craig, Colorado which is 25 miles (40 km) east of Maybell site. Based on the limited historic data, it was not practical to reasonably predict the climatic conditions for a 1000-year design life. However, the prediction that a design frost depth will not be exceeded within at least a 200-year return period could be made with a reasonable degree of accuracy using existing temperature records (8). Therefore, a 200-year design life was adopted for the frost depth penetration. A computer solution to the modified Berggren equation (9) was used to calculate the depth of frost penetration. A maximum frost depth of 4 feet (1.2 m) was calculated. Therefore, a four-foot-thick (1.2 m) frost barrier comprised of locally available sandy material was placed on top of the radon /infiltration barrier.

Bedding Layer : A 6-inch- thick (15 cm) bedding layer was placed on top of the frost barrier. The bedding layer, consisting of sandy gravelly material, was designed to resist erosion of the underlying frost protection material while providing adequate drainage capacity for the embankment top and side slopes. This layer also protected the frost protection layer from damage during the placement of the overlying erosion protection layer.

Erosion Protection Layer: The disposal cell top and side slopes were covered by rock erosion protection materials designed to prevent wind and water erosion of the tailings, the frost barrier, and the radon/infiltration layer. The design flows and velocities for the cell top and side slopes were developed from the PMP event. The Safety Factors Method (10) and Stephenson's method (11) were used to design the erosion protection on the 3 percent topslope and 20 percent

sideslope, respectively. The parameters needed to design the rock for the erosion protection are: the angle of repose of rock, the specific gravity of the rock, the slope over which the rock will be placed, the velocity of flow and the depth of flow over the rock. Table III shows the erosion protection requirements and layer thicknesses for the disposal cell and permanent drainage features.

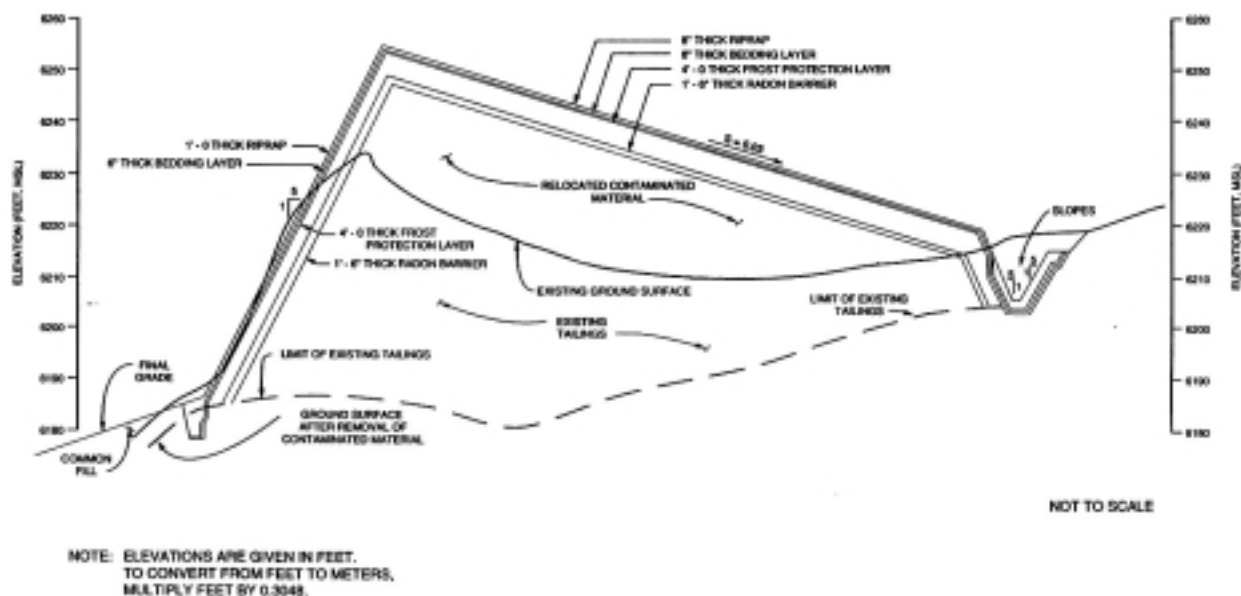


Table III - Erosion Protection Requirements for the Maybell Disposal Cell

<u>Location</u>	<u>Rock Size Requirements (in)</u>			<u>Layer Thickness (ft)</u>
	<u>D_{50,min}</u>		<u>D_{100,min}</u>	<u>D_{100,max}</u>
Topslope	1.7	2.2	2.9	0.67
East Sideslope	3.1	3.9	5.3	1.0
West Sideslope	3.8	4.8	6.5	1.0
Ditch No. 1 and No. 2, and Gullies Side slopes	11.0	13.9	18.8	2.0
Ditch No. 1 Key Trench, and Gullies Key Trench	24.0	30.2	41.0	4.0

GEOTECHNICAL ENGINEERING EVALUATION

Slope Stability

The stability of the disposal embankment was analyzed for both static and seismic loading conditions. Two disposal cell cross sections were selected for stability analysis. One section was on the southeast side of the cell where the embankment is at its maximum height of approximately 70 feet (21.3 m); and the other section was on the west side of the cell, where thick layers of slime, up to 17 feet (5.2 m), were encountered in boreholes along the cell's edge. Material properties summarized in Table II were used in the analysis. The results of the analyses indicated factors of safety ranging from 1.1 (for the end-of-construction, seismic condition) to 2.2 (for the long-term, static condition).

Settlement Analysis

Embankment settlement was evaluated at 51 locations where piezocone sounding tests were performed. These locations represent a mixture of conditions across the cell and include areas with the thickest zones of slime. Continuous stratigraphic data obtained from piezocone soundings were used to construct the geotechnical profiles for the tailings pile. The consolidation properties of the particular tailings type in each profile were used to evaluate settlement. Because the settlement of concern was the post-construction settlement, the loading sequence was also taken into account. The post-construction settlement is the settlement which occurs after the embankment cover has been placed. In the analysis both primary consolidation and secondary compression were evaluated.

The calculated total embankment settlement ranges from 1 inch (2.5 cm) to about 36 inches (91cm). The predicted maximum settlement occurs at the south central portion of the embankment where thick layers of slime up to 24 feet (7.3 m) are located. The predicted post-construction settlement ranges from 1 inch (2.5 cm) to approximately 15 inches (38 cm). The time from the beginning of placement of contaminated materials to completion of primary consolidation settlement ranges from approximately 10 months to nine years. Settlement monuments were placed on top of the disposal cell to monitor the actual settlement. Based on previous experience on other UMTRA Project sites the calculated settlement based on consolidation test data usually overestimates the actual ultimate settlement and underestimates the actual measured rate of settlement of uranium mill tailings (12).

Cover cracking analysis

Differential settlement, which tends to increase with increasing total settlement, is a critical design parameter due to its potential to cause drainage flow concentrations that can erode the embankment cover system and/or cause the radon barrier to crack. Either condition can lead to failure of the cover system. The south central portion of the Maybell embankment is expected to have the greatest potential for differential settlement. The effect of differential settlement on cover cracking was evaluated by comparing the estimated maximum horizontal tensile strain developed in the radon barrier layer with the strain required to cause cracking (13). The calculated maximum horizontal tensile strain that would develop at the top surface of radon barrier is 0.04 percent. This strain is not considered to be sufficient to cause cracking of the

radon barrier. For soils compacted at moisture contents which are not drier than about 3% below optimum, a minimum tensile strength of 0.05% is required for cracking (14).

CONSTRUCTION

Contaminated Material Excavation and Placement

The majority of contaminated materials were excavated using scrapers. The contaminated materials were excavated and placed so that the materials with the highest Ra-226 concentration were placed first and the less contaminated materials were placed at or near the top of the disposal cell. All contaminated demolition debris were reduced to manageable pieces and placed carefully in the embankment to ensure that no voids or nesting existed around the debris. Excavation of all contaminated materials was continually monitored by Health Physics personnel to make sure that all contaminated materials had been excavated and to prevent inclusion of unnecessary, uncontaminated materials in the cell. Final verification surveys were performed by documenting average Ra-226 concentrations on all 100 m² areas remediated. Composite surface soil samples were collected for each 100 m² area and analyzed by gamma spectroscopy to verify compliance with EPA standards. Average surface Ra-226 concentrations had to be below 5 pCi/g plus background and measured to within plus or minus 30 percent of the mean at the 95 percent confidence level. Motor graders and dozers were used to spread the contaminated materials on the embankment and CAT 815's were used to compact the contaminated materials. The material was spread to a maximum 12 inch (30 cm) loose lift thickness and was then compacted to a minimum of 90 percent of Standard Proctor maximum dry density.

Cover Placement

A sandy silty material from an on-site borrow source was mixed with 7 percent Wyoming bentonite and used for radon barrier. A pugmill was used to amend the borrow material with bentonite and also to properly moisture condition the material. After the radon barrier material was properly mixed, scrapers were used to haul the material to the placement area. The first lift of radon barrier had to be header banked over the contaminated materials by a dozer to prevent contamination of either the equipment or radon barrier material. Radon barrier material was compacted to a minimum of 95 percent of maximum dry density and at a moisture content within zero to plus 2 percent of the optimum moisture content, as determined by ASTM D698. The moisture content of the radon barrier had to be monitored carefully, because if the material had too much moisture, the finishing of the material would be impossible until the material dried out to no greater than 2 percent above optimum moisture. Due to the strict requirements on the moisture content of the radon barrier, the placed material was compacted and finished as soon as possible so it could be covered with a minimum of one lift of frost barrier. After the final layer of radon barrier was placed and finished, but prior to placement of subsequent layers, the radon flux was measured at 101 points on the disposal cell to verify compliance with EPA standards.

The frost protection layer was constructed in 9-inch (23 cm) lifts to a total thickness of 4 feet (1.2 m). A sheepsfoot-type roller was used to compact this material to a minimum of 90 percent of Standard Proctor maximum dry density.

The erosion protection materials were hauled and stock piled on the site by either belly dump trucks or end dump trucks. The smaller size rocks were then hauled to the placement areas by scrapers while the larger rocks were hauled by rock wagons. After the materials had been placed to a rough grade, smooth drum rollers and trackhoes were used to achieve a smooth, well keyed, densely placed layer. Gradation tests were performed during production and placement of the erosion protection materials to ensure that the materials satisfied the gradation requirements shown in Table III.

Site Grading and Revegetation

During the remedial action, portions of the site outside the stabilized embankment were excavated to varying depths below the natural grade to remove contaminated materials. These areas were restored to natural grade (or as specified in design) with soil compacted to a minimum of 90 percent of the maximum dry density as determined by the standard proctor method (ASTM D698). The top 6 inches of soil were not compacted and prepared with adequate organic substance, and fertilizer to promote vegetation. These areas were then seeded with hardy native grasses.

ACKNOWLEDGMENTS

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REFERENCES

1. UMTRCA, "Public Law 95-604, Uranium Mill Tailings Radiation Control Act of 1978, 42 USC 7901," 95th Congress of the United States of America, Washington, D.C.(November 1978).
2. U.S. Environmental Protection Agency, "Health and Environmental Protection Standards for Uranium Mill Tailings," 40 CFR 192 (January 1983).
3. U.S. Department of Energy, "Remedial Action Plan and Site Design for Stabilization of the Inactive Uranium Mill Tailings for Maybell, Colorado," DOE UMTRA Project Office, Albuquerque, New Mexico (June 1994).
4. U.S. Nuclear Regulatory Commission, "Radon Attenuation Handbook for Uranium Mill Tailings Cover Design, NUREG/CR-3533," Prepared by Rogers and Associates Engineering, Salt Lake City, Utah, for the U.S. Nuclear Regulatory Commission, Washington, D.C. (1984).
5. Rawls, W.J. and Brakensiak, D. L., "Estimating Soil Water Retention from Soil Properties," Journal of the Irrigation and Drainage Division, ASCE, Vol. 108, No. IR2 (June 1982).

6. Chamberlain, E.J., and Ayorinde, O.A., "Freeze-Thaw Effects on Clay Covers and Liners," Proceedings of the 6th International Specialty Conference, West Lebanon, NH (February 1991).
7. Banani, A.M., and Claire, R.F., "Design of UMTRA Coveres to Mitigate the Effect of Frost Penetration," Proceedings of the WM'94 Conference, Tucson Arizona, (March 1994).
8. U. S. Department of Energy, "Technical Approach Document," UMTRA-DOE/AL-050425.0002, DOE UMTRA Project Office, Albuquerque, New Mexico (December 1989).
9. Aitken, G. W., Berg, R.L., "Digital Solution of Modified Berggren Equation to Calculate Depths of Freeze and Thaw in Multilayered System," U.S. Army Corp of Engineers Cold Regions Research and Engineering Laboratory, Special Report 122 (1986).
10. Stevens, M. A., Simons, D. B., and Lewis, G. L., "Safety Factors for Riprap Protection," ASCE Journal of the Hydraulics Division, Vol. 102, No. HY5 (May 1976).
11. Stephenson, D., Rockfill in Hydraulic Engineering, Elsevier Scientific Publication, New York (1979)
12. Banani, A. M., and Randeni, J., "Consolidation Characteristics of Uranium Mill Tailings," U.S. DOE ER'93- Environmental Remediation Conference, Augusta, Georgia (October 1993).
13. Lee, K. L., and Shen, C.K., "Horizontal Movement Related to Subsidence," ASCE, Journal of SMFD (January1969).
14. Morrison Knudsen Corporation, "UMTRA Design Procedure Manual," San Francisco, California (January 1989).