

THE U.S. URANIUM MILL TAILINGS RADIATION CONTROL ACT  
AN ENVIRONMENTAL LEGACY OF THE COLD WAR

**Chris D. Watson**

Jacobs Engineering Group Inc.  
Albuquerque Operations Office  
Albuquerque, New Mexico

**Paul Mann**

U.S. Department of Energy  
Albuquerque Operations Office  
Albuquerque, New Mexico

**Roger A. Nelson**

Jacobs Engineering Group Inc.  
Albuquerque Operations Office  
Albuquerque, New Mexico

## Table of Contents

ABSTRACT .....	3
1.0 INTRODUCTION .....	3
1.1 Historical Background .....	3
1.1.1 Purpose .....	3
2.0 DESCRIPTION OF THE PROJECT .....	4
2.1 Regulations .....	5
2.1.1 Long-Term Stability .....	5
2.1.2 Radon Emissions Control .....	5
2.1.3 Proposed EPA Groundwater Standards .....	5
2.2 Technical Approaches .....	6
2.2.1 Geologic and Geotechnical Stability .....	6
2.2.2 Radon Barrier .....	7
2.2.3 Surface-Water Hydrology .....	7
2.2.4 Cover Design .....	7
2.3 Project Documentation .....	8
2.3.1 NEPA Documentation .....	9
2.3.2 Remedial Action Plan .....	9
2.3.3 Quality Assurance Plan .....	9
2.3.4 Completion Report .....	9
2.3.5 Long-Term Surveillance Plan .....	9
2.3.6 Environmental Safety and Health Plan .....	9
2.3.7 Public Involvement/Public Participation Plan .....	9
2.3.8 Guidance Documents and Special Studies .....	9
2.4 Groundwater Restoration .....	10
3.0 LESSONS LEARNED .....	10
3.1 Costs .....	10
3.2 United States Nuclear Regulatory Commission .....	11
3.3 Grand Junction, Colorado .....	11
3.4 Falls City, Texas .....	11
3.5 Risk Assessment and Mitigation .....	14
4.0 CONCLUSIONS .....	14
References .....	15

## List of Tables

Table 1 UMTRA Project Completion .....	4
Table 2 Uranium Ore Processed, Disposal Cell Material, and Cost for Remediation of UMTRCA Title I Uranium Mill Sites .....	12

## List of figures

Figure 1 Vegetated Cover .....	8
Figure 2 Rock Cover .....	8
Figure 3 UMTRA Remediation Costs vs. Remediated Material .....	13
Figure 4 UMTRA Remediation Costs vs. Radiation Avoided .....	13
Figure 5 UMTRA Remediation Costs vs. Uranium Produced .....	13

## ABSTRACT

The United States Department of Energy (DOE) has guided the Uranium Mill Tailings Remedial Action (UMTRA) Project through the successful remediation of the designated sites. The Uranium Mill Tailings Radiation Control Act (UMTRCA), passed in 1978, identified 24 uranium mill tailings sites in need of remediation to protect human health and the environment from the residual contamination resulting from the processing of uranium ore. The UMTRCA was promulgated in two titles: Title I and Title II. This paper describes the regulatory structure, required documentation, and some of the technical approaches used to meet the Act's requirements for managing and executing the \$1.4 billion project under Title I. Remedial actions undertaken by private industry under Title II of the Act are not addressed in this paper.

Some of the lessons learned over the course of the project's history are presented so that other countries conducting similar remedial action activities may benefit.

## 1.0 INTRODUCTION

As the chapter on the Cold War between world superpowers has closed, many communities around the world face the environmental legacy of this period—enormous quantities of hazardous and low-level radioactive materials from the production of uranium used for energy and nuclear weapons. The United States Uranium Mill Tailings Radiation Control Act (UMTRCA) of 1978 was the beginning of the United States' attempt to clean up 24 sites in 10 states across the country. UMTRCA's goal was to protect human health and mitigate the environmental harm caused by uranium mill tailings and their effects on local communities. Construction has been completed at all of the sites as shown in Table 1. The Grand Junction Vicinity Properties (VP) program has remediated over 5,300 properties. The amount of material stabilized and isolated to date exceeds 46 million cubic yards (33 Million cubic meters) of tailings. Windblown contamination, subpile contamination, rubble, or VP material are not included in that volume of material.

### 1.1 Historical Background

Uranium ore was mined in significant quantities in the United States for over 40 years. In many cases, the ore was mined by private companies for the United States Government to use in national defense programs. These activities produced tailings piles at uranium ore processing sites.

The tailings are sand-like materials that remain after the uranium is extracted. These extraction processes were not 100 percent efficient; therefore, the tailings material contains small concentrations of uranium and other naturally occurring radioactive daughters of uranium. Of most concern are the immediate daughters: thorium, radium, and especially radon.

Over the years, public concern surfaced around the issue of radioactivity from uranium mill tailings and its

effect on human health. Concern focused on the potential health hazard associated with low levels of radiation exposure over extended periods of time due to the misuse of these materials by man. One source of exposure was the radium and radon gas from the tailings piles. This public concern led the United States Congress to pass Public Law 95-604, the UMTRCA. The Act legally authorized the cleanup program called the Uranium Mill Tailings Remedial Action (UMTRA) Project. The inactive mill sites were included in Title I of the UMTRCA, whether uranium from these facilities was sold to the United States Government or not. Title II of the UMTRCA was established to provide a regulatory framework for remedial actions at the active uranium milling facilities owned and operated by private industry.

The mission of the project was explicitly stated and directed in UMTRCA. Simply put, the United States Congress found that uranium mill tailings at active and inactive mill operations may pose a significant radiation health hazard to the public. The protection of public health, safety, and welfare requires that every reasonable effort be made to stabilize, dispose of, and control the tailings in a safe and environmentally sound manner. The goal was to prevent or minimize radon diffusion into the environment and other environmental hazards. The United States Department of Energy (DOE) was directed under Title I to undertake remedial action at 24 designated inactive uranium processing sites and associated vicinity properties (VP) containing uranium mill tailings and other residual radioactive material (RRM).

The Act defined the term "processing site" as any site containing RRM at which all or substantially all of the uranium was produced for sale to any federal agency. The term "residual radioactive material" was defined to mean waste in the form of tailings resulting from the processing of ores for the extraction of uranium and other valuable constituents of the ores. The term "tailing" was defined to mean the remaining portion of the metal-bearing ore after some or all of such metal, such as uranium, had been extracted.

**1.1.1 Purpose.** The Act specified 24 potential processing sites for remedial action under Title I. As part of the program, the actual processing site boundaries were determined and located at these sites. These sites were then known as designated processing sites for remedial action.

The public law also specified a number of tasks and a specific time frame for completion. The primary tasks were to assess the potential health hazard to the public from the RRM at the designated processing sites and to complete remedial action at these sites prior to the termination of authority under the Act.

The following remedial actions undertaken by the project were to be accomplished in concert with several special provisions:

**Table 1 UMTRA Project Completion**

Site Name	Surface Remediation Completion Date	NRC Certification Date	NRC Licensing Date	Transfer to LTSM (GJPO) Date
	Fiscal Year			
Ambrosia Lake, New Mexico	1995	1996	1997	1997
Belfield, North Dakota <sup>1, 2</sup>	1997	1998	NA	NA
Bowman, North Dakota <sup>1</sup>	1997	1998	1998	1998
Canonsburg, Pennsylvania <sup>2, 3</sup>	1987	1995	1996	1994
Durango, Colorado <sup>2</sup>	1991	1996	1996	1996
Falls City, Texas	1994	1996	1997	1997
Grand Junction, Colorado <sup>2</sup>	1994	1999	1999	2000
Green River, Utah	1990	1992	1996	1996
Gunnison, Colorado <sup>2</sup>	1996	1997	1997	1998
Lakeview, Oregon <sup>2</sup>	1990	1994	1995	1995
Lowman, Idaho	1992	1994	1994	1995
Maybell, Colorado	1997	1998	1998	1998
Mexican Hat, Utah	1995	1996	1996	1997
Monument Valley, Arizona <sup>2</sup>	1994	1996	NA	NA
Naturita, Colorado <sup>2</sup>	1997	1998	1998	1998
Rifle, Colorado (2 sites) <sup>2</sup>	1996	1998	1998	1998
Riverton, Wyoming <sup>2</sup>	1990	1995	NA	NA
Salt Lake City, Utah	1989	1997	1998	1998
Shiprock, New Mexico	1987	1991	1996	1997
Slick Rock, Colorado (2 sites) <sup>2</sup>	1996	1998	1998	1998
Spook, Wyoming	1989	1992	1993	1994
Tuba City, Arizona	1990	1996	1997	1996

1) The State of North Dakota requested that DOE remove these sites from the designation list under the Uranium Mill Tailings Radiation Control Act. 2) Indicates remote disposal cell. 3) This date represents the licensing date for the processing site. Remote disposal cell was licensed in 1994.

(1) In cooperation with the affected states and Indian tribes. Cooperative agreements set forth the funding, real estate acquisition, and technical review requirements necessary to perform remedial actions at the designated UMTRA sites.

(2) With the concurrence of the United States Nuclear Regulatory Commission (NRC). The NRC's concurrence was required on the remedial action plan (RAP) at each site to ensure that the selected action meets the United States Environmental Protection Agency (EPA) standards, as required by the Act. The DOE also was required to obtain licenses from the NRC for long-term, post-remedial action surveillance and maintenance activities at the disposal sites.

(3) In accordance with standards promulgated by the EPA and with applicable federal and state laws. The groundwater portions of the EPA standards were remanded in 1985. The EPA was instructed to produce numerical standards for specific water-quality parameters. Draft proposed groundwater standards were issued by the EPA in 1987.

The project also was to complete the environmental investigations, documentation, and public review required by the National Environmental Policy Act (NEPA) of 1969. In addition, the project was to determine the economic feasibility of reprocessing the tailings to extract any valuable minerals remaining. The project surveyed all of the sites and found that none of the remaining tailings piles possessed valuable minerals in sufficient quantity to profitably reprocess the tailings.

## 2.0 DESCRIPTION OF THE PROJECT

A complex regulatory structure, based on standards promulgated by the EPA, evolved after the Act was passed. Section 2.1 discusses the prescriptive promulgated standards for long-term stability, radon emission, and groundwater. These standards were set with the intent that any mill site remediated to meet them would be completely protective of human health and the environment, regardless of local setting and exposure potential. Therefore, the standards were

generally prescriptive and do not take exposure risk into account.

Technically, the challenges were to define the existing conditions at each site, then determine a RAP that would meet the standards. Because of the many affected and involved parties (federal, state and local regulators; the state and local elected representatives; and the public), reaching consensus on a proposed remedial action was difficult. Consequently, the period for building a consensus and obtaining approval to start remedial action in accordance with the proposed plan usually took more time than the period required to physically remediate a site. The technical approaches used to clean up and isolate the contaminants from the environment for 1,000 years are discussed in Section 2.2. Extensive documentation was required by the project to establish consensus. Documentation for remedial action and the NEPA process are discussed in Section 2.3.

Finally, the preliminary planning for the groundwater restoration phase of the program is discussed in Section 2.4.

## **2.1 Regulations**

The requirements in the standards promulgated by the EPA cover three areas: (1) long-term isolation and stabilization of tailings, (2) radon control, and (3) protection of water quality.

The standards discussed below, under which the project has completed the remedial actions, are generally prescriptive. That is, quantitative limits were imposed regardless of the presence of human receptors. Worst-case future exposure scenarios consistently required conservative prescriptive remedial action solutions. This led to actions that were costly in comparison to the actual risk (and exposure) reduction achieved. An example of this is the relocation of tailings from the processing site to a nearby location, even though the nearest population to the original site was several kilometers away.

**2.1.1 Long-Term Stability.** The primary objective of the EPA standards is to isolate and stabilize the tailings to prevent misuse by humans and dispersal by natural forces. Accordingly, long-term stability was emphasized when the standards were developed and promulgated. This is consistent with the guidance provided by the legislative history of the UMTRCA, which stressed the importance of avoiding remedial actions that would be effective only for a short period of time and that would require future Congressional consideration.

The EPA distinguished "passive controls," such as thick earthen covers, below-ground disposal, rock covers, and massive earth and rock dikes, from "active controls," such as semi permanent covers, warning signs, and restrictions on land use. Active control covers may need frequent replacement or other major repairs requiring the continued appropriation and expenditure of public funds. In setting the standards, the EPA called for designs that rely primarily on passive controls.

The standards are framed as a longevity requirement that recognizes the difficulty in predicting very long-term performance with a high degree of confidence. In establishing the longevity requirement, the EPA concluded that existing knowledge permits the design of control systems that have a high expectation of lasting at least 1,000 years. Therefore, a design objective of 1,000 years was to be satisfied whenever reasonably achievable. In any case, a minimum performance of 200 years was stipulated.

The standards recognize the need for institutional controls such as custodial maintenance, monitoring, and contingency response measures. In its preamble to the standards, the EPA calls for such controls to be provided as an essential backup to the primary passive controls. An example would be the addition of a system in the disposal cell to monitor for ponded water that will allow for corrective action should the level of ponding exceed the levels predicted.

**2.1.2 Radon Emissions Control.** The secondary objective of the EPA's standards is a reduction of radon emissions from tailings piles. The EPA considered several alternative approaches and selected emission limits as the primary form of control. In addition, the EPA established a concentration limit as an alternative form of control in cases where the DOE determined that the alternative was appropriate.

In establishing the radon standard, the EPA determined that the emission limit could be achieved by well-designed thick earthen covers, and that such control techniques would be compatible with the requirements of the EPA longevity standard.

In establishing the emission limits for tailings piles, the EPA sought to reduce both the maximum risk to individuals living very near to the sites and the risk to the population as a whole. With regard to individuals living very near disposal sites, the EPA estimated that exposure to radon emissions would be reduced by more than 96 percent after remedial action. The radon standard would limit the increase in radon concentration attributable to a pile to a small increase above the background radon level near the disposal site. Both radon standards are design standards, with compliance to be determined on the basis of predicted rather than measured emission rates and concentrations. Post-remediation monitoring was not required to show compliance. However, the DOE has found post-remediation monitoring useful in determining whether the anticipated performance of the control system was achieved.

**2.1.3 Proposed EPA Groundwater Standards.** Under UMTRCA, the DOE had to comply with the proposed standards until the final standards were promulgated. The proposed EPA groundwater standards [40 CFR 192(a)(3)] include the following:

- (1) The identification of hazardous constituents [40 CFR 192.02(a)(3)(i)];
- (2) The establishment of compliance levels for the hazardous constituents, which may include background concentration limits, maximum concentration limits, or

alternate concentration limits (40 CFR 192.02(a)(3)(iii));

(3) The establishment of a point of compliance [40 CFR 192.03(a)(3)(iv)].

In establishing the proposed groundwater standards, the EPA gave the NRC authority to approve the site-specific groundwater protection standards. The site-specific standards include alternate concentration limits (ACL) and supplemental standards. ACLs may be applied if it can be demonstrated that (1) the hazardous constituent will not pose a substantial present or future hazard to human health or the environment as long as the ACL is not exceeded, and (2) the ACL is as low as is reasonably achievable. In addition, the proposed standards provide the framework for obtaining the groundwater supplemental standards for disposal and groundwater restoration. Supplemental standards (40 CFR 192.21) for a disposal site can be obtained when groundwater is limited in use (Class III groundwater). When supplemental standards are applied under the limited-use criterion (40 CFR 192.22), the remedial actions must come as close to meeting the otherwise applicable standards as is reasonably achievable and must protect human health and the environment.

Compliance with these standards must be evaluated differently, depending on whether the tailings material was relocated to a separate disposal cell or stabilized at the original processing site. For relocated sites, the standards are to be applied to the new site for the protection of groundwater from contaminants isolated in the disposal cell. For the sites stabilized in place, the standards are to be applied to the incremental effect due to additional leaching of contaminants into the groundwater.

## **2.2 Technical Approaches**

The general approaches and design criteria adopted by the DOE to implement RAPS that comply with EPA standards are outlined in a 1989 document called the *Technical Approach Document* (TAD). In the TAD, the project identified key elements to be considered in developing the remedial action design for the surface remediation of a uranium mill site. These areas include, but are not limited to, the controlled releases of radon and radon barrier design; protection of groundwater resources; geological stability; geotechnical stability; surface water hydrology; and cover design.

The Act required that the RAP be reviewed and concurred upon by the NRC and representatives of the state in which the remedial action was occurring. The NRC's concurrence with the DOE's selected remedial action (with the conclusion that the action complies with the standards promulgated by the EPA) provides assurance that the remedial action removes the health risk to the population at large.

Remedial actions by the project typically consisted of two types: stabilization in place or on the site, and relocation of all contaminated materials. The type of permanent isolation technique selected depended on long-term compliance with prescriptive groundwater standards. Regardless of this, the disposal cell covers were designed and constructed in various ways. Some

are simple double layers of clay (to prevent radon emission and water infiltration) with rock to prevent surface erosion. Others are complex (seven-layer) covers with components for biointrusion prevention, subsurface drainage, enhanced evapotranspiration, and even aesthetics.

One of the first activities in the design process was to conduct an alternate-site selection survey. This survey evaluated the existing site and potential disposal sites within an 8-kilometer radius of the existing mill site. The alternate-site selection survey sought to identify sites that minimize hydrologic impacts; are geologically and geomorphically stable; are located out of the floodplain with minimal upstream surface drainage area; are close to suitable borrow materials; are away from existing human development; are removed from critical wildlife habitats; and are close to existing transportation networks.

The project initially estimated that only a few sites would be relocated. However, the groundwater compliance requirements of the EPA standards resulted in the relocation of approximately one-half of the 24 sites. The groundwater compliance standards drove the site-selection process more than all other factors combined.

Stabilization in place involves minimal movement of contaminated materials; therefore, this option is usually the most cost effective. Generally, windblown materials are consolidated and the tailings pile is reshaped. A cover system is then constructed over the reshaped pile for erosion and radon control.

Contaminated materials are usually relocated to another site when the existing site is unsuitable. This option was used when the DOE determined that the site did not meet the criteria cited above in the alternate-site selection process.

The primary goals during the design process were to meet the EPA standards, protect public health, and perform remedial action in the most cost-effective manner. However, in some situations socioeconomic or political issues prevailed, affecting the remedial action and ultimately the cost of the project. Thus, it was important to fully explore all the potential options with the full cooperation of all affected participants: local communities; federal, state, and local governments; and regulating agencies. This objective was accomplished through a proactive public participation program to encourage public support of and input into the decision-making process. This input directly influenced project policy and technical decisions made regarding the site.

**2.2.1 Geologic and Geotechnical Stability.** The geologic stability of a site and its impact on the disposal cell design are functions of the site's seismotectonic and geomorphic setting. The seismotectonic characterization of the proposed disposal site provided a set of earthquake design parameters and an analysis of the potential for on-site fault rupture. The geomorphic hazard assessment identified the geomorphic processes that affect the site, estimated the probability of their occurrence, and evaluated the possible magnitude of their effects during the design life of the disposal cell.

The geotechnical stability of a specific disposal cell depended on site-specific conditions and the overall design of the cell. The primary concern was the differential settlement of the materials within the cell, which tends to increase in total settlement. This can cause cracking in the radon barrier or drainage flow concentrations that could lead to failure of the disposal cell cover system.

**2.2.2 Radon Barrier.** The radon barrier's primary purpose is to reduce the radon emissions (flux) from the contaminated materials. A secondary benefit is the reduction of water infiltration into the contaminated materials. Water infiltration leaches out heavy metals and other chemicals, which could potentially contaminate the groundwater at the site.

### **Radon Emissions**

The disposal cell design influences the amount of barrier material required to inhibit radon emissions. The radon flux standard as promulgated by the EPA was slightly less than 1 Becquerel per square meter-second ( $\text{Bq/m}^2\text{S}$ ). The radon barrier thickness therefore depended on the activity level of the tailings and the location of various higher and lower levels of tailings activity within the disposal cell. Beyond a given depth of tailings, an increasing depth of contaminated material (no matter its activity level) does not affect the required thickness of the radon barrier to meet the flux standard. Thus, minimizing the area of the cell by increasing its depth reduced the amount of radon barrier material required and, in turn, reduced the overall cost of remedial action at the expense of the geotechnical stability.

The thickness of the radon barrier was also governed by construction technique limitations. The heavy construction equipment used in the remediation of mill sites mandates that the minimum thickness be 15 centimeters to ensure that adequate material is placed. Bentonite was successfully added to the radon barrier material at sites with sandy materials to augment control over radon emanation and water infiltration. This design feature can increase the cost of remedial action. Therefore, it was essential that a balance be achieved between the area of the cell, the radon barrier's thickness, construction technique limitations, and the addition of bentonite.

### **Water Infiltration**

The second consideration influencing the radon barrier design was the need to limit the infiltration of precipitation into the disposal cell. This aspect of the radon barrier was critical to the groundwater protection strategy, since water infiltrating through the tailings can transport contaminants from the tailings into the groundwater.

Steps were taken in the design of the disposal cells to minimize infiltration. Drain layers were sometimes used immediately above the radon barrier to divert precipitation from the disposal cell and minimize ponding on the radon barrier. At some sites, vegetative top slopes have been used to take advantage of the evapotranspiration effects of vegetation. The key

consideration in the water resources protection strategy was the elimination or minimization of infiltration through the completed disposal cell.

**2.2.3 Surface-Water Hydrology.** The choice of stabilization in place or relocation of the materials was influenced by the expected magnitude of the hydrologic events. On-pile and upland watershed runoff determined the magnitude of erosion protection required for the disposal cell. The amount of erosion protection needed then affected project costs.

The primary design conditions affecting the disposal cell were on-pile surface runoff, upland watershed runoff, and flooding associated with nearby large streams or watersheds. The impacts from the upland runoff and flooding can be the most disruptive. Where these conditions exist, the best solution is to relocate the tailings material to another site with more favorable conditions. This is because the amount of upland watershed runoff also determines the size of the drainage ditches, erosion protection of those ditches, and the toe of the disposal cell. The flooding potential of nearby large streams or large watersheds also affects the design of the drainage facilities and the erosion protection of the disposal cell. The runoff is generally allowed to drain around the disposal cell either in direct contact with the side slopes or in drainage diversion channels.

Consideration was given to managing the on-pile surface runoff to avoid increasing flow on the top or side of the cell. This could result in long-term erosion of the cover system.

**2.2.4 Cover Design.** The project generally used two main types of disposal cell covers: vegetated covers and rock covers (Figures 1 and 2, respectively) (measurements in feet). There are many variations of these two cover types, depending on site conditions.

The vegetated cover was used only on the top slopes of selected project disposal cells to further minimize water infiltration. The side slopes of these disposal cells are covered with rock as described in the previous paragraph. The key to the design of the vegetated cover is to use the proper combination of plants and soil to ensure that some plants survive the drought periods that will occur during the disposal cell's 1,000-year design life. Rock mulch may be required at arid sites to prevent Bullying. Frost protection, bioinvasion, and drainage layers may also be needed for vegetated covers.

The rock covers consist of three components: a radon barrier, bedding, and riprap. The radon barrier is the layer immediately above the tailings. It consists of compacted clay or bentonite-amended soil. A bedding or filter layer of sand lies immediately above the radon barrier. A top layer of rock riprap was used to protect the disposal cell from erosion. Site-specific conditions may have required the addition of a frost protection layer, bioinvasion barrier, and a drain layer in less arid areas.

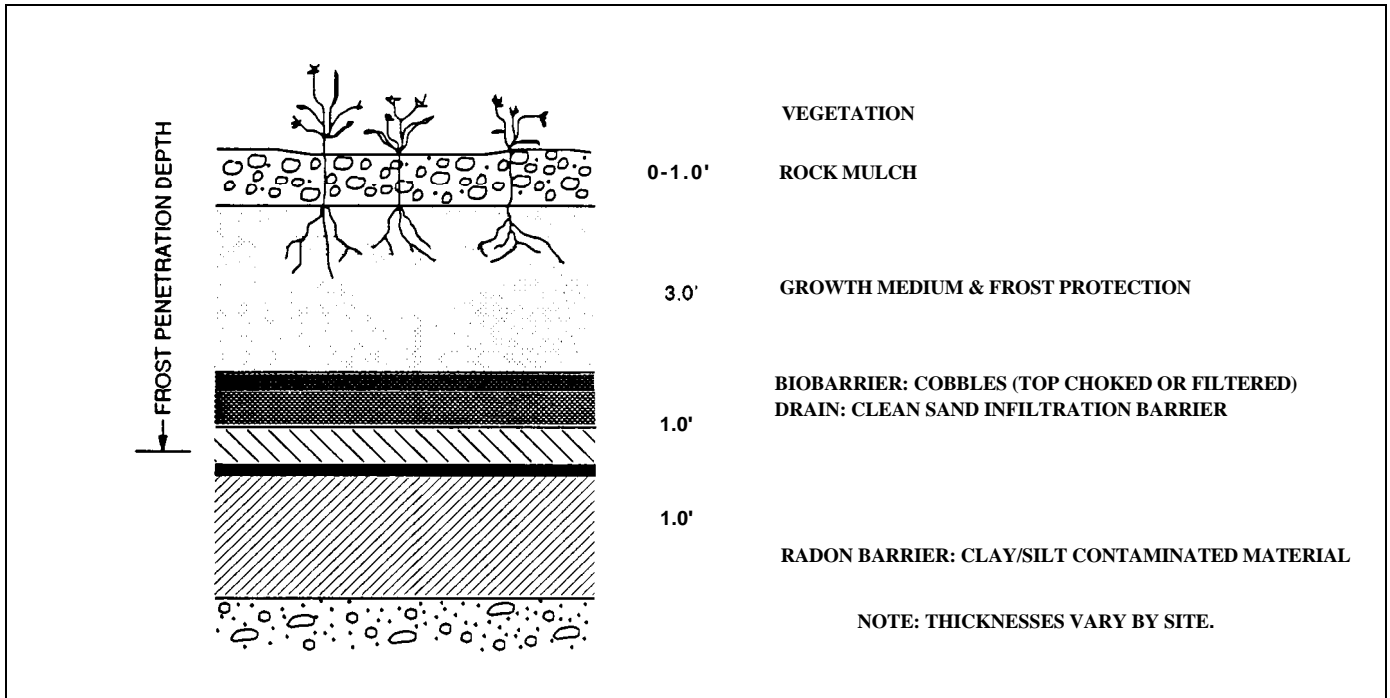


Figure 1 Vegetated Cover

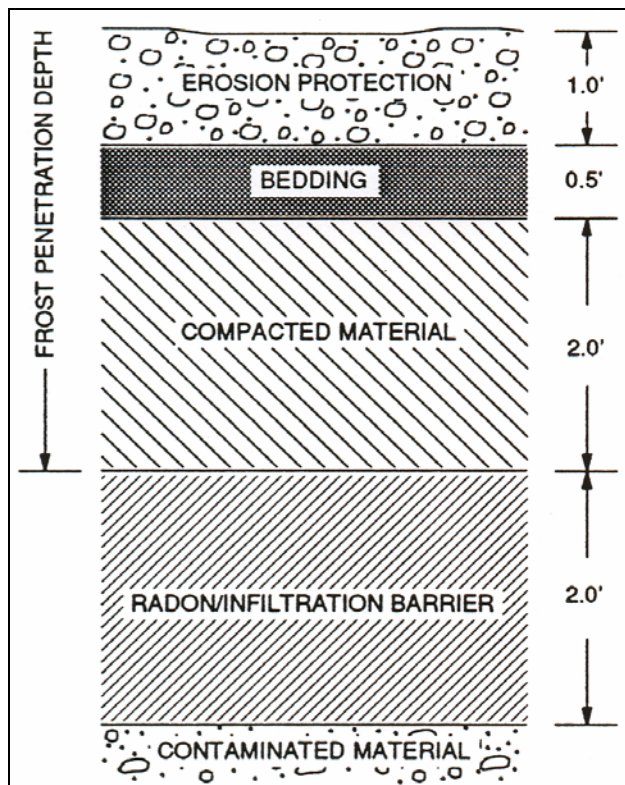


Figure 2 Rock Cover

### 2.3 Project Documentation

The documentation developed on the project demonstrated that all proposed activities would accomplish the long-term stabilization and control of RRM at each disposal site. This documentation covered such technical areas as surface-water hydrology and erosion control, geotechnical analysis of the disposal cell design, radiological analysis for radon emission, and groundwater protection strategy.

Because the project was complex, it required a management system to fully document all internal and external activities. The project internal documentation consisted of a project charter and plan; a public information and participation plan; a project management plan; schedule and budget data and reports; contractor management plans; a document control system manual; project status reports; and a vicinity property management and implementation manual, among others.

External documentation addresses remediation-related activities that had to be reviewed and approved by others. Before the mill sites could be remediated, the project had to complete the following activities:

- (1) Environmental analyses required by the NEPA.
- (2) Site characterization and design development to obtain the concurrence of the NRC and the affected state or Indian tribe.
- (3) An economic analysis to determine whether the tailings could be economically reprocessed.

After remedial action was complete at a site, the project (1) documented that the remediation was

completed in accordance with the RAP, (2) described the long-term surveillance activities, and (3) provided evidence of ownership of the disposal cell and related appurtenances by the DOE.

### **2.3.1 NEPA Documentation**

The NEPA requires that the impacts to humans and the physical environment be evaluated whenever (1) a proposed action will be funded with federal funds, or (2) a proposed action will occur on land owned or administered by a federal agency or other federal entity. The project was subject to the requirements of the NEPA and to the specific guidance developed by the DOE (10 CFR 1021)(April 24, 1992) to carry out the NEPA mandates.

The project typically prepares an environmental assessment (EA). An EA describes a proposed action and analyzes its impacts. The EA is issued in draft and final versions, which are distributed to other federal and state agencies for review and comment. After all changes and relevant comments are integrated, a final decision document is prepared that summarizes the proposed action and impacts and determines whether further analysis is required.

If additional analysis was required, an environmental impact statement (EIS) was prepared. If the action did not result in significant impacts, a finding of no significant impact (FONSI) was issued. The FONSI is a decision document that accompanies the EA and constitutes the legal approval of the EA and proposed action. Activities that would produce a disturbance to the site began once the FONSI was signed.

### **2.3.2 Remedial Action Plan**

The project TAD provided the criteria for developing the design features for site remedial action. The TAD was prepared in accordance with the EPA standards, the NRC review plan for remedial action at mill sites, and state-of-the-art engineering practices. It was used to prepare the site RAP that contained the plans, specifications, and supporting documentation for site remediation.

The RAP is divided into several technical areas. Its organization is consistent with the NRC's "Standard Format and Content Guide for Documentation of Remedial Action Selection at Title I Uranium Mill Tailings Sites." The main sections contain the remedial action selection, site geology, geotechnical stability, surface water hydrology and erosion protection, water resources protection strategy (hydrogeology), radon attenuation, construction plans, and specifications and information for bidders (boring logs, climatological data, and other site-specific information).

### **2.3.3 Quality Assurance Plan**

The Quality Assurance Plan provided the foundation for construction activities on the project. The plan established the guidelines for the Quality Assurance Program, which ensured that work was completed in accordance with the specifications set forth in the RAP.

### **2.3.4 Completion Report**

The completion report documents that all remedial action activities were executed as presented in the RAP. It also documents that the site meets the EPA standards. The completion report contains the as-built drawings for the disposal cell and the results of the quality control tests, verification sampling, and radon emanation tests. This report is supplemented by a certification summary. Upon NRC concurrence, the certification summary documents that the site is certified as meeting the EPA cleanup standards.

### **2.3.5 Long-Term Surveillance Plan**

Another key document in the site licensing process was the site-specific long-term surveillance plan. Each plan describes the key features of the disposal cell and any activities that should take place annually to ensure the disposal cell's integrity. It identifies possible failure scenarios and lists corrective actions that could be taken to mitigate potential failures. The long-term surveillance program will continue for the 1,000-year design life of the disposal cell. This plan also contains real estate transfer documentation indicating that the DOE has taken title to the disposal cell.

### **2.3.6 Environmental Safety and Health Plan**

The project developed an environmental, safety and health (ESH) plan that identified the basic federal health and safety standards and special DOE requirements applicable to remedial action activities. The project complied with numerous local, state, and federal regulations governing activities at mill sites in 10 states.

The ESH plan cannot identify all the pertinent regulations applicable to mill site remediation. The project developed a regulatory operating envelope that identified the various regulations and requirements that apply to remedial action activities. This ensured that the project complied with all the applicable regulations and requirements. The final regulatory operating envelope was extremely detailed. It identified more than 750 internal and external documents applicable to project activities, encompassing more than 10,000 regulatory requirements.

### **2.3.7 Public Involvement/Public Participation Plan**

The project also developed a plan for public involvement and public participation. The plan outlined steps to disseminate information to the public and established mechanisms for the public to provide input to help shape project activities.

### **2.3.8 Guidance Documents and Special Studies**

The project also developed numerous technical guidance documents dealing with the analysis and interpretation of radiological and hydrogeological data. Numerous special studies were completed addressing erosion protection design, infiltration into disposal cells, vegetation growth, and other topics. The project also participated in technology development efforts for

surface stabilization, and for the groundwater phase of the project.

## **2.4 Groundwater Restoration**

Groundwater cleanup in the vicinity of tailings piles was not originally considered to pose a significant restoration effort. However, the project discovered significant volumes of groundwater contamination and in response developed plans for groundwater restoration at all sites. The purpose of the UMTRA Groundwater Project is to ensure that unacceptable risks to human health and the environment are mitigated in a timely and cost-effective manner.

To achieve this goal, the DOE developed a broad-based Programmatic Environmental Impact Statement (PEIS). Affected states, tribes, and the public were involved in evaluating and determining programmatic groundwater compliance strategies. The PETS addressed programmatic issues common to all 24 UMTRA sites, and individual EA's for site-specific actions were used to make groundwater restoration decisions in compliance with NEPA. During 1992, drafts of two other programmatic documents were completed. The technical approach to Groundwater Restoration provided a blueprint for how the groundwater restoration project would be conducted. A preliminary draft of the Quality Assurance Implementation Plan was also prepared during 1992.

## **3.0 LESSONS LEARNED**

The project continues to be one of the most successful DOE remediation projects to date. However, it experienced many challenges in completing the remediation at all the sites. The lessons learned are not limited to the project; they should be considered by any other project dealing with environmental remediation.

Public involvement and participation in the direction of a remediation project is essential in developing the trust and understanding necessary to successfully complete remedial actions. Several project mill sites exemplify the problems encountered when the public is not involved in the decision-making process. These sites also represent the changes that occur when the public is included in planning activities, and now serve as prime examples of the benefits of strong public participation in project activities. Communication and openness about project activities are important in establishing the trust that is so vital to the success of large-scale remedial action projects.

### **3.1 Costs**

Projected to cost \$150 – 200 million in 1978, the UMTRA program had cost approximately \$2 billion dollars by the year 2000. Various measures of the project costs are present in Table 2. The cost of remediation for each site is presented as cost in \$/ton; \$/unit of radiation (Ra 226) in the tailings and \$/pound of yellowcake produced at the site. When the uranium mills at the UMTRA sites were operating, they sold

their yellowcake for approximately \$8/pound, a price set by the US Atomic Energy Commission (AEC).

As measured by cost per cubic yard of tailings - and shown in Figure 3 – UMTRA costs ranged from \$7.68 at Ambrosia Lake, New Mexico to \$142.46 at Lowman, Idaho. The average (mean) cost of UMTRA project activities is \$32.04 per cubic yard of tailings.

As measured by cost per Curie of Radium 226 contained in the tailings – as shown in Figure 4, remediation costs ranged from \$21,600 at Ambrosia Lake to \$1,536,167 at Lowman, Idaho. The average (mean) cost of the UMTRA project activities is \$105,250 per Curie of Radium 226 contained in the tailings.

As measured by pound of yellowcake (U3O8) produced at the site – as shown in Figure 5, costs ranged from \$3.07 at Ambrosia Lake to \$97.27 at Lakeview, Oregon. The average (mean) cost of the UMTRA project activities is \$12.67 per pound of yellowcake produced, more than 50% more than the price paid for yellowcake when the tailings at the UMTRA sites were produced.

While surface remediation of the UMTRA sites is essentially complete, ground water contamination continues at most UMTRA sites including three of the four sites on the Navajo Reservation and the Falls City, Texas site. Active ground water remediation continues at Monument Valley, Shiprock and Tuba City on the Navajo Reservation where contamination - including uranium, selenium, radium, cadmium, sulfate and nitrate continues to exceed clean-up standards. At Shiprock, the peak uranium concentrations in contaminated ground water in the San Juan River floodplain reached 4.3 mg/l – more than 97 times the uranium maximum concentration limit (MCL) of 0.044 mg/l in 2001. At Falls City, a pattern of increasing uranium concentrations continued in 2003 as uranium concentrations in ground water beneath the disposal cell reached 9 mg/l – more than 200 times the uranium MCL of 0.044 mg/l. Falls City is one of 12 UMTRAP sites for which DOE has sought NRC approval for Supplemental Standards, or Alternative Concentration Limits, in combination with Institutional Control on land use and water use, as a basis to reduce or eliminate the need to continue active ground water remediation efforts.

Following completion of UMTRA remediation, DOE has projected costs for long-term surveillance and maintenance (LSTM) activities at UMTRA sites for 70 years. DOE projections have identified the cost of these multi-decade programs for future years and average years in future decades thru 2070.

These projected costs do not include active ground water remediation costs at sites not yet subject to Nuclear Regulatory Commission (NRC) - approved LSTM plans. Active ground water remediation costs are anticipated to exceed \$50 million at Tuba City, Monument Valley and Shiprock through the year 2025.

DOE's initial attempt at a comprehensive radioactive waste clean-up program provides unique and important disposal cost and technology benchmarks for assessing the effectiveness of DOE clean-up methods and its

capacity to demonstrate “long-term environmental stewardship” across its nuclear weapons complex.

### **3.2 United States Nuclear Regulatory Commission**

A good working relationship with the project regulator is essential for success. The project took steps to work with the NRC to understand their requirements for documentation of project activities. Through numerous meetings and daily interaction, a good working relationship evolved.

When the project began, there were no standards for the remediation of the mill sites. The EPA standards evolved over 5 years, from 1978 when the UMTRCA was passed until 1983 when the final standards were published in the Federal Register. During these years, the standard documents for the project began to take shape through discussions with the NRC. The RAP was established as the engineering design and construction document for the project.

The RAP continued to evolve as a stand-alone document that includes all information necessary for NRC review. Its organization reflects NRC's format for documentation of the remedial action selection at mill sites. The RAP review by the NRC could then be accomplished in a more orderly fashion, since the RAP and NRC report formats are the same.

The project initiated meetings with the NRC to discuss both programmatic and site-specific issues related to RAP concurrence, completion reports, and certification and licensing activities. Through these meetings, the UMTRA Project Office received clear direction on the documentation and analysis required for regulatory concurrence. The NRC fulfilled a vital role in providing an independent check to ensure that the EPA standards were met. It also provided the public with an assurance that an independent analysis had been performed and that the project was undertaking remediation that was well-conceived. Site-specific topics were discussed and regulatory requirements were specifically identified so the project could fulfill those requirements promptly. In some cases, several meetings were held on the same topic to refine the data analysis and create a complete record for review.

The NRC also kept involved in construction field changes through project interface documents. The NRC was alerted and involved when any change was proposed during construction. Timely involvement ensured that any changes implemented would not deviate from the EPA standards.

Establishing and keeping schedules is vital to the success of any project. Scheduling internal project and external NRC document reviews helped prevent bottlenecks in the review process. The project conducted weekly status conference calls with the NRC to update document progress. Priorities for the review of documents were assigned, and any problems or delays were discussed and resolved. Additionally, quarterly management meetings were held and a long-range document production forecast was provided to the NRC. This was used for budget and manpower planning by the NRC.

The NRC also conducted periodic construction inspections. These inspections gave the NRC a chance to measure the remedial action activities against the plans and specifications. They also ensured that all appropriate quality control tests were performed and that the results were within the specified limits. A conference call was held immediately before the inspection to provide the current level of construction progress and to ensure that the NRC was able to inspect the activities of interest.

### **3.3 Grand Junction, Colorado**

The Grand Junction, Colorado, mill site is located near downtown Grand Junction on the Colorado River. The tailings were relocated to a disposal cell southeast of the city. Initial plans were to transport the tailings to the disposal cell by truck. The haul route for the trucks wound through several kilometers of city streets then followed a heavily traveled tourist highway to the disposal cell.

At first, too little attention was given to community concerns that the truck traffic through town and on the busy highway would create unacceptable safety concerns. The city and county objected to this inattention. They decided to use Congressional inquiries, land use permit restrictions, and other local control measures to force the project to use trains to haul the tailings out of the city.

The community was also frustrated with the DOE for not providing site characterization and design information promptly. The lack of information and communication with the public created an atmosphere of distrust within the community and the project. In fact, the community simply wanted basic information and answers to their questions. Without communication, rumors developed about the project activities and goals. Those rumors were greatly exaggerated and detrimental to the project's execution.

As a result of this poor communication, and other occurrences in the planning of the Grand Junction site remediation, the DOE relocated a full-time government official to the Grand Junction area. Relations with the community improved markedly. The DOE official understood the concerns of the community, since he was a part of that community.

### **3.4 Falls City, Texas**

The Falls City, Texas, mill site learned a slightly different lesson than that experienced at Grand Junction. The news media did not completely understand the DOE's role in the mill site remediation and did not understand the difference between inactive and active uranium mills. Environmental groups criticized what they viewed as slow progress in remediating the site. Both problems stemmed from a lack of communication and education concerning the risks posed by the tailings, the regulatory process, and the steps the DOE was taking to ensure that the cleanup standards were being met.

**Table 2 Uranium Ore Processed, Disposal Cell Material, and Cost for Remediation of UMTRCA Title I Uranium Mill Sites**

Remediation Project (Mill Site Name, State)	Uranium Ore Processed		Disposal Cell	Remediation Project Cost			
	Ore	Uranium Production	Remediated Material Volume	Total Cost <sup>A</sup>	Per Pound Produced	Per Unit of Remediated Material	Per Unit of Radiation Avoided
	(Million Short Tons)	(Million Pounds U <sub>3</sub> O <sub>8</sub> )	(Million Cubic Yards)	(Thousand U.S. Dollars)	(Dollars per Pound U <sub>3</sub> O <sub>8</sub> )	(Dollars per Cubic Yard)	(Dollars per Curie, <sup>226</sup> Ra)
Ambrosia Lake, NM <sup>B</sup>	3.05	13.02	5.2	39961	3.07	7.68	21,600.54
Belfield, ND	0.05	0.34	C	C	C	C	C
Bowman, NM	0.08	0.61	C	C	C	C	C
Burrell, PA	D	D	0.07	D	D, E	E	E
Canonsburg, PA	E	E	0.19	47,591	E	E	475,910.00
Durango, CO	1.61	7.85	2.53	67,618	8.61	26.68	48,298.57
Edgemont, SD	1.98	6.86	3	5,411	0.79	1.8	10,267.55
Falls City, TX	2.72	8.66	5.8	56,254	6.49	9.7	44,051.68
Grand Junction, CO	2.28	11.69	4.43	504,048	43.12	113.9	F
Green River, UT	0.18	0.83	0.38	23,633	28.44	61.87	787,766.67
Gunnison, CO	0.54	1.45	0.74	58,917	40.61	79.62	336,668.57
Lakeview, OR	0.13	0.34	0.94	33,325	97.27	35.3	793,452.38
Lowman, ID	0.2	0.37	0.13	18,434	50.47	142.46	1,536,166.67
Maybell, CO	1.76	4.03	3.5	63,528	15.75	18.15	139,621.98
Mexican Hat, UT	2.2	11.38	3.48	54,482	4.79	15.66	30,267.78
Monument Valley, AZ	1.1	0.77	0.93	24,126	31.43	G	G
Naturita, CO	0.7	3.18	0.79	86,332	27.18	108.84	1,092,810.13
Rifle, CO <sup>H</sup>	2.7	16.54	3.76	119,165	7.2	31.72	43,522.64
Riverton, WY	1.06	3.89	1.79	49,664	12.76	I	I
Salt Lake City, UT	1.69	9.57	2.8	94,165	9.84	33.63	60,751.61
Shiprock, NM	1.53	7.42	2.8	24,771	3.34	8.85	33,116.31
Slick Rock, CO <sup>J</sup>	0.63	2.68	0.86	50,428	18.82	58.84	288,160.00
Spook, WY	0.19	0.35	0.32	10,106	29.03	32.08	80,848.00
Tuba City, AZ	0.8	4.7	1.4	34,143	7.27	24.39	36,322.34
<b>Total and Averages:</b>	<b>27.17</b>	<b>116.53</b>	<b>46.07</b>	<b>\$1,476,340</b>	<b>\$12.67</b>	<b>\$32.04</b>	<b>\$105,249.88</b>

<sup>A</sup> Includes site characterization; environmental, health, and safety; remedial action for site design, acquisition, construction, and field management; vicinity property design and construction; surveillance and maintenance; technology development, and project management allocation.

<sup>B</sup> The Ambrosia Lake (Phillips) mill generated about 3.1 million tons of tailings. Some 0.4 million tons were used to backfill underground mines.

<sup>C</sup> Combined Belfield and Bowman cost was \$10,239,000. The former uranium ore processing sites were not remediated under the UMTRA Program. Lignite ash produced at these sites was processed at mills in Colorado and New Mexico.

<sup>D</sup> Uranium ore was not processed at the Burrell site. Radioactively contaminated materials at this site were stabilized on site for economic reasons.

<sup>E</sup> Ore processing data are not available for the Canonsburg facility. Total cost includes Canonsburg and Burrell remediation. Cost for Unit of Radiation Avoided includes Canonsburg and Burrell sites.

<sup>F</sup> A portion of the Cheney Disposal Cell will remain open as late as 2023, or until filled. Disposal cell radioactivity will be determined at that time.

<sup>G</sup> Radioactively contaminated materials from Monument Valley, Arizona, mill site were relocated/stabilized at the Mexican Hat, Utah, disposal cell.

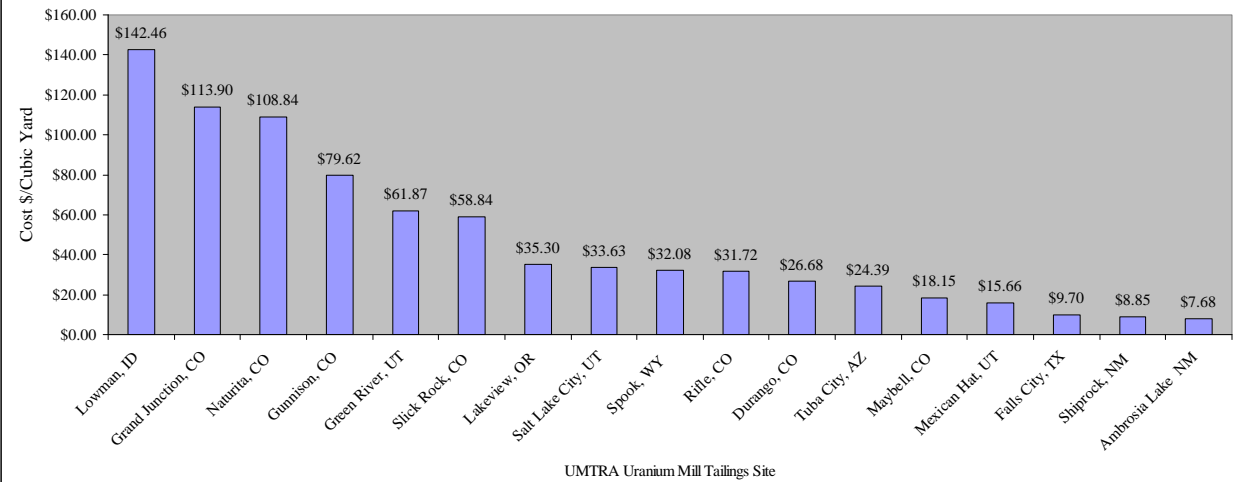
<sup>H</sup> Includes uranium produced at the Rifle mill from Green River and Slick Rock uranium-upgrader slimes and Belfield lignite-ash mill-feed product.

<sup>I</sup> Radioactively contaminated materials from the Riverton, Wyoming, mill site were relocated/stabilized at the UMETCO uranium facility in the Gas Hills Uranium Mining District, Wyoming.

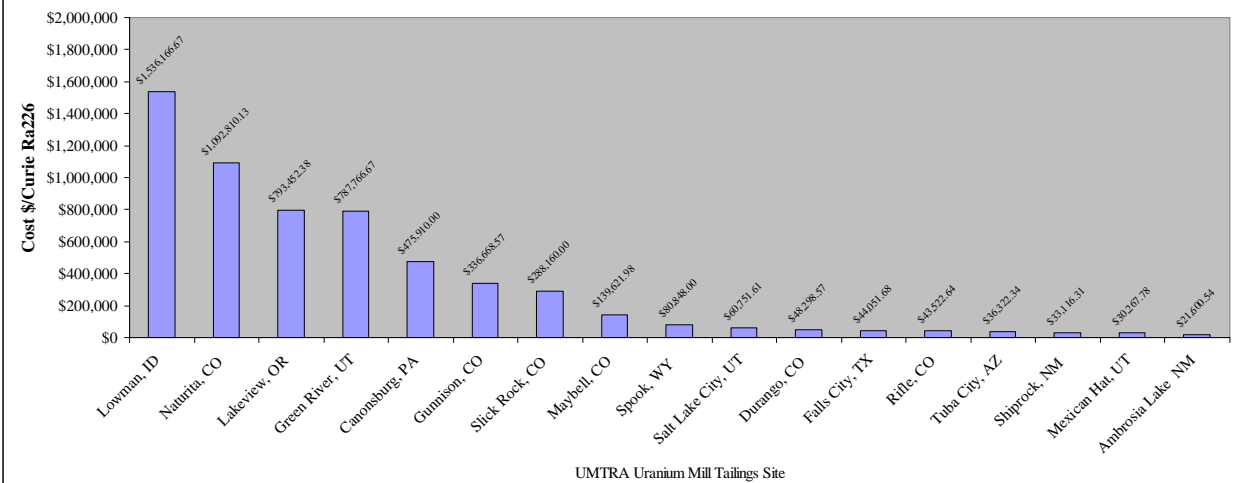
<sup>J</sup> Includes the Slick Rock uranium mill site and the Slick Rock uranium concentrator site.

-- = Not applicable.

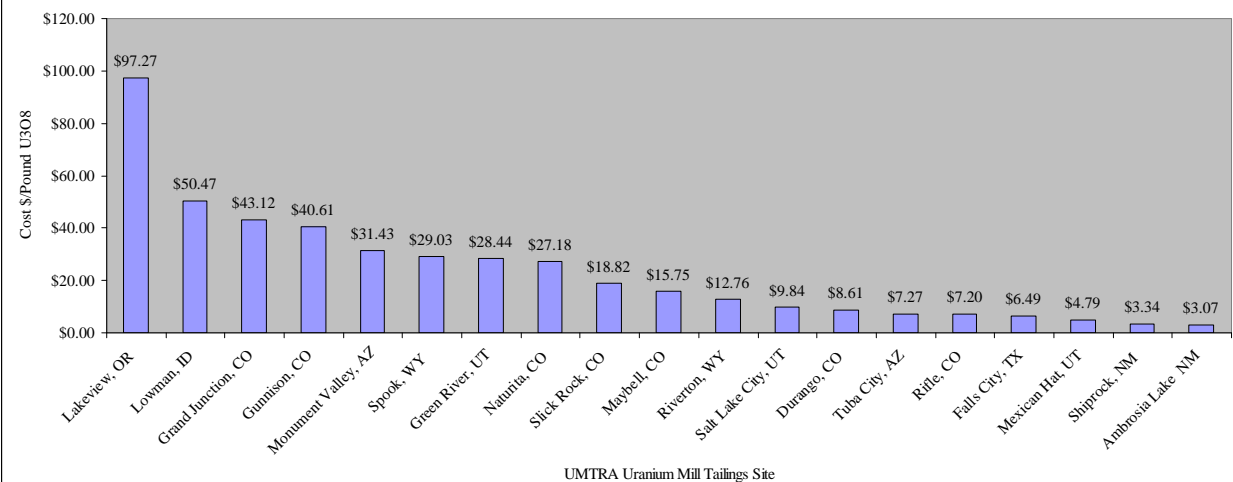
**Figure 3 UMTRA Remediation Costs vs. Remediated Material**



**Figure 4 UMTRA Remediation Costs vs. Radiation Avoided**



**Figure 5 UMTRA Remediation Costs vs. Uranium Produced**



The news media, obtaining their information mainly from those individuals opposing the project, began reporting one-sided accounts of the project's progress. To avoid further media problems, the project site manager visited the local television, radio, and newspaper media to discuss project activities at Falls City. These visits generally occurred before public meetings that were held in the community. As a result, the media began providing more balanced reporting on project activities.

The project then established a new thrust for the periodic public meetings. The main purpose of the public meetings was to discuss, in-depth, the remedial action planning process and to give the public and environmental groups a better understanding of what was to be accomplished. The roles of the NRC and the Texas Department of Health as regulator and partner, respectively, were discussed in detail. Additionally, all data collected to characterize the site were presented to inform the citizens of the true impact the tailings had on the environment.

This openness led to a better understanding of the project activities by the local community and groups. The most vocal critic then said that he believed the project was doing the right things to remediate the mill site, but that he would monitor the project closely to ensure that it keeps its commitments. This was a significant change from the mistrust and outright opposition that existed at the beginning of the project. This change can be attributed directly to an honest and open approach of sharing information with the public and educating the public concerning the requirements and regulations that must be met before the beginning remedial action.

Similar events occurred at other project mill sites. These events underscored the importance of true public involvement, education, and openness. The UMTRA Groundwater Project incorporated these lessons learned into the public involvement plan. The project worked with schools and the public to create a genuine understanding of groundwater compliance and provided meaningful opportunities for education, interaction, and input by the public.

### **3.5 Risk Assessment and Mitigation**

The planning and design activities for remediation can span several years. The DOE was concerned about protecting health and safety prior to remedial action. Therefore, the project conducted risk analyses and assessments to ensure that the public health and safety were protected, both before and during remedial action. These risk assessments were conducted in conformance with EPA guidelines. Any situation that might bring the public into contact with contamination from the mill site, with subsequent impact to public health, was mitigated quickly by the project.

The Gunnison, Colorado, mill site provides an example of mitigative measures employed to protect public health. The groundwater contamination plume from the mill tailings pile had migrated into an area where wells were located to provide water to individual residences in a subdivision. Several of the wells drew water contaminated by the plume. The project made bottled water available to all residents of the subdivision. This temporary mitigating measure was

employed until a water distribution network could be constructed through a joint effort of the DOE, the city, and county. The water distribution network provided clean potable water to the subdivision and eliminated any potential use of contaminated groundwater.

## **4.0 CONCLUSIONS**

The project resulted from widespread public concern over the potential health effects of radiation release into the environment from uncontrolled uranium mill tailings primarily in the form of radon gas. Ironically, the same concern was not evidenced over radiation that also releases radon gas from uranium mines in the United States. The milling process was usually performed on uranium ore that was mined elsewhere and brought to a central location near population centers. Therefore, due to proximity, the potential total exposure from the tailings was higher than that from the associated mines. Thus, the project was established for inactive mill sites (Title I of UMTRCA) to address this public health concern.

The regulatory community (as established in the Act) was uncertain of the level of compliance necessary to protect public health. This led to the establishment of prescriptive standards versus risk-based standards. The initial remedial designs were straightforward applications of existing remediation techniques to meet uniform cleanup standards. As these designs were developed and constructed, and as groundwater standards evolved, the implementation of the project was affected. In addition, the regulatory community learned more, thereby influencing them to request more rigorous demonstrations of compliance. While the initial sites did comply with the standards, more documentation and analysis was required. This situation required that the project develop an agreement with the regulatory community on how compliance would be demonstrated at future sites. Consequently, a standardized approach and streamlined regulatory approval process quickly ensued.

Public participation in the execution of the project also evolved over time. Initially, few local residents became involved because they were satisfied that their concerns had been addressed by the passage of the Act, and they expected an immediate solution from the project activities. However, as the project proceeded, some of the public realized that the project would (or could) directly impact them and their community. The public involvement intensified, both for and against the project. In some cases, this led to better remediation solutions than originally planned. In other situations, the increased public involvement by those unfamiliar with the project made consensus much more difficult to reach. The project found that involvement of the regulatory community at the local level substantially helped convince the public that the project was being conducted in their best interest. This greater level of public involvement required the project to develop more detailed information when planning its activities and building consensus to address the public's request for more conservative approaches. While this initially delayed the project, the overall implementation went more smoothly after the public understood and actively supported the project.

Another area of project execution that evolved over time was funding. Early in the project, funding was readily available at both the federal and state levels. As more conservative approaches were developed, and as the public became more familiar with the true risks involved and the cost of risk reduction, funding became more difficult to obtain. At this point, the impact of prescriptive standards versus risk-based standards became clear. The prescriptive standards required that remediation be conducted even though there may be no human population near the tailings. Under risk-based standards, remediation would probably not be conducted.

A major goal of the project was to develop new and innovative approaches to remediation, compliance with standards, execution, and management of this project to avoid, minimize, or reduce costs. With the states contributing 10 percent of the cost for the remedial actions, they (and the local communities) had to "buy in" to the project activities. By participating in the project, the states became equal partners interested in solving the technical issues while keeping the costs as low as possible. State participation was a vital contribution to the successful implementation of this project.

Overall, the project successfully isolated and stabilized over 33 million cubic meters of uranium mill tailings and associated contaminated material from the environment. This work represents phenomenal success in a social environment that had effectively precluded the construction of even one single low-level radioactive waste facility (non-uranium tailings) in the entire country during the projects activities.

## References

DOE (United States Department of Energy), 1997, "Uranium Mill Tailings Remedial Action Project fiscal year 1997 annual report to stakeholders," DOE/AL/62350-T18, prepared by the United States Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (United States Department of Energy), 1992, "Environmental Assessment of Remedial Action at the Gunnison Uranium Mill Tailings Site, Gunnison, Colorado," DOE/EA-0376, prepared by the United States Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (United States Department of Energy), 1992, "Groundwater Monitoring Program Plan," prepared by the United States Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (United States Department of Energy), 1992, "Groundwater Protection Management Program Plan," UMTRA-DOE/AL-400327.0000, prepared by the United States Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (United States Department of Energy), 1992, "Guidance for Implementing the UMTRA Project Long-term Surveillance Program," UMTRA-DOE/AL-350125.0000, Rev. 1, prepared by the United States

Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (United States Department of Energy), 1992, "Remedial Action Plan and Site Design for Stabilization of the Inactive Uranium Mill Tailings Sites at Rifle, Colorado," prepared by the United States Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (United States Department of Energy), 1992, "UMTRA Project Environmental Protection Implementation Plan," UMTRA-DOE/AL-150128.0000, prepared by the United States Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (United States Department of Energy), 1992, "UMTRA Project Quality Assurance Program Plan," UMTRA-DOE/AL-400324.0185, prepared by the United States Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (United States Department of Energy), 1991, "Albuquerque Operations Environmental Restoration and Waste Management Five-Year Plan," prepared by the United States Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (United States Department of Energy), 1991, "Analysis of Infiltration through a Clay Radon Barrier at an UMTRA Disposal Cell," UMTRA-DOE/AL-400667.0000, prepared by the United States Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (United States Department of Energy), 1991, "Annual Status Report on the Uranium Mill Tailings Remedial Action Program," DOE/EM-0001, prepared by the United States Department of Energy, Office of Environmental Restoration and Waste Management, Washington, D.C.

DOE (United States Department of Energy), 1990, "Final Environmental Impact Statement, Remedial Actions at the Former Union Carbide Corporation Uranium Mill Sites, Rifle, Garfield County, Colorado," DOE/EIS-0132-F, DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (United States Department of Energy), 1989, "Technical Approach Document," UMTRA-DOE/AL-050425.0002, prepared by the United States Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (United States Department of Energy), 1989, "UMTRA Project Environmental, Health, and Safety Plan," UMTRA-DOE/AL-150224.0006, prepared by the United States Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (United States Department of Energy), 1989, "UMTRA Project Surveillance and Maintenance Guideline Document," UMTRA-DOE/AL-350124.0000, prepared for the United States Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (United States Department of Energy), 1988, "Alternate Site Selection Process for UMTRA Project Sites," UMTRA-DOE/AL X00129.0007, prepared by the

United States Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (United States Department of Energy), 1988, "Alternative Cover Materials," UMTRA-DOE/AL-400602.0000, prepared by the United States Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

EPA (United States Environmental Protection Agency), 1991, "Environmental Protection Agency," Code of Federal Regulations, Title 40, Chapter 1, Offices of the Federal Register, National Archives and Records Administration, Washington, D.C.

EPA (United States Environmental Protection Agency), 1991, Groundwater Protection Standards, SAR 1166, Document GWSTDI.WP5, Office of Radiation Programs, Washington, D.C.

EPA (United States Environmental Protection Agency), 1991. "National Primary Drinking Water Regulations; Radionuclides," 40 CFR Parts 141, 142, Federal Register, Vol. 56, No. 138, 33050, Washington, D.C.

NRC (United States Nuclear Regulatory Commission), 1990, "Custody and Long-Term Care of Uranium and Thorium Mill Tailings Disposal Sites," 10 CFR Part 40, in Federal Register, Vol. 55, No. 210, Washington, D.C.

NRC (United States Nuclear Regulatory Commission), 1990, "Final Staff Technical Position-Design of Erosion Protection Covers for Stabilization of Uranium Mill Tailings Sites," Denver, Colorado.

NRC (United States Nuclear Regulatory Commission), 1989, "Standard Format and Content for Documentation of Remedial Action Selection at Title I Uranium Mill Tailings Sites," Staff Technical Position, Division of Low-Level Waste Management and Decommissioning, Office of Nuclear Material Safety and Safeguards, Washington, D.C.

NRC (United States Nuclear Regulatory Commission), 1986, "Methodologies for Evaluating Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments," NUREG/CR-4620, ORNL/TM-10067, prepared by Colorado State University, Fort Collins, Colorado, and Oak Ridge National Laboratory, Oak Ridge, Tennessee, for the United States Nuclear Regulatory Commission, Washington, D.C.