MASTER

ENGINEERING ASSESSMENT OF
INACTIVE URANIUM MILL TAILINGS

SHIPROCK SITE
SHIPROCK, NEW MEXICO

JULY 1981

PREPARED FOR
UNITED STATES DEPARTMENT OF ENERGY
ALBUQUERQUE OPERATIONS OFFICE
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REMEDIAL ACTIONS PROJECT OFFICE
ALBUQUERQUE, NEW MEXICO
CONTRACT NO. DE-AC04-76GJ01658

BY

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Prepared for

U.S. DEPARTMENT OF ENERGY
ALBUQUERQUE OPERATIONS OFFICE
URANIUM MILL TAILINGS REMEDIAL ACTIONS
PROJECT OFFICE
ALBUQUERQUE, NEW MEXICO

Contract No. DE-AC04-76GJ01658

By

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375 Chipeta Way
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NOTICE

This engineering assessment has been performed under DOE Contract No. DE-AC04-76GJ01658 between the U.S. Department of Energy and Ford, Bacon & Davis Utah Inc.

Copies of this report may be obtained from the Uranium Mill Tailings Remedial Action Project Office, U.S. Department of Energy, Albuquerque Operations Office, Albuquerque, New Mexico 87115.

FOREWORD

This report has been authorized by the U.S. Department of Energy (DOE), Albuquerque Operations Office, Uranium Mill Tailings Remedial Action Project Office, Albuquerque, New Mexico, under Contract No. DE-AC04-76GJ01658. The report is a revision of an earlier report dated March 1977, entitled "Phase II - Title I Engineering Assessment of Inactive Uranium Mill Tailings, Shiprock Site, Shiprock, New Mexico," which was authorized by DOE, Grand Junction, Colorado, under Contract No. E(05-1)-1658.

This report has become necessary as a result of changes that have occurred since 1977 which pertain to the Shiprock site and vicinity, as well as changes in remedial action criteria. The new data reflecting these changes are presented in this report. Evaluation of the current conditions is essential to assessing the impacts associated with the options suggested for remedial actions for the tailings.

Ford, Bacon & Davis Utah Inc. (FB&DU) has received excellent cooperation and assistance in obtaining new data to prepare this report. Special recognition is due Richard H. Campbell and Mark Matthews of DOE, as well as Harold Tso and Ben Benally of the Environmental Protection Commission, Navajo Nation, and Chris Eastin of the Navajo Engineering and Construction Authority. The Bureau of Indian Affairs, Shiprock Agency, contributed information, as did several local, county, and state agencies and private individuals.

ABSTRACT

Ford, Bacon & Davis Utah Inc. has reevaluated the Shiprock site in order to revise the March 1977 engineering assessment of the problems resulting from the existence of radioactive uranium mill tailings at Shiprock, New Mexico. This engineering assessment has included the preparation of topographic maps, the performance of core drillings and radiometric measurements sufficient to determine areas and volumes of tailings and radiation exposures of individuals and nearby populations, the investigations of site hydrology and meteorology, and the evaluation and costing of alternative corrective actions.

Radon gas released from the 1.5 million dry tons of tailings at the Shiprock site constitutes the most significant environmental impact, although windblown tailings and external gamma radiation also are factors. The eight alternative actions presented in this engineering assessment range from millsite decontamination with the addition of 3 m of stabilization cover material (Option I), to removal of the tailings to remote disposal sites and decontamination of the tailings site (Options II through VIII). Cost estimates for the eight options range from about \$13,400,000 for stabilization in place to about \$37,900,000 for disposal at a distance of about 16 mi.

Three principal alternatives for the reprocessing of the Shiprock tailings were examined:

- (a) Heap leaching
- (b) Treatment at an existing mill
- (c) Reprocessing at a new conventional mill constructed for tailings reprocessing.

The cost of the uranium recovered would be about \$230/lb by heap leach and \$250/lb by conventional plant processes. The spot market price for uranium was \$25/lb early in 1981. Therefore, reprocessing the tailings for uranium recovery is not economically attractive.

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CHAPTER 1

SUMMARY

CHAPTER 1

SUMMARY

1.1 INTRODUCTION

The U.S. Energy Research and Development Administration (ERDA) contracted in 1975 with Ford, Bacon & Davis Utah Inc. (FB&DU) of Salt Lake City, Utah, to provide architect-engineering services and final reports based on the assessment of the problems resulting from the existence of large quantities of radioactive uranium mill tailings at inactive mill sites in eight western states and in Pennsylvania. In 1980, the U.S. Department of Energy (DOE) contracted with FB&DU to produce revised reports of the sites designated in the Uranium Mill Tailings Remedial Action (UMTRA) program in order to reflect the current conditions, new criteria and options, and to estimate current remedial action costs.

A preliminary survey (Phase I) was carried out in 1974 by the U.S. Atomic Energy Commission (AEC) in cooperation with the U.S. Environmental Protection Agency (EPA) and the affected states. In a summary report,⁽¹⁾ ERDA identified 17 sites in Arizona, Colorado, Idaho, New Mexico, Utah, and Wyoming for which practical remedial measures were to be evaluated. Subsequently, ERDA added five additional sites (Riverton and Converse County, Wyoming; Lakeview, Oregon; Falls City and Ray Point, Texas). More recently, DOE has added a site in Canonsburg, Pennsylvania, one near Baggs, Wyoming, and two sites in North Dakota (Belfield and Bowman) and deleted Ray Point, for a total of 25 sites. DOE continues to investigate the status of the site near Baggs, Wyoming. Most of the mills at these sites produced by far the greatest part of their output of uranium under contracts with the AEC during the period 1947 through 1970. After operations ceased, some companies made no attempt to stabilize the tailings, while others did so with varying degrees of success. Recently, concern has increased about the possible adverse effects to the general public from long-term exposure to low-level sources of radiation from the tailings piles and sites.

Prior to 1975, the studies of radiation levels on and in the vicinities of these sites were limited in scope. The data available were insufficient to permit assessment of risk to people with any degree of confidence. In addition, information on practicable measures to reduce radiation exposures and estimates of their projected costs was limited. The purposes of these recent studies performed by FB&DU have been to update the information necessary to provide a basis for decision making for appropriate remedial actions for each of the 25 sites.

Evaluations of the following factors have been included in this engineering assessment in order to assess the significance of the radiological conditions that exist today at the Shiprock site:

- (a) Exhalation of radon gas from the tailings
- (b) On-site and off-site direct radiation
- (c) Land contamination from windblown tailings
- (d) Hydrology and contamination by water pathways
- (e) Potential health impact
- (f) Potential for extraction of additional minerals from the tailings

Investigation of these and other factors originally led to the evaluation of 11 potential practicable remedial action alternatives.⁽²⁾ Since that time, some alternatives have been judged unacceptable because of new criteria that have been proposed. In the work performed in the preparation of this report, the remedial action alternatives are revised as follows:

- (a) Option I - Stabilization of tailings on site with a 3-m cover
- (b) Option II - Disposal at site 2, Many Devils, 4 mi south of tailings piles
- (c) Option III - Disposal at site 1, Shiprock Campground, 6.8 mi south of tailings piles
- (d) Option IV - Disposal at site 5, Rattlesnake, 8.3 mi west of tailings piles
- (e) Option V - Disposal at site 8, Salt Creek Area, 8.5 mi northeast of tailings piles
- (f) Option VI - Disposal at site 6, Oil Field, 8.5 mi southeast of tailings piles
- (g) Option VII - Disposal at site 4, Hogback, 16 mi southwest of tailings piles
- (h) Option VIII - Disposal at site 7, Operating Open-Pit Coal Mines, 26 mi east of tailings piles

1.1.1 Background

On March 12, 1974, the Subcommittee on Raw Materials of the Joint Committee on Atomic Energy (JCAE), Congress of the United States, held hearings on S. 2566 and H.R. 11378, identical bills submitted by Senator Frank E. Moss and Representative Wayne Owens of Utah. The bills provided for a cooperative arrangement between the AEC and the State of Utah in the area of the Vitro tailings site in Salt Lake City.* The bills also provided for the assessment of an appropriate remedial action to limit the exposure of individuals to radiation from uranium mill tailings.

Dr. William D. Rowe, testifying on behalf of the EPA, pointed out that there are other sites with similar problems. He recommended the problem be approached as a generic one, structured to address the most critical problem first.

Dr. James L. Liverman, testifying for the AEC, proposed that a comprehensive study should be made of all such piles, rather than treating the potential problem on a piecemeal basis. He proposed that the study be a cooperative two-phase undertaking by the states concerned and the appropriate federal agencies, such as the AEC and EPA. Phase I would involve site visits to determine such aspects as their condition, ownership, proximity to populated areas, prospects for increased population near the site, and need for corrective action. A preliminary report then would be prepared which would serve as a basis for determining if a detailed engineering assessment (Phase II) were necessary for each millsite. The Phase II study, if necessary, would include evaluation of the problems, examination of alternative solutions, preparation of cost estimates and of detailed plans and specifications for alternative remedial action measures. This part of the study would include physical measurements to determine exposure or potential exposure to the public.

The Phase I assessment began in May 1974, with teams consisting of representatives of the AEC, the EPA, and the states involved visiting 21 of the inactive sites. The Phase I report was presented to the JCAE in October 1974. Table 1-1, adapted from Reference 1, summarizes the conditions in 1980. Based on the findings presented in the Phase I report, the decision was made to proceed with Phase II.

*The proceedings of these hearings and the Summary Report on the Phase I Study were published by the JCAE as Appendix 3 to ERDA Authorizing Legislation for Fiscal Year 1976. Hearings before the Subcommittee on Legislation, JCAE, on Fusion Power, Biomedical and Environmental Research; Operational Safety; Waste Management and Transportation, Feb 18 and 27, 1975, Part 2.

On May 5, 1975, ERDA, the successor to AEC, announced that Ford, Bacon & Davis Utah Inc. of Salt Lake City, Utah, had been selected to provide the architect-engineering (A-E) services for Phase II. ERDA's Grand Junction, Colorado, Office (GJO) was authorized to negotiate and administer the terms of a contract with FB&DU. The contract was effective on June 23, 1975. The Salt Lake City Vitro site was assigned as the initial task, and work began immediately. Work at the Shiprock site began in February 1976, and the original Phase II - Title I Engineering Assessment was published in March 1977.(2)

On November 8, 1978, the Uranium Mill Tailings Radiation Control Act of 1978 (PL 95-604) became effective. This legislation provides for state participation with the Federal Government in the remedial action for inactive tailings piles. Pursuant to requirements of PL 95-604, the EPA has the responsibility to promulgate remedial action standards for the cleanup of areas contaminated with residual radioactive material and for disposal of tailings. The U.S. Nuclear Regulatory Commission (NRC) has the responsibility for enforcing these standards.

In 1979, DOE established the UMTRA Program Office in Albuquerque, New Mexico. Work on the program has since been directed by personnel in that office. The supplementary field work by FB&DU in support of this report was performed during the week of August 25, 1980.

1.1.2 Scope of Phase II Engineering Assessment

Phase II A-E Services are divided into two stages: Title I and Title II.

Title I services include the engineering assessment of existing conditions and the identification, evaluation, and costing of alternative remedial actions for each site. Following the selection and funding of a specific remedial action plan, Title II services will be performed. These services will include the preparation of detailed plans and specifications for implementation of the selected remedial action.

This report is a continuation of the assessment made for Title I requirements and has been prepared by FB&DU. In connection with the field studies made in 1976, the Oak Ridge National Laboratory (ORNL) at Oak Ridge, Tennessee, under separate agreement with DOE, made measurements of the radioactivity concentrations in the soil and water samples and gamma surveys. The EPA staff provided the results of radiation surveys they previously had made at the Shiprock site.

The specific scope requirements of the Title I assessment as given in the contract may include but are not limited to the following:

- (a) Preparation of an engineering assessment report for each site, and preparation of a comprehensive report suitable for submission to the Congress on reasonable remedial action alternatives and their estimated cost.
- (b) Determination of property ownership in order to obtain release of Federal Government and A-E liability for performance of engineering assessment work at both inactive millsites and privately owned structures.
- (c) Preparation of topographic maps of millsites and other sites to which tailings and other radioactive materials might be moved.
- (d) Performance of core drillings and radiometric measurements ample to determine volumes of tailings and other radium-contaminated materials.
- (e) Performance of radiometric surveys, as required, to determine areas and structures requiring cleanup or decontamination.
- (f) Determination of the adequacy and the environmental suitability of sites at which mill tailings containing radium could be disposed; and once such sites are identified, performance of evaluations and estimation of the costs involved.
- (g) Performance of engineering assessments of structures where uranium mill tailings have been used in off-site construction to arrive at recommendations and estimated costs of performing remedial action.
- (h) Evaluation of various methods, techniques, and materials for stabilizing uranium mill tailings to prevent wind and water erosion, to inhibit or eliminate radon exhalation, and to minimize maintenance and control costs.
- (i) Evaluation of availability of suitable fill and stabilization cover materials that could be used.
- (j) Evaluation of radiation exposures of individuals and nearby populations resulting from the inactive uranium millsite, with specific attention to:
 - (1) Gamma radiation

- (2) Radon
- (3) Radon daughter concentrations
- (4) Radium and other naturally occurring radioisotopes in the tailings
- (k) Review existing information about site hydrology and meteorology.
- (l) Evaluation of recovering residual values, such as uranium and vanadium in the tailings and other residues on the sites.
- (m) Performance of demographic and land use studies. Investigation of community and area planning, and industrial and growth projections.
- (n) Evaluation of the alternative corrective actions for each site in order to arrive at recommendations, estimated costs, and socioeconomic impact based on population and land use projections.
- (o) Preparation of preliminary plans, specifications, and cost estimates for alternative corrective actions for each site.

1.2 SITE DESCRIPTION

1.2.1 Location

The Shiprock site is located on a 230-acre tract of land on the Navajo Indian Reservation, on the south side of the San Juan River as it passes through the town of Shiprock, New Mexico. The site is shown in the aerial photograph in Figure 2-1. The relationship of the site to its surroundings is shown in the regional map in Figure 2-2. The country generally is arid and desert-like, with low rolling hills and occasional steep ridges and mesas. Vegetation is sparse except on some irrigated lands along the river. The elevation of the site is about 4,960 ft above sea level.

1.2.2 Ownership and History of Milling Operations and Processing

The mill was constructed and operated from 1954 to 1963 by Kerr-McGee Oil Industries, Inc., and from 1963 to 1968 by Vanadium Corporation of America and its successor, Foote Mineral Company.

Before and during the milling operations the site was leased from the Navajo Tribe. When the Foote Mineral Company's lease expired in 1973, full control of the site reverted to the Navajo Nation.

During its operating life (1954 to 1968) the mill processed 1.5 million dry short tons of ore, including ore concentrate from the Monument Valley mine. The average grade was 0.25% U_3O_8 and 1.07% V_2O_5 . The mill produced 3,711 tons of U_3O_8 in concentrate. Vanadium concentrate also was produced in 1955 and again from 1960 to 1968.

The ore processed at Shiprock was mostly sandstone containing carnotite as the principal ore mineral. Ore was trucked to the mill from many small mines. During the Kerr-McGee operation, about 80% of the ore came from company-controlled mines in northeastern Arizona; the rest came from other small mines, the majority in northeastern Arizona and northwestern New Mexico. After the change in ownership in 1963, more than half of the ore came from the Uruan Mineral Belt. The average distance hauled was approximately 100 mi.

1.2.3 Present Condition of the Site

Figure 2-6 is a descriptive map of the site as it now exists. The tailings are located in two adjacent piles and cover approximately 72 acres. The upper (north) pile covers 26 acres and varies from 14 to 40 ft in height. This pile has been stabilized with 0.5 to 2 ft of pit-run soil and gravel, and some natural plant growth has taken root. The upper pile has resisted wind erosion. The dikes built along the pile face that abuts the San Juan River have prevented the spread of the tailings to the river as a result of water erosion.

The lower (south) pile covers 46 acres and is approximately 15 ft in height. It contains the contaminated materials and rubble that were removed from the mill and the ore storage areas during recent decontamination efforts. The lower pile is covered with approximately 0.5 ft of material and/or soil as a result of decontamination activities by the Navajo Engineering and Construction Authority (NECA).

After mill operations ceased in 1968, some of the buildings and equipment were dismantled and buried in the tailings and washes. A few buildings have been left standing.

In November 1973, the Navajo Tribal Chairman asked the EPA and other federal agencies for assistance in stabilizing the tailings and in developing procedures for site decontamination. During April 1974, radiation surveys around the site were conducted by the EPA to determine the extent of contamination from wind and water erosion of mill tailings in order to provide a basis for defining a decontamination plan, a cost estimate, and necessary procedures. The plan developed by the EPA was given to the Navajo Tribe in October 1974.

In 1973, however, the Navajo Tribe already had authorized the NECA to use the site as a training school to instruct Navajo students in the operation of earthmoving machinery.

The NECA is headquartered at the site and uses the buildings for administration, classroom, shop, and storage purposes. At the time of the EPA survey, the NECA training program was utilizing portions of the tailings piles for practice in earthmoving techniques. The EPA decontamination plan therefore specified that the NECA earthmoving training program would include the removal of contaminated soil from areas surrounding the piles and placement of these materials on the piles. All buildings were to be decontaminated, as well as the entry road and parking and ore storage areas. An interim stabilization cover of 6 in. of earth was to be placed on the lower pile, and containment dikes were to be constructed. The plan was based on 10 tasks resulting from input by the Navajo Environmental Protection Commission, Indian Health Service, New Mexico Environmental Improvement Agency, as well as from the EPA and the NECA. The decontamination project is now complete.

The activities of the NECA between 1977 and 1980 have resulted in extensive changes in the condition and configuration of the Shiprock site. These changes are apparent upon comparison of the aerial photograph, Figure 2-1 in the 1977 report, with Figure 2-1 in this report. The upper tailings pile surface has been left relatively undisturbed. However, a graded road now surrounds the pile, and the dikes along the upper pile face, where it abuts the San Juan River, have been reduced to grade, rendering the whole eastern area relatively flat. The lower pile is also surrounded by a dike, the top of which has been graded to form a road, and grading on the surface of the pile is evident in Figure 2-1. These changes are also reflected in Figure 2-3. Two estimated profiles of the upper and lower piles in cross-section are shown in Figure 2-5.

The irrigation system that had been installed on the lower pile for dust control during decontamination has been dismantled and partially removed. The component parts remain scattered over the tailings pile. The depressed area at the extreme north end of the site has been filled in, and the contours of the old pond have been modified considerably. Immediately south of the old plant office building, part of the former raffinate pond area, now decontaminated, has been fenced in and is currently used by the NECA as a shipping and receiving area.

Only four of the original mill buildings at the site remain; they are the shower building, the engineering office building, and the classroom and shop buildings. The main mill building has been completely demolished and removed. The former plant office building is now leased to the U.S. Public Health Service Water and Sanitation Engineering Group. The NECA shop and equipment storage area is in good condition, and is fenced with chainlink and secured by a guard at night.

There are two new buildings on site; one is a maintenance shop and motor pool area and the other, a two-story concrete structure, houses the NECA engineering and administrative

offices. The NECA no longer uses the site for the training of Navajo operators of earthmoving equipment; this function was moved to Crown Point, New Mexico, in 1978.

1.2.4 Tailings and Soil Characteristics

Several types of materials make up the Shiprock tailings: a combination of uranium and vanadium tailings, dike material, rubble, and stabilization cover of pit-run gravel. Bulk densities range between 82 and 107 lb/ft³. Borings and samples taken from the piles indicate that the tailings were not uniformly deposited in the tailings ponds. There are approximately 1.5 million dry tons of tailings and 1.58 million tons of other contaminated materials on site. As given in Table 2-1, the total mass, including moisture, of all materials (dikes, tailings, rubble, stabilization cover, and contaminated earth) is approximately 3.2 million tons. The soil on the site is a combination of decomposed shale and a conglomerate of river-deposited sand and cobbles with a maximum dimension of 12 in.

1.2.5 Geology, Hydrology, and Meteorology

The Shiprock tailings and millsite are situated on benchland adjacent to the southwest bank of the San Juan River; the benchland is an ancient river terrace that has been left elevated from continued downcutting of the river.

Underlying much of the tailings are up to 10 ft of terrace deposits that form a layer between the Mancos Shale and the tailings. These materials have been deposited over a long period of time on the benchland by the San Juan River when it flowed at a higher level. The materials are poorly sorted and range in size from 12-in. boulders to sand- and silt-sized particles that are cemented together in places. The Mancos Shale directly below this alluvium is at least several hundred feet thick. A simplified stratigraphic cross-section is illustrated in Figure 2-9.

The elevated topography at the millsite eliminates the possibility of flooding or erosion of the tailings by the waters of the San Juan River. Undercutting of the bank also is not a problem. South and west of the tailings, the terrain is relatively flat near the site. Drainage from the higher ground farther to the south is carried to Dead Mans Wash, which empties into the San Juan River about 0.5 mi southeast of the site.⁽¹⁾

The confined ground water aquifers underlying the site are protected against contamination by both an upward pressure gradient and thick impermeable strata, and there is no possibility of contamination of these aquifers from the tailings. There is a potential for further contamination of the terrace gravel immediately underlying the tailings piles if sufficient

water is allowed to collect and percolate through sections of the piles. However, reshaping of the surface of the piles can prevent the collection of rainwater in a single area.

As indicated by eolian deposits (see Figure 2-10), the prevailing winds are from the southwest. For the purposes of health effects calculations, meteorological data recorded at the Farmington airport were used. In any case, the direction of transport of materials by winds is away from population centers and over farmlands.

1.3 RADIOACTIVITY AND POLLUTANT IMPACTS ON THE ENVIRONMENT

About 85% of the total radioactivity originally in uranium ore remained in the tailings after removal of the uranium. The principal environmental radiological impact and associated health effects arise from the ^{230}Th , ^{226}Ra , ^{222}Rn , and ^{222}Rn daughters contained in the uranium tailings. Although these radionuclides occur in nature, their concentrations in tailings material are several orders of magnitude greater than their average concentrations in the earth's crust. Because of the chemical treatments they have experienced, they appear to be more soluble and, therefore, more mobile.

1.3.1 Radiation Exposure Pathways, Contamination Mechanisms, and Background Levels

The major potential environmental routes of exposure to man are:

- (a) Inhalation of ^{222}Rn and its daughter products, resulting from the continuous radioactive decay of ^{226}Ra in the tailings. Radon is a gas which diffuses from the piles. The principal exposure results from inhalation of the ^{222}Rn daughters. This exposure affects the lungs. For this assessment, no criteria have been established for radon concentrations in air. However, the pathway for radon and radon daughters accounts for the major portion of the exposure to the population.
- (b) External whole-body gamma exposure directly from radionuclides in the piles.
- (c) Inhalation and ingestion of windblown tailings. The primary health effect relates to the alpha emitters ^{230}Th and ^{226}Ra , each of which causes exposure to the bones and lungs.
- (d) Ingestion of ground and surface water contaminated with radioactive elements (primarily ^{226}Ra) and other toxic materials.

- (e) Contamination of food through uptake and concentration of radioactive elements by plants and animals is another pathway that can occur; however, this pathway was not considered in this study.

1.3.1.1 Radon Gas Diffusion and Transport

Measurements of radon flux from the tailings, made in 1976⁽²⁾ using the charcoal canister technique,⁽³⁾ ranged from 53 to 157 pCi/m²-s on the tailings piles. Measurements of radon flux made in August 1980 ranged from 2.1 to 340 pCi/m²-s, with the mean flux on the upper and lower tailings piles estimated to be about 110 pCi/m²-s. Radon flux depends principally on radium content of tailings; however, it also varies considerably because of moisture, soil characteristics, and climatological conditions.

Short-term radon measurements were performed by FB&DU in 1976 with continuous radon monitors (Wrenn chambers) supplied by ERDA at 12 locations in the vicinity of the Shiprock tailings piles. The locations and values of the radon measurements are shown in Figure 3-5. One set of measurements on the upper pile indicated an average radon concentration of 12 pCi/l for a 24-hr period. Measurements in the NECA office and training buildings averaged about 7 pCi/l for 24 hr.

No further measurements of atmospheric radon were possible in 1980 since calibrated instrumentation was not available during the field work. It is judged that radon attributable to the piles is smaller because of the greater depths of cover material on the lower pile.

No background measurements of radon in the atmosphere were available prior to the measurements performed during this assessment. Four 24-hr measurements of atmospheric radon at locations from 0.8 to 3 mi from the tailings site indicated an average background concentration of about 0.8 pCi/l.

Radon daughters measured by ORNL personnel⁽⁴⁾ in the NECA office building concurrently with FB&DU measurements ranged from 0.006 to 0.02 WL.

1.3.1.2 Direct Gamma Radiation

The range of natural background values in the Shiprock area was between 6 and 13 μ R/hr, as measured by ORNL. A value of 13 μ R/hr was used by the EPA as the average background gamma radiation level,⁽⁵⁾ and 9 μ R/hr was determined in these studies. Above the surface of the tailings piles, gamma readings ranged from 30 to over 300 μ R/hr. This could be reduced to near-background levels by a cover of approximately 2 ft of sand and gravel.

1.3.1.3 Windblown Contaminants

Measurements of radioactive airborne particulates were performed at several locations around the Shiprock tailings site by the EPA, Office of Radiation Programs, Las Vegas Facility (ORP-LVF), during a 7-mo period in 1974.⁽⁵⁾ The concentrations of all isotopes measured were below the most restrictive maximum permissible concentrations given in 10 CFR 20.

A 10 μ R/hr isoexposure line determined by the EPA in 1974 and believed to be due to residual windblown tailings is illustrated in Figure 3-14. Also shown in this figure is an estimate, based on measurements made by FB&DU in 1980, of that area within which soil contamination was in excess of 5 pCi/g of ^{226}Ra .

1.3.1.4 Ground and Surface Water Contamination

Water samples were obtained from two surface locations and three locations along the San Juan River. No water was found in any of the holes drilled through the tailings piles to investigate subsoil contamination. Water from a pond near the ore storage area contained 2 pCi/l of dissolved ^{226}Ra .⁽⁴⁾ A dissolved ^{226}Ra concentration of 3.5 pCi/l was measured in a water sample taken from a stagnant pond at the base of the shale bluff at the northeast corner of the tailings site. These figures compare with the EPA Interim Primary Drinking Water Regulations⁽⁶⁾ of 5-pCi/l total maximum concentration of ^{226}Ra and ^{228}Ra .

1.3.1.5 Soil Contamination

The leaching of radium from the tailings into the subsoil generally extends about 3 ft before reaching the background level of 1.7 pCi/g. Two times the background level was reached at approximately 2 ft beneath the tailings-soil interface. In some regions of the ore storage area, the radium concentration is 2 times background at depths of about 3 ft. In the mill area, contamination to an 8-ft depth has been found in isolated locations.

1.3.2 Remedial Action Criteria

For the purpose of conducting the original engineering assessment,⁽²⁾ provisional criteria provided by the EPA were used. The criteria were in two categories, and applied either to structures with tailings present or to land areas to be decontaminated. For structures, the indoor radiation level below which no remedial action was indicated was considered to be an external gamma radiation level of less than 0.05 mR/hr above background and a radon daughter concentration of less than 0.01 WL above background. Land could be released for unrestricted use if the external gamma radiation levels were less than 10 μ R/hr above background. When cleanup was necessary,

residual radium content of the soil after remedial action should not exceed twice background in the area.

Since enactment of the Uranium Mill Tailings Radiation Control Act of 1978 (PL 95-604), which was effective November 8, 1978, the EPA has published interim (45 FR 27366) and proposed (46 FR 2556) standards for structures and open lands. These standards establish the indoor radon daughter concentration, including background, below which no remedial action is indicated at 0.015 WL. The indoor gamma radiation limit is 0.02 mR/hr above background.

For open land, remedial action must provide reasonable assurance that the average concentration of ^{226}Ra attributable to residual radioactive material from any designated processing site in any 5-cm thickness of soils or other materials within 1 ft of the surface, or in any 15-cm thickness below 1 ft, shall not exceed 5 pCi/g.

Environmental standards have been proposed by the EPA (46 FR 2556) for the disposal of residual radioactive materials from inactive uranium processing sites. These standards require that disposal of residual radioactive materials be conducted in a way which provides a reasonable assurance that for at least 1,000 yr following disposal:

- (a) The average annual release of ^{222}Rn from the disposal site to the atmosphere by residual radioactive materials will not exceed 2 pCi/m²-s.
- (b) Substances released from residual radioactive materials after disposal will not cause:
 - (1) the concentrations of those substances in any underground source of drinking water to exceed the level specified below,* or
 - (2) an increase in the concentrations of those substances in any underground source of drinking water where the concentrations of those substances prior to remedial action exceed the levels specified below for causes other than residual radioactive materials.*

*These requirements apply to the dissolved portion of any substance listed above at any distance greater than 1.0 km from a disposal site that is part of an inactive processing site, or greater than 0.1 km if the disposal site is a depository site.

<u>Substance</u>	<u>mg/l</u>
Arsenic	0.05
Barium	1.0
Cadmium	0.01
Chromium	0.05
Lead	0.05
Mercury	0.002
Molybdenum	0.05
Nitrogen (in nitrate)	10.0
Selenium	0.01
Silver	0.05
	<u>pCi/l</u>
Combined ^{226}Ra and ^{228}Ra	5.0
Gross alpha particle activity (including ^{226}Ra but excluding radon and uranium).	15.0
Uranium	10.0

- (c) Substances released from the disposal site after disposal will not cause the concentration of any harmful dissolved substance in any surface waters to increase above the level that would otherwise prevail.

Since the passage of PL 95-604, the NRC has published final regulations for uranium mill tailings licensing in the Federal Register (45 FR 65521). They include the requirement that the stabilization method must include an earth cover of at least a 3-m thickness and sufficient to reduce the radon emanation rate from the tailings to 2 pCi/m²-s above background. In addition, seepage of materials into ground water should be reduced by design to the maximum extent reasonably achievable.

While these standards may undergo further limited revisions, they will not likely experience changes that would significantly alter the nature of the remedial actions or their estimated costs. Therefore, the interim and proposed standards as indicated above form the basis for determining required remedial actions and their associated costs.

1.3.3 Potential Health Impact

Radon gas exhalation from the piles and the subsequent inhalation of radon daughters account for most of the total dose to the population within 2 mi of the Shiprock site under present conditions. The gamma radiation exposure from the piles is virtually zero past 0.4 mi. The population density within 0.5 mi of the perimeter of the piles is low.

Gamma radiation can be reduced effectively by shielding with any dense material. However, experience has shown that it is very difficult to control the movement of radon gas through porous materials. Once released from the radium-bearing minerals in the tailings, the gaseous radon diffuses by the path of least resistance to the surface. The radon has a half-life of about 4 days, and its daughter products are solids. Therefore, part of the radon decays en route to the surface and leaves daughter products within the tailings pile. If the diffusion path can be made long enough, then, theoretically, virtually all of the radon and its daughter products will have decayed before escaping to the atmosphere. Calculations using the theoretical techniques of Kraner, Schroeder, and Evans⁽⁷⁾ earlier indicated that 13 ft of earth cover would be required to reduce the radon diffusion from the Shiprock tailings by 95%. Later experimental work⁽⁸⁾ has demonstrated that 2 to 3 ft of compacted clay may be sufficient to reduce radon flux to less than 2 pCi/m²-s, assuming the continued integrity of the clay cover.

The health significance to man of long-term exposure to low-level radiation is a subject that has been studied extensively. Since the end results of long-term exposure to low-level radiation may be diseases such as lung cancer or leukemia, which are also attributable to many other causes, the determination of specific cause in any given case becomes very difficult. Therefore, the usual approach to evaluation of the health impact of low-level radiation exposures is to make projections from observed effects of high exposures on the premise that the effects are linear. A considerable amount of information has been accumulated on the high incidence of lung cancer in uranium miners and others exposed to radon and its daughters in mine air. This provides a basis for calculating the probable health effects of low-level exposure to large populations. (The term "health effect" refers to an incidence of disease; for radon daughter exposure, a health effect is a case of lung cancer.) This is the basis of the health effects calculated in this report. It should be recognized, however, that there is a large degree of uncertainty in such projections. Among the complicating factors is the combined effect of radon daughters with other carcinogens. As an example, the incidence of lung cancer among uranium miners who smoke is far higher than can be explained on the basis of either smoking or the radiation alone.

The risk estimators used in this report are given in the report of the National Academy of Sciences Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR-III report).⁽⁹⁾ This report presents risk estimators for lung cancer derived from epidemiological studies of both uranium miners and fluorspar miners. The average of the age-dependent absolute risk estimator for these two groups as applied to the population at large is 150 cancers per year per 10⁶ person-WLM of continuous exposure, assuming a lifetime plateau to age 75.

The term WLM means working level months, or an exposure to a concentration of one working level of radon daughter products in air for 170 hr, which is a work-month. A working level (WL) is a unit of measure of radon daughter products which recognizes that the several daughter elements are frequently not in equilibrium with each other or with the parent radon. Because of the many factors that contribute to natural biological variability and of the many differences between exposure conditions in mines and residences, this estimator (150 cancer cases per year per 10^6 person-WLM of continuous exposure) is considered to have an uncertainty factor of about 3. Another means of expressing risk is the relative risk estimator, which yields risk as a percentage increase in health effects per 10^6 person-WLM of continuous exposure. However, this method has been shown to be invalid⁽¹⁰⁾ and is not considered in this assessment.

For the purpose of this engineering assessment, it was assumed that about 50% equilibrium exists inside structures between radon and its daughter elements resulting in the following conversion factors:

$$1 \text{ pCi/l of } ^{222}\text{Rn} = 0.005 \text{ WL}$$

For continuous exposure:

$$0.005 \text{ WL} = 0.25 \text{ WLM/yr}$$

On the basis of predictions of radon concentrations in excess of the background value under present conditions, it was calculated that the average lung cancer risk attributable to radon released from the piles in the area within 6 mi of the Shiprock site is 6.3×10^{-6} per person per year, or about 14% of the average lung cancer risk due to all causes for the Navajo Nation (4.5×10^{-5}).⁽¹¹⁾ For those within 0.75 mi of the site, the average lung cancer risk due to the piles is 2.0×10^{-5} per person per year, or about 44% of the cancer risk due to all causes.

The 25-yr health effects were calculated for three population projections using a present estimated population of 6,052 in the 0- to 6-mi area, and 960 in the 0- to 0.75-mi area. The results for pile-induced radon and background radon for the two areas (0 to 6 mi and 0 to 0.75 mi) were as follows:

25-Year Cumulative Health Effects within 6 Miles of Edge of Site

<u>Projected Population Growth</u>	<u>Pile-Induced RDC</u>	<u>Background RDC</u>
0.8% constant growth rate	1.1	4.8
2.5% declining growth rate*	1.2	5.4
4.0% declining growth rate*	1.3	6.2

25-Year Cumulative Health Effects within 0.75 Mile of Edge of Site

<u>Projected Population Growth</u>	<u>Pile-Induced RDC</u>	<u>Background RDC</u>
0.8% constant growth rate	0.52	0.74
2.5% declining growth rate*	0.59	0.83
4.0% declining growth rate*	0.68	1.0

Pile-induced radon daughter health effects are approximately 23% and 70% of the background radon daughter health effects for the 0- to 6-mi and 0- to 0.75-mi areas, respectively. The exposure and consequent risk will continue as long as the radiation source remains in its present location and condition.

1.3.4 Nonradioactive Pollutants

There are other potentially toxic materials in the tailings. Chemical analyses of solid tailings samples from drill holes on the Shiprock tailings piles showed arsenic, barium, vanadium, and lead in concentrations between 100 and 600 ppm. The highest selenium, cadmium, and chromium concentrations were 52 ppm, 2 ppm, and 15 ppm, respectively. Iron concentration was as high as 14,700 ppm.

Samples from stagnant water in the Shiprock ore storage area contained concentrations of arsenic 10 times the maximum allowable concentration for drinking water and selenium 60 times the maximum allowable. However, there was no measurable increase in selenium found in the San Juan River below the millsite. Samples taken upstream and downstream from the millsite indicated increased concentrations of arsenic, iron, cadmium, and lead in the river below the site. The arsenic and lead additions are small and the resulting contents in the river are below the limits of the EPA Interim Primary Drinking Water Regulations.⁽⁶⁾ The cadmium and iron concentrations are relatively large. However, impurity levels of these two

*Declines linearly from its initial value to zero in 25 yr and remains constant at zero thereafter.

minerals upstream from the tailings are substantially above the recommended limits of the EPA drinking water regulations. Consequently, removal of the tailings apparently would not substantially upgrade the environmental quality of the San Juan River, nor increase its potential use.

1.4 SOCIOECONOMIC AND LAND USE IMPACTS

Because all reservation land is owned commonly by the Navajo Nation, there is no conventional valuation for these properties. However, there are several criteria that might be used to assess the value of the site land. Land values might be estimated on the basis of recent exchanges of tribal land for off-reservation land, lease payments for Navajo lands, or comparisons with similar-use off-reservation land. Even more important is that Shiprock has been designated by tribal authorities to be one of five Navajo communities with the greatest potential for primary growth. It is expected to absorb some of the growth impact of the Navajo Irrigation Project, proposed coal gasification plants, and oil exploration and development activities. If the tribe's efforts to attract industry succeed, the expansion of agriculture and increased mineral activity will produce pressures to develop the tailings site area for industrial and commercial use. Since the location of the tailings site is adjacent to an industrial park along the San Juan River, and near U.S. Highway 666 and the new Shiprock airport, the value of the site is estimated to range from \$50 to \$3,500/acre, depending on its use.

1.5 RECOVERY OF RESIDUAL VALUES

Available historical records that provide reliable data on specific mineral contents of the Shiprock tailings site are limited. Only a few samples of tailings were obtained during this study. Consequently, calculations based on these samples would not be statistically representative.

There are, however, five factors that can be considered to evaluate whether reprocessing Shiprock tailings to extract uranium and other mineral values would be practicable:

- (a) The amount of tailings present
- (b) Concentrations of residual values
- (c) Projected recovery
- (d) Current market price of recovered values
- (e) Proximity to processing mills

Three principal alternatives for the reprocessing of the Shiprock tailings were examined:

- (a) Heap leaching
- (b) Treatment at an existing mill
- (c) Reprocessing at a new conventional mill constructed for tailings reprocessing.

The cost of the uranium recovered would be about \$230/lb and \$250/lb of U_3O_8 by heap leach and conventional plant processes, respectively. The spot market price for uranium was \$25/lb early in 1981. Therefore, reprocessing the Shiprock tailings for uranium recovery does not appear to be economical under present market conditions.

1.6 MILL TAILINGS STABILIZATION

Investigations of methods of stabilizing uranium mill tailings piles from wind and water erosion have indicated a variety of deficiencies among the methods. Chemical stabilization (treatment of the tailings surface) has been successful only for temporary applications and is thus viewed as inadequate for currently proposed disposal criteria. Volumetric chemical stabilization (solidifying the bulk of the tailings) techniques appear to be costly and of questionable permanence. Physical stabilization (emplacement of covers over the tailings) methods using soil, clay, or gravel have been demonstrated on a laboratory scale to be effective in stabilizing tailings. Artificial cover materials are attractive but have the disadvantage of being subject to degradation by natural and artificial forces. Vegetative stabilization (establishment of plant growth) methods are effective in limiting erosion. However, where annual precipitation is less than about 10 in., soil moisture content may be inadequate to ensure viability of the plant life.

Migration of contaminants into ground water systems must be limited under the NRC and EPA criteria. Control of water percolating through the tailings can be accomplished by stabilizing chemically, by physically compacting the cover material, and by contouring the drainage area and tailings cover surface. Isolation of the tailings from underlying ground water systems can be accomplished by lining a proposed disposal site with natural or artificial impermeable membranes.

Several materials have been identified which sufficiently retard radon migration so that the radon flux is substantially reduced, on a laboratory scale. Unfortunately, no large-scale application has been undertaken which would demonstrate that these materials satisfy all of the technical criteria in the EPA-proposed standards and NRC regulations for licensing of uranium mills. However, extensive investigations of these questions continue in the Technology Development program of the Uranium Mill Tailings Remedial Actions Project Office in Albuquerque, New Mexico.

In view of findings from stabilization research, it appears that physical stabilization of tailings with 3 m of well-engineered cover material may be sufficient to appropriately stabilize tailings at their disposal site to meet NRC regulations.

1.7 OFF-SITE REMEDIAL ACTION

A mobile scanning unit performed a gamma radiation survey of the Shiprock area in 1971. Nine anomalies above the background criteria were discovered. Ore was found and removed from one location. Three locations had tailings more than 10 ft from structures and were not considered further. Tailings were found within 10 ft of four houses, and the last location was a former ore-buying station. Since the mobile survey, an additional location was found with elevated gamma and working level measurements. The latter six locations will be considered for remedial action based upon more complete measurements.

1.8 DISPOSAL SITE SELECTION

In this report, seven of the alternative remedial action options include moving the Shiprock tailings to a disposal site. The corresponding seven disposal sites were selected after consultation with officials of the Navajo Environmental Protection Agency, the State of New Mexico, the Indian Health Service, and the Bureau of Indian Affairs. Each site was evaluated to a limited extent on the bases of hydrology, meteorology, geology, ecology, economics, and proximity to population centers. Seven other potential disposal sites in three general areas have been identified for disposal of the Shiprock tailings and evaluated to a limited extent.⁽¹²⁾ Since the responsibility for disposal site selection lies with the Federal Government, with input from the Navajo Indian Tribe, the disposal sites evaluated in this report must be considered only as tentative. Subsequent studies associated with preparation of the Environmental Impact Statement will result in a recommended disposal site that is fully characterized and satisfies appropriate disposal site characteristics.

The relative locations of the disposal sites listed in Table 1-2 as Options II through VIII are shown in Figure 8-1. In each of these options, surface material would be removed, as appropriate, from the disposal area and stockpiled. A retaining dike and diversion ditches would be constructed if necessary. The tailings would be emplaced, contoured, and covered with 3 m of soil. The surface would be covered with 0.3 m of riprap or vegetation established for erosion control, and the entire site would be fenced.

1.9 REMEDIAL ACTIONS AND COST-BENEFIT ANALYSES

1.9.1 Remedial Action Options

The remedial action options examined include stabilization of the tailings piles in their present location and removal of all radioactive materials to an area where these materials could be isolated from the public. The options for which cost estimates were made include stabilization on the present site with 3 m of cover material and the removal of tailings to seven possible locations. The options are summarized in Table 1-2.

The basis for comparison, from which the cost effectiveness of other remedial alternatives can be judged, is the present condition of the site with no remedial action.

Option I represents remedial action activities to stabilize the piles more completely in their present location with the addition of a 3-m depth of cover and the construction of additional dike protection. Erosion of the tailings would be controlled more completely, and radon exhalation would be reduced to not more than 2 pCi/m²-s above background. The site would have limited future use.

Seven sites were evaluated for possible disposal of the Shiprock tailings and contaminated materials, and cost estimates for disposal at each site were made. Their locations are given in Figure 8-1 and Table 8-1.

The Many Devils site (Option II) rarely is used for grazing and appears to be an unauthorized dump site. This site has the advantage of being closest to the Shiprock site, but the disadvantage of being closest to human habitation.

The Shiprock Campground site (Option III) is attractive because it is near the tailings site and easily accessible from existing roads. However, the site's accessibility is also a potential liability because of the possibility of encroachment.

The Rattlesnake site (Option IV) would offer the advantages of a limited amount of land disturbed during disposal (being relatively near the tailings site) and a convenient haul route. The primary disadvantages are the location of the site on sandstone bedrock, which may act as a ground water recharge area, and the limited amount of material available for stabilization cover.

The Salt Creek site (Option V), presently used as grazing land, has all the advantages of the Many Devils site except that it is located farther from the tailings site.

The Oil Field site (Option VI) includes several possible disposal locations with the advantages of excellent drainage and proximity to cover materials and highways. The major

disadvantage is the insufficient amount of cover materials on the site itself.

The Hogback site (Option VII) in the area southeast of Shiprock is very isolated. Its principal disadvantage is distance from the tailings site.

Option VIII, providing for the disposal of tailings in a mined-out area of an open-pit coal mine, would provide a disposal area that would isolate the tailings from the public. The 26-mi haul distance, however, represents a disadvantage of this potential disposal site. In addition, site availability and the timing of placement raise questions about the viability of this site for disposal.

1.9.2 Cost-Benefit Analyses

As summarized in Table 9-1, the total estimated costs for the eight remedial action options vary from about \$13,400,000 to about \$37,900,000. Each of these options would have associated health and monetary benefits. The options are identified by number in Paragraph 1.1.

The number of cancer cases avoided per million dollars expended for each option is given in Figure 9-2. The curves in Figure 9-2 indicate an increase in benefit-cost ratio with time due to the greater reduction in population exposure over longer periods of time as a result of remedial action. The potential cancer cases avoided for each option and the cost per potential cancer case avoided are given in Table 9-2.

TABLE 1-1

SUMMARY OF CONDITIONS NOTED AT TIME OF 1980 SITE VISITS

	Condition of Tailings ^a	Condition of Structures On Site ^b	Mill Housing ^c	Adequate Fencing, Posting, Security	Property Close to River or Stream	Houses or Industry within 0.5 Mi	Evidence of Wind or Water Erosion	Possible Water Contam- ination	Tailings Removed for Private Use	Other Hazards On Site
<u>ARIZONA</u>										
Monument Valley	U	R	N	No	No	Yes	Yes	No	Yes	No
Tuba City	U	PR-UO	E-P	No	No	Yes	Yes	No	No	Yes
<u>COLORADO</u>										
Durango	P	PR-UO	N	Yes	Yes	Yes	Yes	No	Yes	Yes
Grand Junction	S	PR-O	N	Yes	Yes	Yes	Yes	Yes	Yes	No
Gunnison	S	B-O	N	No	Yes	Yes	No	Yes	No	No
Maybell	S	R	N	Yes	No	No	Yes	No	No	No
Naturita	RMS	PR-O	N	Yes	Yes	Yes	Yes	Yes	No	No
New Rifle	P	M-O	N	Yes	Yes	Yes	Yes	Yes	No	No
Old Rifle	S	PR-UO	N	Yes	Yes	Yes	No	Yes	Yes	No
Slick Rock (NC)	S	R	N	Yes	Yes	Yes	Yes	Yes	No	No
Slick Rock (UCC)	S	R	E-P	Yes	Yes	Yes	No	Yes	No	No
<u>IDAHO</u>										
Lowman	U	R	N	No	Yes	Yes	Yes	Yes	Yes	No
<u>NEW MEXICO</u>										
Ambrosia Lake	U	PR-O	N	No	No	No	Yes	No	No	No
Shiprock	S	PR-O	N	Yes	Yes	Yes	No	Yes	Yes	No
<u>NORTH DAKOTA</u>										
Belfield	R	PR-O	N	No	No	Yes	No	No	No	No
Bowman	R	R	N	No	No	No	No	No	No	No
<u>OREGON</u>										
Lakeview	S	B-O	N	Yes	No	Yes	Yes	No	No	No

TABLE 1-1 (Cont)

	<u>Condition of Tailings^a</u>	<u>Condition of Structures On Site^b</u>	<u>Mill Housing^c</u>	<u>Adequate Fencing, Posting, Security</u>	<u>Property Close to River or Stream</u>	<u>Houses or Industry within 0.5 Mi</u>	<u>Evidence of Wind or Water Erosion</u>	<u>Possible Water Contam- ination</u>	<u>Tailings Removed for Private Use</u>	<u>Other Hazards On Site</u>
<u>PENNSYLVANIA</u>										
Canonsburg	P	B-O	N	Yes	Yes	Yes	No	Yes	Yes	Yes
<u>TEXAS</u>										
Falls City	P	B-O	N	Yes	No	No	Yes	No	No	No
<u>UTAH</u>										
Green River	S	B-Y	N	Yes	Yes	Yes	Yes	Yes	No	No
Mexican Hat	U	PR-UO	E-O	No	No	Yes	Yes	Yes	No	No
Salt Lake City	U	R	N	No	Yes	Yes	Yes	Yes	Yes	Yes
<u>WYOMING</u>										
Converse County	U	R	N	Yes	No	No	No	No	No	No
Riverton	S	PR-O	N	No	No	Yes	No	No	No	No

^aS - Stabilized but requires improvement

P - Partially stabilized

U - Unstabilized

RMS - Reprocessed, moved and stabilized - contamination remaining

R - Removed - contamination remaining

^bM - Mill intact

B - Building(s) intact

R - Mill and/or buildings removed

PR - Mill and/or buildings partially removed

O - Occupied or used

UO - Unoccupied or unused

^cN - None

E - Existing

O - Occupied

P - Partially occupied

TABLE 1-2

SUMMARY OF REMEDIAL ACTION OPTIONS AND EFFECTS

<u>Option Number</u>	<u>Site Specific Cost (\$000)</u>	<u>Description of Remedial Action</u>	<u>Benefits</u>	<u>Adverse Effects</u>
I	13,400	The piles would be stabilized in place with 3 m of local earth cover. Natural vegetation would be established or a 0.3-m cover of riprap would be provided. On- and off-site contaminated materials would be cleaned up as necessary.	A-E,H,I	X
II	25,600	The tailings, contaminated soil and rubble would be removed by truck to site 2, Many Devils area, located about 4 mi from the tailings site. The tailings site would be decontaminated as in Option I and released for unlimited use.	A,C-G, I,J	--
III	29,000	Same as Option II, except tailings removed to site 1, Shiprock Campground, located about 6.8 mi from the tailings site.	A,C-G, I,J	--
IV	27,400	Same as Option II, except tailings removed to site 5, Rattlesnake area, located about 8.3 mi from the tailings site.	A,C-G I,J	--
V	30,100	Same as Option II, except tailings removed to site 8, Salt Creek area, located about 8.5 mi from the tailings site.	A,C-G I,J	--

TABLE 1-2 (Cont)

<u>Option Number</u>	<u>Site Specific Cost (\$000)</u>	<u>Description of Remedial Action</u>	<u>Benefits</u>	<u>Adverse Effects</u>
VI	29,500	Same as Option II, except tailings removed to site 6, Oil Field area, located about 8.5 mi from the tailings site.	A,C-G, H,I	--
VII	37,900	Same as Option II, except tailings removed to site 4, Hogback area, located about 16 mi from the tailings site.	A,C-G, H,I	--
VIII	34,100	Same as Option II, except tailings removed to site 7, Operating Open-Pit Coal Mines, located about 26 mi from the tailings site.	A,C-G, H,I	--

Notes

1. All options include on- and off-site remedial action.
2. For Options II through VIII, costs include removal of 3 ft of contaminated earth below the tailings.

TABLE 1-2 (Cont)

Definition of Benefits

- A. Off-site structures decontaminated
- B. Access to the tailings site controlled by fencing and posting
- C. Off-site windblown tailings cleaned up
- D. Wind and water erosion controlled
- E. Gamma radiation reduced
- F. The source of gamma radiation and radon gas removed from the area
- G. No building restrictions on or near site
- H. The prime use of the final disposal location unchanged
- I. Radon flux reduced to not more than 2 pCi/m²-s
- J. Maintenance and fencing eliminated

Definition of Adverse Effects

- X. Limited use of the tailings site

CHAPTER 1 REFERENCES

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9. "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation"; Report of Advisory Committee on Biological Effects of Ionizing Radiation; NAS, National Research Council; 1980.
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CHAPTER 2
SITE DESCRIPTION

CHAPTER 2

SITE DESCRIPTION

The purpose of this chapter is to describe the physical characteristics of the Shiprock site, its surroundings, and the characteristics of the tailings materials present on the site.

2.1 LOCATION

The tailings and millsite are located on the south side of the town of Shiprock, New Mexico, on the Navajo Indian Reservation. They are on the southwest bank of the San Juan River as it passes through Shiprock (see Figure 2-1). Farmington, New Mexico, is approximately 30 mi east of the Shiprock site. More specifically, the Shiprock site is located in Sections 25 and 36, Township 30 North, Range 18 West, New Mexico Principal Meridian, at 36 deg 46 min 39 sec north latitude and 108 deg 41 min 20 sec west longitude.

The closest population centers to the site are approximately 0.5 mi to the west and southwest of the tailings, and the center of Shiprock is about 1 mi to the north.

The Shiprock community and the site are accessible via U.S. 550 from Farmington and via U.S. 666 from Cortez, Colorado, or Gallup, New Mexico. The location of the site in relationship to its surroundings is shown in Figure 2-2.

2.2 TOPOGRAPHY

The site is located in a valley formed by the San Juan River. The Chaco River enters the San Juan about 3 mi upstream from the site. The country is arid and desert-like, with low rolling hills and occasional steep ridges and mesas. Vegetation is sparse except immediately along the San Juan River. The elevation of the site is about 4,960 ft above sea level. The tailings site is approximately 75 ft above the San Juan River, on a bench that drops sharply to the river.

The site includes a total of 230 acres. The 4.5-acre area that was occupied by the mill buildings is in the northwest portion of the site. The two adjoining tailings piles, located south of the former mill buildings, cover approximately 72 acres. The upper pile (i.e., the north pile) is the higher of the two piles, occupies about 26 acres, ranges in depth from 14 to 40 ft, and contains about 1.05 million tons of tailings (64% of the total). The lower pile (i.e., the south pile) occupies about 46 acres to a depth averaging 15 ft and contains about 0.6 million tons of tailings (36% of the total).

The two areas that were used for ore storage are immediately north and south of the former mill buildings, and west of each of the two tailings piles. The north ore storage area covered approximately 5.6 acres; the south ore storage area covered approximately 6.2 acres.

The northeast area of the site was used for water pumping and water storage and for purposes unrelated to the uranium milling activities. The area south of the tailings was leveled and used as an airstrip for private planes.

The present topography of the site is shown in Figure 2-3, which reflects changes that have resulted from activities of the Navajo Engineering Construction Authority, as described in Paragraph 2.5.

2.3 OWNERSHIP

The mill was constructed and operated from 1954 to 1963 by Kerr-McGee Oil Industries, Inc., and from 1963 to 1968 by Vanadium Corporation of America and its successor, Foote Mineral Company.

The mill was built on land leased from the Navajo Nation. Consequently, after the plant was shut down and partially dismantled (the Foote Mineral Company lease expired in 1973), control of the tailings and the site reverted to the Navajo Nation (which is still the owner).

A site description and ownership map has been prepared for DOE and is published in the Federal Register.⁽¹⁾ Figure 2-4 was adapted from this map.

2.4 HISTORY OF MILLING OPERATIONS AND PROCESSING⁽²⁾

Ore was first processed in the Navajo Mill in November 1954. The last ore was processed in June 1968, and the final finished product was removed from the circuit in August 1968.

During its operating life the mill processed 1.5 million short tons of ore with an average grade of 0.25% U_3O_8 and 1.07% V_2O_5 , and produced 3,711 tons of U_3O_8 in concentrate. All of the U_3O_8 concentrate was purchased by the AEC. Vanadium concentrate also was produced in 1955 and again from 1960 to 1968 and sold on the commercial market.

The uranium-vanadium ore was mostly sandstone, containing carnotite as the principal ore mineral. Ore was trucked to the mill from many small mines. During the Kerr-McGee operation (1954 to 1963), about 80% of the ore came from company-controlled mines in northeastern Arizona; the remaining ore processed came from other small mines, mostly in northeastern Arizona and northwestern New Mexico. After the change in ownership in 1963, more than half of the ore supply came from

the Uravan Mineral Belt. The average truck haul distance was about 100 mi. Another source of feed to the mill was the upgraded slime product that was the principal output of the Monument Valley plant.

The process used called for the ore to be crushed and ground to minus-35 mesh. It was then fed to the sulfuric acid leaching circuit. Leaching was in two stages, with the strong acid solution produced in the second stage recirculated to the first stage for partial neutralization by the entering ore slurry. The high concentration of acid in the second stage was required for good vanadium extraction. The bulk precipitate from the Monument Valley concentrator and upgrader was added ahead of the first leaching stage. Old tailings, which contained vanadium, were processed in the second stage of leaching. Following leaching, the sands and slimes entered the countercurrent washing system, in which the sands were washed in classifiers and the slimes were washed in thickeners. Uranium and vanadium were recovered from the pregnant liquors by solvent extraction. Tailings from the washing circuit were pumped to tailings ponds. Raffinate from the solvent extraction operation was disposed of by evaporation in separate holding ponds.⁽³⁾

2.5 PRESENT CONDITION OF THE SITE

The activities of the Navajo Engineering Construction Authority (NECA) between 1977 and 1980 have resulted in extensive changes in the condition and configuration of the Shiprock site. These changes are evident in Figures 2-1 and 2-3.

The upper tailings pile was covered with from 0.5 to 2 ft of pit-run soil and gravel and has some natural plant growth. This pile is resisting wind erosion fairly well, although tailings are exposed in a few areas. Dikes were built along the upper pile face, which abuts the San Juan River, to prevent water erosion of the tailings into the river. These dikes were improved around 1977. A graded road now surrounds the pile, and the dikes along the upper pile face where it abuts the river have been reduced to grade, rendering the whole eastern area relatively flat.

The lower pile has been disturbed and recontoured as a result of the training activities of the NECA, and it is now the repository for contaminated material resulting from cleanup of other parts of the site. The lower pile is also surrounded by a dike, the top of which has been graded to form a road. The irrigation system that had been installed on the lower pile for dust control during decontamination has been dismantled and partially removed. The component parts remain scattered over the tailings pile.

Two profiles of the upper and lower piles in cross-section are shown in Figure 2-5.

The decontaminated low area at the extreme northern end of the site has been filled in and the contours of the pond in that area have been modified considerably. Part of the former raffinate pond area, immediately south of the former plant office building, now decontaminated, has been fenced and currently is used by the NECA as a shipping and receiving area.

Only four of the original mill buildings at the site remain; they are the shower building, the engineering office building, and the classroom and shop buildings. The main mill building has been completely demolished and buried in the lower pile. The former plant office building is now leased to the U.S. Public Health Service Water and Sanitation Engineering Group. The NECA shop and equipment storage area is in good condition, and is fenced with chainlink and secured by a guard at night.

There are two new buildings on site; one is a maintenance shop and motor pool area and the other, a two-story concrete structure, houses the NECA engineering and administrative offices. The NECA no longer uses the site for the training of Navajo operators of earthmoving equipment. This function was moved to Crown Point, New Mexico, in 1978.

2.6 TAILINGS AND SOIL CHARACTERISTICS

Several types of material are present on the Shiprock piles: a combination of uranium and vanadium tailings, dikes, rubble, material from the decontamination program, and stabilization cover material. The types, volumes, and weights of materials presently on site are summarized in Table 2-1.

Bulk densities of tailings samples obtained in this assessment are shown in Table 2-2. The sample locations are given in Figure 2-6. These samples generally were finely-ground tailings with a high clay content. The bulk densities ranged between 82.0 and 106.8 lb/ft³. Table 2-2 shows the pH of tailings samples taken from on-site test holes to be in the neutral range; therefore, no problems are expected as a result of equipment or piping facilities coming in contact with the tailings.

Assay results of composite tailings samples are shown in Table 5-1. Analyses of samples indicate that the uranium tailings were not deposited uniformly in the piles. This nonuniformity can be attributed to changes in the refining process, to the variety of ore sources, and to the differential rates of tailings deposition and slimes migration from the discharge point. Also included in Table 5-1 are average assay results based on plant records.

2.7 GEOLOGY, HYDROLOGY, AND METEOROLOGY

2.7.1 Geology⁽⁴⁾

The Shiprock tailings and millsite are situated on benchland adjacent to the southwest bank of the San Juan River; the benchland is an ancient river terrace approximately 75 ft above the present river level. The topography of the site is shown in Figure 2-3.

Underlying much of the tailings are up to 10 ft of terrace deposits that form a layer between the Mancos Shale and the tailings. This terrace material has been deposited over a long period of time on the benchland beside the San Juan River, when the river flowed at a higher level. The material is poorly sorted and ranges in size from 12-in. boulders to sand- and silt-sized particles that are cemented together in places. The Mancos Shale directly below this terrace alluvium is at least several hundred feet thick.

2.7.2 Surface Water Hydrology

While no opportunity was provided for FB&DU to conduct field evaluations of site hydrology, existing information was examined to characterize general hydrologic conditions in the vicinity of the site. The results of this survey are contained in this and Paragraph 2.7.3. Apparently no further hydrologic characterization of the Shiprock tailings site is contemplated at this time.

Downcutting by the San Juan River has left the bench on which the site is located so high that the river waters pose no threat to the tailings, even in times of maximum flooding. As shown in Figure 2-7, surface tributaries drain from the south into the San Juan River near the millsite.⁽⁵⁾ The most important tributary is Dead Mans Wash, which is 0.75 mi southeast of the site. The river and the wash provide drainage for most of the area south of the site, leaving only a fractional part of a relatively flat, one-square-mile watershed area to drain toward the river channel at the plant site.

2.7.3 Ground Water Hydrology

The thick Mancos Shale layer in the Shiprock area is not water-bearing and overlies rocks of an older aquifer system. This aquifer system (Figure 2-8) extends beneath the town of Shiprock and receives its recharge from 15 mi or more west and southwest of Shiprock in the Carrizo and Chuska Mountains area.⁽⁶⁾

Beneath the Shiprock area, the water in the older aquifer system, containing high concentrations of dissolved solids, is confined under artesian pressure and rises to the surface

in flowing wells.⁽⁶⁾ Thus the confined systems are self-pressurized against contamination from surface water in the Shiprock area. Consequently, there is no possibility of downward migration of radioactive contamination through the Mancos Shale.

The Mancos Shale that underlies the Shiprock area also constitutes an effective barrier to both the upward and downward migration of ground waters. As evidenced by contaminated seeps along portions of the Mancos Shale outcropping, unconfined ground waters move through the recent alluvial gravels of the present San Juan River flood plain, but because the millsite is on the ancient bench well above the flood plain, the unconfined waters do not come in contact with the tailings. Figure 2-9 is a simplified stratigraphic cross-section of the rock formations in the Shiprock vicinity.

The Gallup Sandstone, a unit within the Mancos Shale, is made up of thin sandstone wedges and is water-bearing in some locales. It is not known at what depth this unit occurs beneath the Shiprock site, but the unit is not tapped as an aquifer in the Shiprock area and probably underlies the site by at least 200 ft.

An examination of the tailings in the two piles indicates that the tailings have porosity and water-holding characteristics similar to a clay or a clay-loam soil. The moisture storage capacity is estimated to be about 2.5 in./ft of depth of soil. The average precipitation at Shiprock is less than 8 in./yr, with the maximum amounts occurring from August through October, when evaporation is near its peak. The 24-hr maximum rainfall ever recorded at Shiprock is about 4 in. If a 24-hr storm equal to this maximum should occur, or even if the rainfall should exceed a 100-yr 24-hr storm, water from the resultant storm probably would not penetrate the tailings deeper than 2 ft, assuming the water is restrained from flowing over the surface. The water then would be returned to the surface by capillary action due to evaporation from the surface. Except for the brief period during and immediately following the rainfall, the soil moisture gradient always would be upwards.

Recent^(7,8) and ongoing research by the Research Institute for Geochemistry and Environmental Chemistry suggests that the presence of soluble sulfate salts in the tailings greatly modifies the hydrologic environments of the piles. The principal investigator⁽⁷⁾ states that "the general trend of material transfer within the piles is from the interior to the surface where salts with the contaminants precipitate." Since the San Juan River is close to the tailings piles, it appears there may be a substantial source of water to drive this phenomenon. It is also possible that a similar condition exists at some of the suggested disposal sites.

2.7.4 Meteorology

Limited quantitative wind data are available at the site, but comparable records are available from Farmington. Table 2-3 presents the frequency and direction of surface winds at Farmington, New Mexico, based on observations from 1960 to 1964.⁽⁹⁾ These data were used in estimating health effects attributable to the tailings piles.

Strong winds are said to be common in the area by Cooley, et al.⁽⁶⁾ The distribution and orientation of sand and dunes and the directions of crossbeds of eolian deposits indicate regional wind patterns during recent as well as geologic time (see Figure 2-10). The prevailing winds are from the southwest, but strong winds and storms also occasionally come from the west and northwest. Material eroded by these winds probably would be carried to the river or the bluff area south of the millsite.

These two sources of data do not agree on the direction of prevailing winds. However, since the population in the vicinity is distributed primarily in the westerly direction (see Table 4-1), the predominance of winds from the east, as shown in Table 2-3, assures that the predicted impact on public health has been conservatively estimated.

The available data indicate that the tailings materials may be eroded and carried away by the winds if a protective layer of some kind, e.g., gravel, is not placed on the exposed surface.

The precipitation at Shiprock averages less than 8 in. annually.

FIGURE 2-1. AERIAL PHOTOGRAPH OF SITE

360-02 REV 12/80

FIGURE 2-2. LOCATION OF SITE

FIGURE 2-3. TOPOGRAPHIC MAP

360-02 REV 12/80

SHIPROCK SITE

BEGINNING AT A POINT WHICH LIES $N43^{\circ}52'30''W$, 1355.3 FT FROM THE S.E. CORNER OF SECTION 36, T30N, R18W, N.M.P.M. AND RUNNING THENCE $N45^{\circ}00'W$, 2925 FT, THENCE $N45^{\circ}00'E$, 1993.71 FT, THENCE $S52^{\circ}35'E$, 2376.3 FT, THENCE $S7^{\circ}47'53''E$, 715 FT, THENCE $S45^{\circ}00W$, 1875 FT TO THE POINT OF BEGINNING.

CONTAINS 143.6 ACRES (MORE OR LESS)

NOTE: ADAPTED FROM REFERENCE 1

FIGURE 2-4. LAND OWNERSHIP AND SITE DESIGNATION MAP

PROFILE AT STA. 15+00

PROFILE AT STA. 24+50

FIGURE 2-5. CROSS-SECTIONS AT STATIONS 15+00 AND 24+50

NOTE: SEE FIGURE 2-6. DESCRIPTIVE MAP FOR PLAN

360-02 REV 12/80

NOTE
MAP DEVELOPED FROM AERIAL PHOTOGRAPH

- LEGEND
- x— FENCE
 - ▨ EDGE OF TAILINGS
 - 10 HOLE LOCATION AND NUMBER
 - ▽ SUDDEN CHANGE IN SLOPE (DOWNWARD)

FIGURE 2-6. DESCRIPTIVE MAP

360.02 REV 12/80

TOPOGRAPHY IN THE VICINITY OF THE SHIPROCK MILLSITE
 NOTE THAT THE CONTOURS INDICATE THAT MOST OF THE SURFACE
 RUNOFF FROM THE WATERSHED AREAS TO THE SOUTH AND WEST
 WILL NOT DRAIN ONTO THE SITE (ADAPTED FROM U S G S CHIMNEY
 ROCK, NEW MEXICO - COLORADO 15 MINUTE QUADRANGLE)

FIGURE 2-7. SURFACE DRAINAGE PATTERNS

360-02 3/77

FIGURE 2-9. SIMPLIFIED STRATIGRAPHIC CROSS-SECTION

350-02 3/77

TABLE 2-1

TYPES OF MATERIALS ON THE SHIPROCK PILES

<u>Material</u>	<u>Volume (yd³)</u>	<u>Weight (tons)</u>
Tailings	1,254,000	1,650,000 ^a
Contaminated Soil Under Tailings ^b	349,000	471,000
Dikes	45,000	61,000
Rubble Moved to Site	30,000	45,000
Stabilization Material	24,000	33,000
Contaminated Material ^c	650,000	964,000
Off-Site Locations	1,000	1,000
TOTAL	2,353,000	3,225,000

^aWeight based on average existing field densities, which include moisture.

^bBased on 72 acres contaminated to an average depth of 3 ft.

^cOn- and off-site material that has been deposited on the lower tailings pile by cleanup activities of the Navajo Engineering and Construction Authority.

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TABLE 2-2
PHYSICAL PROPERTIES AND pH
OF THE URANIUM TAILINGS SAMPLES

<u>Sample Location*</u>	<u>Water (%)</u>	<u>Bulk Density (lb/ft³)</u>	<u>pH of Sample (5% H₂O by wt)</u>
35	6.66	104.2	6.40
22	5.63	106.8	7.90
15	35.10	82.0	6.30
11	12.80	102.8	6.20
26	13.0	106.8	--
23	19.4	90.6	--

*See Figure 2-6.

360-02 3/77

TABLE 2-3

FARMINGTON, NEW MEXICO METEOROLOGY,
SURFACE WINDS, 1960 THROUGH 1964

<u>Direction</u>	<u>Frequency (%)</u>	<u>Direction</u>	<u>Frequency (%)</u>
N	3.3	S	2.7
NNE	2.9	SSW	2.6
NE	8.2	SW	6.7
ENE	8.4	WSW	6.4
E	8.6	W	7.6
ESE	4.6	WNW	5.5
SE	2.8	NW	2.3
SSE	1.3	NNW	1.4
Calms - 24.6%			
Annual average windspeed - 2.7 m/s			
			360-02 6/81

CHAPTER 2 REFERENCES

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CHAPTER 3

RADIOACTIVITY AND POLLUTANT IMPACT ON THE ENVIRONMENT

CHAPTER 3

RADIOACTIVITY AND POLLUTANT IMPACT ON THE ENVIRONMENT

The principal objective of the assessment in this chapter is to determine the magnitude and characteristics of the radiation emitted from the Shiprock uranium tailings piles and the resulting potential exposure to the population residing and working in the vicinity of Shiprock, New Mexico. In addition, this chapter briefly describes the potential radioactive and chemical pollutants and their pathways in the environment. The notations and abbreviations used are given in Table 3-1.

A radiological survey of the Shiprock site was conducted by Oak Ridge National Laboratory (ORNL)⁽¹⁾ concurrently with work performed by FB&DU in 1976. The principal results of that work are included in this engineering assessment.

3.1 RADIOACTIVE MATERIAL CHARACTERISTICS

Many elements spontaneously emit subatomic particles; therefore, these elements are radioactive. For example, when the most abundant uranium isotope, ^{238}U , undergoes radioactive decay, it emits a subatomic particle called an alpha particle; the ^{238}U after undergoing decay becomes ^{234}Th , which is also radioactive; and ^{234}Th subsequently emits a beta particle and becomes ^{234}Pa . As shown in Figure 3-1, this process continues with either alpha or beta particles being emitted, and the affected nucleus thereby evolves from one element into another. It is noted in Figure 3-1 that ^{230}Th decays to ^{226}Ra , which then decays to ^{222}Rn , an isotope of radon. Radon, a noble gas, does not react chemically. The final product in the chain is ^{206}Pb , a stable isotope that gradually accumulates in ores containing uranium. Uranium ore contains ^{226}Ra and the other daughter products of the uranium decay chain. One of the daughters of ^{226}Ra is the isotope ^{214}Bi , which emits a significant amount of electromagnetic radiation known as gamma radiation. Gamma rays are very similar to X-rays, only more penetrating. The ^{214}Bi is the principal contributor to the gamma radiation exposure in the uranium-radium decay chain.

Besides knowing the radioactive elements in the decay chain, it is also important to know the rate at which they decay. This decay rate, or activity, is expressed in curies (Ci) or picocuries (pCi), where 1 pCi equals 10^{-12} Ci or 3.7×10^{-2} disintegrations per second. The picocurie often is used as a unit of measure of the quantity of a radioactive element present in soil, air, and water.

Another important parameter used in characterizing radioactive decay is known as the "half life", $T_{1/2}$. This is the time that it takes for half of any initial quantity of the

radioactive atoms to decay to a different isotope. For example, it takes 4.5×10^9 yr for half the ^{238}U atoms to decay to ^{234}Th . Similarly, half of a given number of ^{222}Rn atoms will decay in 3.8 days.

The activity and the total number of radioactive atoms of a particular type depend upon their creation rates as well as their half life for decay. If left undisturbed, the radioactive components of the decay chain shown in Figure 3-1 all reach the same level of activity, matching that of the longest-lived initiating isotope. This condition is known as secular equilibrium. When the uranium is removed in the milling process, ^{230}Th , which is not removed, becomes the controlling isotope. After processing the ore for uranium, the thorium, radium, and other members of the decay chain remain in the spent ore solids in the form of a waste slurry. The slurry is pumped to a tailings pond. The sands and slimes that remain constitute the tailings piles. Generally, as at Shiprock, the slimes constitute only 20% of solid waste material, but they may contain 80% of the radioactive elements of major concern: radium and its daughters.

3.2 RADIATION EFFECTS

The radioactive exposure encountered with uranium mill tailings occurs from the absorption within the body of the emitted alpha and beta particles, and gamma radiation. The range of alpha particles is very short; they mainly affect an individual when the alpha emitter is taken internally. Beta particles have a much lighter mass than alphas, and have a longer range; but they still cause damage, mainly to the skin or internal tissues when taken internally. Gamma rays, however, are more penetrating than X-rays and can interact with all of the tissue of an individual near a gamma-emitting material.

The biological effects of radiation are related to the energy of the radiation; therefore, exposure to radiation is measured in terms of the energy deposited per unit mass of a given material. In the case of radon and its daughter products, the principal effect is from alpha particles emitted after the radon and its daughter products are inhaled.

The basic units of measurement for the alpha particles from short-lived radon daughters are the working level (WL) and the working level month (WLM). The working level is defined as any combination of the short-lived radon daughters in a liter of air that will result in the ultimate emission of 1.3×10^5 MeV of alpha energy. The working level is so defined because it is a single unit of measure, taking into account the relative concentrations of radon daughter products which vary according to factors such as ventilation. One WLM results from exposure to air containing a radon daughter concentration (RDC) of 1 WL for a duration of 170 hr.

The basic units of measurement for gamma radiation exposure and absorption are the roentgen (R) and the rad. One R is equal to an energy deposition of 88 ergs/g of dry air, and 1 rad is the dose that corresponds to the absorption of 100 ergs/g of material. The numerical difference between the magnitude of the two units is often less than the uncertainty of the measurements, so that exposure of 1 R is often assumed equivalent to an absorbed dose of 1 rad or a gamma dose of 1 rem. (Refer to the Glossary at the end of the report.)

3.3 NATURAL BACKGROUND RADIATION

There are several sources of radiation that occur naturally in the environment. Natural soils contain trace amounts of uranium, thorium, and radium that give rise to radon gas and to alpha, beta, and gamma radiation. The average background value in nine off-site soil samples for each member of the uranium decay chain, assuming equilibrium, was 1.7 pCi/g.⁽¹⁾ The sample locations taken within a 40-mi radius of Shiprock and the corresponding ^{226}Ra concentrations are shown in Figure 3-2. No previous measurements are available for the area. Another natural source of radiation in the environment arises from the decay of ^{232}Th , the predominant thorium isotope. The half-life of ^{232}Th is 1.4×10^{10} yr. It is also the parent of a decay chain containing isotopes of radium and radon. The average background value in the same off-site samples for each member of the thorium decay chain, assuming equilibrium, is about 0.98 pCi/g of soil. Table 3-2 lists the major background radioactive sources. It is noted that background values of the radium and thorium chains vary with locations by factors of 2 to 3.

During the 1980 field work, soil samples were collected from the topmost 12 in. of earth at five locations at an average distance of 1.3 mi from the site. The sample locations are shown in Figure 3-3, along with the corresponding soil concentrations of ^{226}Ra and ^{232}Th . The average values in these samples for ^{226}Ra and ^{232}Th were found to be about 1.2 and 0.3 pCi/g, respectively. These results correspond reasonably well to those described above.

Background values of radon concentrations were measured in 1976 at four locations using continuous radon monitors supplied by the ERDA. An average outdoor background value of about 0.8 pCi/l was obtained as the average of three 24-hr samples. However, the range of the measurements extends from 0.66 to 0.98 pCi/l. One additional measurement made 5 mi south of the millsite gave an anomalously high value of 1.4 pCi/l. This value was not included in the average background.

Background external gamma radiation levels, as measured 3 ft above the ground, also were determined at several locations from 1.5 to 4.5 mi from the site by using a calibrated and energy-compensated Geiger Mueller detector and a sodium-iodide

scintillometer. A value of 9 $\mu\text{R/hr}$ was established as the average background level, but the values ranged from 6 to 13 $\mu\text{R/hr}$.⁽¹⁾ Cosmic rays contribute to background radiation levels. The contribution from cosmic rays is generally dependent upon the altitude and is approximately 6.5 $\mu\text{R/hr}$ in the Shiprock area,⁽²⁾ or approximately 70% of the measured average background value. Currently, a value of 13 $\mu\text{R/hr}$, established with a pressurized ion chamber, is being used as the gamma background for the remedial action under way at the Shiprock site.⁽³⁾

3.4 RADIATION EXPOSURE PATHWAYS AND CONTAMINATION MECHANISMS

As noted previously, the principal environmental radiological implications and associated health effects of uranium mill tailings are related to radionuclides of the ^{238}U decay chain: primarily ^{230}Th , ^{226}Ra , ^{222}Rn , and ^{222}Rn daughters. Although these radionuclides occur in nature, their concentrations in tailings material are several orders of magnitude greater than in average natural soils and rocks. The major potential routes of exposure to man are:

- (a) Inhalation of the ^{222}Rn daughters, from decay of ^{222}Rn escaping from the pile; the principal exposure hazard is to the lungs.
- (b) External whole-body gamma exposure directly from the radionuclides in the tailings pile (primarily from ^{214}Bi) and in surface contamination from tailings spread in the general vicinity of the pile.
- (c) Inhalation of windblown tailings; the primary hazard relates to the alpha emitters ^{230}Th and ^{226}Ra , each of which causes exposure to the bones and the lungs.
- (d) Ingestion by man of ground or surface water contaminated from either radioactivity (primarily from ^{226}Ra) leached from the tailings pile or from solids physically transported into surface water.
- (e) Erosion and removal of tailings material from the pile by flood waters or heavy rainfall; this can create additional contaminated locations with the same problems as the original tailings pile.
- (f) Physical removal from the tailings pile also provides a mechanism for contamination of other locations.

- (g) Contamination of food through uptake and concentration of radioactive elements by plants and animals is another pathway that can occur; however, this pathway was not considered in this assessment.

The extent of radiation and pollution transport from the piles into the environment is discussed in the following paragraphs.

3.4.1 Radon Gas Diffusion and Transport

Measurements made in 1976 of the radon exhalation flux from the tailings using the charcoal canister technique.⁽⁴⁾ The locations and resulting fluxes are shown in Figure 3-4. The values range from 53 to 157 pCi/m²-s.⁽⁵⁾ Radon flux principally depends on radium content of the tailings. In general, radon flux varies considerably from time to time at a single sampling location due in part to differing moisture, soil, and climatological factors, to major changes in pile configuration between different locations, and to the difficulty of performing such measurements.

New radon exhalation flux measurements from the tailings were obtained in 1980; the locations and resulting fluxes are shown in Figure 3-4. Canisters were set out at 15 locations throughout the site and were removed about 24 hr later. At that time 15 more canisters were set out and were exposed for 9 to 10 hr. The weather was warm and dry during the exposure periods. The recently measured radon flux values range from about 2.1 to about 300 pCi/m²-s, with an average of 110 pCi/m²-s. These data are consistent with those described above and are well within the possible range of variation of flux when moisture, temperature, soil characteristics, and climate are taken into account.

Radon gas exhaling from the piles has been detected at 0.5 to 0.6 mi from the site. At these locations, radon concentrations are at about background levels during the daytime, but at night the concentrations reach several times the background level. This behavior during this steady period was probably due to an inversion condition and reduced wind velocity, which minimized dispersion and allowed radon to accumulate at greater distances from the piles at night. The locations and corresponding 24-hr average radon concentrations are illustrated in Figure 3-5. Even though the measurement time for each sample was only 24 hr, the values were obtained during atmospheric conditions normal at that time of year. Data were not recorded during wind or rainstorms.

The measurements of radon were made in February and June 1976. The 4.9-pCi/l measurement at site 4 was made in February with a light wind blowing from the piles toward the

measurement location. The 0.9-pCi/l value was obtained in June with the wind blowing at right angles to a line between the piles and the measurement location.

The variation of radon concentration during the measurement period and the existing weather conditions are shown in Figures 3-6 and 3-7. The sample location for Figure 3-6 is about 0.5 mi north of the edge of the piles, and the sample location for Figure 3-7 is at the storeroom of the NECA office on the site.

ORNL personnel performed WL measurements at hourly intervals for a 24-hr period in the NECA office building at the Shiprock site.⁽¹⁾ The continuous radon monitors were operated simultaneously inside and outside the building. The working level measurements are also plotted in Figure 3-7 for a direct comparison of the radon and radon daughter measurements. For this set of measurements, the radon daughter concentration appears to be about 20% of the equilibrium value inside the building.

The results of radon concentration measurements are plotted in Figure 3-8 as a function of distance from the edge of the tailings piles. Also shown in the figure are the FB&DU model results. Model calculations were performed with annual meteorology data and conservatively predicted meteorology to provide an additional estimate of the radon concentration in the vicinity of the piles. The FB&DU model first determines radon flux and the total radon releases from the piles with diffusion theory using radium soil concentrations, and pile configurations deduced from the drilling and survey data. Then the radon transport is calculated by Gaussian diffusion⁽⁶⁾ plus wind drift conditions. Conservatively predicted meteorology was used for the Shiprock area, as well as data from the Farmington airport, which were averaged over 5 yr.

3.4.2 Direct Gamma Radiation

External gamma radiation (EGR) levels measured on the piles in 1976 are shown in Figure 3-9.⁽¹⁾ At a few locations on the lower pile the EGR was over 300 μ R/hr. Readings on the upper pile were all below 300 μ R/hr. Measurements of EGR also were taken at 100-yd intervals on traverses in several directions away from the piles by both FB&DU and ORNL. Results of these measurements, taken with energy-compensated Geiger Mueller detectors, are plotted in Figure 3-10. Other gamma measurements were taken at locations where radon monitors were placed. These values also are shown in Figure 3-10. The decrease of EGR with distance from the edge of the piles in four directions is shown in Figure 3-11. EGR readings reached the background range at about 0.25 mi southeast of the piles and at less than 0.2 mi from the piles in the northwest, southwest, and northeast directions.

Figure 3-9 also shows uncorrected measurements of external gamma radiation (EGR) levels, including background, taken in 1980 in the vicinity of the tailings piles. These measurements were taken with a 1- x 1-in. NaI(Tl) scintillometer held 3 ft above ground level. The highest EGR levels, from 250 to 500 $\mu\text{R/hr}$, were encountered along a westerly traverse originating at the northeast corner of the upper tailings pile. These high readings were associated with correspondingly high "delta" values (see Paragraph 3.4.3 below) and are presumably indicative of surface contamination by ^{226}Ra .

3.4.3 Windblown Contaminants

Another pathway through the environment is the result of windblown tailings deposited off the tailings site. The prevailing winds are from the southwest; however, the tailings deposition to the east and northeast appears to be limited because at the northeast side of the site the upper tailings pile is stabilized with river rock, which tends to reduce blowing of tailings from both the upper and the lower piles. In addition, the airborne tailings are dispersed to a great extent on the northeast edge of the site, since the fine particles that blow over the upper pile soon reach the 90-ft bluff above the San Juan River. The greatest spread of windblown tailings is to the southeast, where above-background gamma radiation levels extend to 1,200 ft from the site boundary. Figure 3-12 shows the results of the EPA gamma radiation rate survey of the Shiprock site.⁽⁷⁾ Two iso-exposure lines are indicated in the figure: a background line and a 10 $\mu\text{R/hr}$ line. If scattered tailings and ore were removed from inside the 10 $\mu\text{R/hr}$ line (toward the piles) and if the piles were removed or covered to provide essentially complete gamma shielding, then the tailings remaining outside the line (away from the piles) would produce a net gamma exposure rate, 3 ft above ground, approximately equal to 10 $\mu\text{R/hr}$.

Soil samples were taken in the area surrounding the site.⁽¹⁾ The sample locations and ^{226}Ra concentrations are shown in Figure 3-13. To the southwest, west, and northwest, all the surface samples contained less than twice the average ^{226}Ra concentration of 1.7 pCi/l. To the southeast, a sample taken 400 yd from the piles had four times the average ^{226}Ra background concentration. At 600 yd from the piles the ^{226}Ra concentration was less than twice the average background value. Below the bluff to the northeast, concentrations ranged from 1.5 to 14 times the background value in four samples taken between the bluff and the river. This contamination probably resulted from windblown tailings prior to the covering of the upper pile. If the river overflows its banks into this area, the contamination would be carried downstream. There is evidence that the river floods portions of the river bottom adjacent to the piles.

In a small dry wash at the eastern corner of the site, very high levels of ^{226}Ra were found 6 in. below the surface, indicating that tailings or other contamination had been carried into the wash by water. Eventually this contaminated material will be washed into the river bottom.

Concentrations of radioactive airborne particulates were measured at several locations in the Shiprock area by EPA-ORP-LVF during a 7-mo period in 1974.⁽³⁾ Table 3-3 lists some of the measured values in the mill yard, an area southeast of the piles, and at the Shiprock High School across the San Juan River from the tailings. With only one exception, all values of concentration for measured isotopes were two orders of magnitude less than the permissible limits shown. The one exception, ^{230}Th in the mill yard, was slightly below the maximum permissible limit.

Measurements and data analyses were performed in 1980 to establish a boundary of that region around the site which exceeds 5 pCi/g of ^{226}Ra concentration in the soil, believed to be due to windblown contamination. A lead-shielded scintillometer, NaI(Tl), was used. One end of the scintillometer was unshielded and directed toward the ground, where it was held about 1 in. above the soil surface. An unshielded reading was obtained. A 0.5-in.-thick lead shield was then placed between the detector and the soil surface and a second reading was taken. The difference between the unshielded and shielded readings, called the "delta", is an indication of the ^{226}Ra concentration in the soil. A delta of about 400 counts/min between the shielded and unshielded count rates with the instrument used has been estimated to indicate a soil concentration of about 5 pCi/g of ^{226}Ra .

Traverses with the scintillometer were conducted across open lands adjacent to the tailings piles and were continued until a soil contamination of 5 pCi/g of ^{226}Ra was indicated. The traverses are shown in Figure 3-14 and the location of 5 pCi/g of ^{226}Ra is marked on each traverse. These points were connected to indicate the area surrounding the site contaminated in excess of 5 pCi/g of ^{226}Ra . In most instances the traverses extended well beyond the 10 $\mu\text{R/hr}$ contour of the 1975 EPA gamma survey,⁽⁷⁾ and surface contamination readings remained at or near background levels. It is readily apparent from Figure 3-14 that the boundary of windblown contamination coincides almost exactly with the edges of the tailings piles. Comparison of Figure 3-14 with Figure 3-12, the EPA gamma survey from the original report, seems to indicate that the extensive decontamination efforts and earthmoving work at the site have succeeded in reducing the area of the site that might be considered contaminated and that any relatively high levels of radiation are contained within the tailings pile boundaries.

3.4.4 Ground and Surface Water Contamination

Two water samples were taken at the tailings site, as shown in Figure 3-13. One sample, taken from a small pond in the ore storage area, had a dissolved ^{226}Ra concentration of 2 pCi/l. The other, from a stagnant pond at the base of the shale bluff at the northeast corner of the site, had a concentration of 3.5 pCi/l.⁽¹⁾ The latter site was in the flood plain of the San Juan River. Both of these samples had ^{226}Ra concentrations below the EPA Interim Primary Drinking Water Regulations⁽⁸⁾ of 5 pCi/l of combined ^{226}Ra and ^{228}Ra . No water was encountered in any drill holes.

3.4.5 Soil Contamination

The amount of ^{226}Ra activity in the tailings and the extent of leaching of radium from the tailings into the soil were determined by drilling boreholes through the tailings and into the soil beneath the upper and the lower piles. The radioactivity profile was measured in these holes with a Geiger tube probe in a lead shield which collimates the radiation. Soil samples were taken with a Shelby tube sampler from selected holes for radiometric analysis. Additional holes were drilled in the mill area, ore storage area, and on the side boundaries. The locations of the boreholes are indicated in Figure 2-6.

Typical radium activity profiles in Shiprock tailings and subsoil are shown in Figures 3-15 and 3-16. The variations in the radioactivity of the tailings noted in the profiles are due to variations in the methods of milling and tailings deposition. Figure 3-15 presents the profile for hole 23 on the lower pile. Soil analysis of a sample 2.5 ft below interface showed a ^{226}Ra concentration of about 2 times the average background value.⁽¹⁾ Other sample analyses of ^{226}Ra concentration at 1.5 ft below interface and immediately above the interface are also plotted in Figure 3-15.

Figure 3-16 is a radiometric profile of hole 15 drilled through the upper pile. A hard layer was encountered in all five holes on that pile and hole 15 was the only one where the layer was penetrated with the rock bit. The level of activity was very high (up to 4,000 pCi/g) at the bottom of the other holes immediately above the hard layer. No Shelby tube samples could be obtained, so a large backhoe from the NECA school was employed to cut trenches for sampling adjacent to holes SRNM-12 and SRNM-15 at the southeast end of the upper pile, where the tailings were not as thick and the hard layer was close to the surface. The hard layer near hole SRNM-15 consisted of cemented sand and gravel conglomerate. Beneath this layer was unconsolidated cobble conglomerate. The gamma log indicated a ^{226}Ra concentration of 2.5 times the background level at a depth of 4 ft below the tailings-soil

interface. Sample analyses of ^{226}Ra concentration from the adjacent pit varied from 2 to 45 times the average background concentration in the 6-ft interval below the tailings. These values are plotted in Figure 3-16.

In the pit adjacent to hole SRNM-12, about 0.5 ft of stained green-brown clay overlies the cobble conglomerate. The radium concentration in the conglomerate was 1,360 pCi/g at a depth of 6 in. below the stained layer and less than twice the average background ^{226}Ra concentration 2.5 ft below the tailings.

At hole 18, in the ore storage area, the radium concentration is as high as 210 pCi/g at a depth of 2 ft. It then decreases rapidly to near background values at a depth of about 4 ft. Radium concentrations in the soil in the mill area are generally above background levels, with the exception of a few locations where there is significant radiation to depths of 8 ft.

Figure 3-17 shows the radium concentration as a function of depth below the tailings-soil interface. The radium concentration is shown to be 5 pCi/g a little more than 1 ft below the tailings-soil interface.

3.4.6 Off-Site Tailings Use

Some of the uranium tailings have been moved from the site and used as fill material under structures and in lots. These locations have been identified by mobile and follow-up gamma surveys. The locations and survey results are discussed in Chapter 7.

3.5 REMEDIAL ACTION CRITERIA

The Grand Junction criteria for remedial action were adopted as a basis for the engineering assessments that preceded the enactment of PL 95-604, the Uranium Mill Tailings Radiation Control Act of 1978. The criteria adopted applied to: (a) the cleanup of structures⁽⁹⁾ where tailings are present, and (b) the cleanup of open land.

Prior to passage of PL 95-604, the criteria applied to structures were the guidelines established by the U.S. Surgeon General by letter of July 27, 1970, to the Director of the Colorado Department of Health for use in dwellings constructed with or on tailings. The guidelines were expressed in terms of external gamma radiation and radon daughter concentrations.

By letter of December 1974, the EPA provided radiological criteria for decontamination of inactive uranium millsites and associated contaminated land areas. These criteria were expressed in terms of the "as low as practicable" philosophy and

required that after remedial action has been completed, the residual gamma radiation levels should not exceed 40 $\mu\text{R/hr}$ above background in unusual circumstances and must be near background levels in most cases. Furthermore, these criteria required that cleanup of radium contamination should reduce the soil concentration of radium to less than twice background. The stabilized tailings area should be designated as a controlled area, restricted from human occupancy and fenced to limit access. However, open land areas where residual gamma levels were less than 10 $\mu\text{R/hr}$ above background were allowed to be released for unrestricted use.

Title II, Section 206 of PL 95-604 required the EPA to promulgate standards for the protection of the public and the environment from radiological and nonradiological hazards associated with residual radioactivity (as defined in the Act) at inactive uranium mill tailings and depository sites. The EPA subsequently published both interim standards (45 FR 27366) and proposed cleanup standards (46 FR 2556). Some changes may be made based on public comments; however, in the absence of substantial new information, changes in the standards sufficient to affect the cleanup actions required or the estimated costs are not expected.

3.5.1 EPA Interim and Proposed Standards

The interim standards and the proposed cleanup standards require that remedial actions be conducted to provide reasonable assurance that:

- (a) For a period of at least 1,000 yr following disposal:
 - (1) Radon released from the disposal site to the atmosphere would not exceed 2 $\text{pCi/m}^2\text{-s}$;
 - (2) Substances released from the disposal site to underground sources of drinking water would not contaminate the water in excess of limits described in the tabulation below; and,
 - (3) Substances released from the disposal site to surface waters would not contribute to contamination otherwise existing in the water.

<u>Substance</u>	<u>mg/l</u>
Arsenic.	0.05
Barium	1.0
Cadmium.	0.01

<u>Substance</u>	<u>mg/l</u>
Chromium	0.05
Lead	0.05
Mercury.	0.002
Molybdenum	0.05
Nitrogen (in nitrate).	10.0
Selenium	0.01
Silver	0.05
	<u>pCi/l</u>
Combined ^{226}Ra and ^{228}Ra	5.0
Gross alpha particle activity (including ^{226}Ra but excluding radon and uranium)	15.0
Uranium	10.0

- (b) The average concentration of ^{226}Ra attributable to residual radioactive material from any designated processing site in any 5-cm thickness of soils or other materials on open land within 1 ft of the surface, or in any 15-cm thickness below 1 ft, shall not exceed 5 pCi/g.
- (c) The levels of radioactivity in any occupied or occupiable building shall not exceed either of the values specified in the listing below, because of residual radioactive materials from any designated processing site.

Average annual indoor radon decay product concentration--including background (WL) 0.015

Indoor gamma radiation--above background (mR/hr). 0.02

3.5.2 NRC Regulations on Uranium Mill Tailings

In the NRC's final regulations for uranium mill licensing requirements, amendments to 10 CFR Parts 40 and 150 incorporate licensing requirements for uranium and thorium mills including tailings and wastes into the Commission's regulations.

The amendments of Part 40, Section 40.2a, include the statement:

Prior to the completion of the remedial action, the Commission will not require a license pursuant to this Part for possession of byproduct material as defined in this Part that is located at a site where milling operations are no longer active, if the site is designated a processing site covered by the remedial action program of Title I of the Uranium Mill Tailings Radiation Control Act of 1978. The Commission will exert its regulatory role in remedial actions, primarily through concurrence and consultation in the execution of the remedial action pursuant to Title I of the Uranium Mill Tailings Radiation Control Act of 1978.

In view of the foregoing and since under provisions of PL 95-604 a site on which tailings have been stabilized must be maintained under a license issued by the NRC, all uranium mill tailings disposal sites under PL 95-604 may eventually be subject to the criteria set out in Appendix A to Part 40. The criteria pertaining to tailings and waste disposal and stabilization that may apply in whole, or in part, to remedial action activities under PL 95-604 are summarized as follows:

Criterion 1 - The disposal site selection process should be an optimization to the maximum extent reasonably achievable for long-term isolation of the tailings from man, considering such factors as remoteness, hydrologic and other natural characteristics, and the potential for minimizing erosion.

Criterion 2 - To avoid proliferation of small waste disposal sites and thereby reduce perpetual surveillance obligations, with certain qualifications, byproduct material from in situ extraction operations and wastes from small remote above-ground extraction operations shall be disposed of at existing large mill tailings disposal sites.

Criterion 3 - The prime option for disposal of tailings is placement below grade. Where this is not practicable, it must be demonstrated that an above-grade disposal program will provide reasonably equivalent isolation of tailings from natural erosional forces.

Criterion 4 - If tailings are located above ground, stringent siting and design criteria should be adhered to. Factors to be considered include the following:

- (a) Minimization of upstream catchment area
- (b) Topographic features for wind protection
- (c) Relatively flat embankment slopes
- (d) Self-sustaining vegetative or riprap cover
- (e) Earthquake impact avoidance
- (f) Promotion of soil deposition

Criterion 5 - Steps shall be taken to reduce seepage of toxic materials into ground water to the maximum extent reasonably achievable.

Criterion 6 - Sufficient earth cover, but not less than 3 m, shall be placed over tailings or wastes at the end of milling operations to result in a calculated reduction in surface exhalation of radon from the tailings or wastes to less than 2 pCi/m²-s above natural background levels. Direct gamma exposure from the tailings or wastes should be reduced to background levels.

Criterion 11 - Provisions are set out for eventual transfer of ownership of the tailings to the State or to the United States.

Criterion 12 - The final disposition of tailings or wastes at milling sites should be such that ongoing active maintenance is not necessary to preserve isolation. Annual inspections should be conducted by owners.

EPA proposed and interim environmental standards for uranium mill tailings stabilization have been circulated to the Interagency Working Group for comment. The draft standards are generally consistent with NRC's proposed criteria as given above. However, they add the important further condition that the stabilization should be designed to provide reasonable assurance of remaining effective for at least 1,000 yr.

3.6 POTENTIAL HEALTH IMPACT

An assessment has been made of the potential health impact of the tailings piles. The environmental pathways described in Paragraph 3.4 were evaluated. A summary of the evaluation of each pathway is presented below:

- (a) Radon Diffusion - Inhalation of radon daughters from radon diffusion constitutes the most significant pathway and results in the largest estimated population dose.⁽¹⁰⁾

- (b) External Gamma Radiation - Gamma radiation is measurable to distances of 0.25 mi from the piles, which is an area void of inhabited dwellings; however, persons on site will receive some gamma exposure until the contaminated ground is cleaned and the piles are covered with sufficient material to attenuate the gamma radiation.
- (c) Airborne Activity - According to EPA data, the limited spread of significant quantities of windblown tailings, coupled with the distance between the piles and inhabited dwellings, indicates that inhalation or ingestion of tailings particulates is a minor component of the total population dose. This is a general result also reported at other uranium tailings piles.(3,11) Stabilization of the Shiprock tailings piles against wind erosion will eliminate the gradual accumulation of tailings off site and the attendant problems thereto.
- (d) Water Contamination - The low radium activity in nearby off-site surface water indicates little, if any, contamination from the tailings piles.
- (e) Subsoil Contamination - The minimal amount of leaching of radioactive materials through the tailings into the ground beneath the piles measured during this project indicates that this pathway results in negligible health effects; however, seepage from ponds during mill operations and subsequent contamination of localized areas have occurred. In one area to the northwest of the raffinate ponds, deep solution migration to 18 ft was discovered previously by the EPA.
- (f) Physical Removal - Tailings which have been placed near a structure or used in its construction are sources of elevated gamma levels and radon daughter concentrations in the structure. Radiation exposure to individuals living or working in these structures can be significant. The off-site remedial action is described in Chapter 7.

Only the potential health effects from the inhalation of radon daughters (pathway a) and from direct gamma radiation (pathway b) are estimated quantitatively in this assessment because these pathways produce the most significant exposures.(10,11) Furthermore, the uncertainty in the estimates

of the potential health effects from these pathways far exceeds the magnitude of the health effects from the other pathways.

It is extremely difficult to predict with any assurance that a specific health effect will be observed within a given time after chronic exposure to low doses of toxic material. Therefore, the usual approach to evaluation of the health impact of low-level radiation exposures is to make projections from observed effects of high exposures on the basis that the effects are linear, using the conservative assumption of no threshold for the effects. The resulting risk estimators also have associated uncertainties due to biological variability among individuals and to unknown contributions from other biological insults which may be present simultaneously with the insult of interest. No synergistic effects are considered explicitly in this analysis. For the purpose of this engineering study, lung cancer is the potential health effect considered for RDC. The health effects were estimated using an absolute risk model.

3.6.1 Assumptions and Uncertainties in Estimating Health Effects

Since radiation exposure from ^{222}Rn progeny is expressed in terms of working levels (WL) and working level months (WLM), total population exposures as well as health risk estimators are based upon these units; i.e., person-WLM. Exposures and resulting health effects are often expressed in terms of rems; however, estimates of the WLM-to-rem conversion factor for internal lung exposure to alpha particles from ^{222}Rn progeny are observed to vary by over an order of magnitude.⁽¹²⁾ Presently, there are significant differences of opinion related to the choice of an appropriate conversion factor. Consequently, disagreements of calculated health effects from RDC occur when these effects are based on the rem.

The BEIR-III⁽¹³⁾ risk estimator for lung cancer is based only on the absolute model since the relative risk model is not considered valid.⁽¹⁴⁾

The BEIR-III risk estimators for radon daughters are age-dependent, with the age specified as the age at the diagnosis of cancer. The minimal latent period following exposure is also age-dependent. The following values can be determined:

Age (yr)	Minimal Latent Period From Age at Exposure (yr)	Excess Risk at Age of Diagnosis (cancers per yr per 10 ⁶ person WLM)
0-14	25	0
15-34	15	0
35-49	10	9
50-65	10	18
66-75	10	42

These risk values are expressed in terms of WLM using the BEIR-III recommended conversion factor of 6 rem/WLM. These risk estimators are based on combined estimates for uranium miners and fluorspar miners; no data exist that indicate whether these values may be used for groups irradiated in childhood. Nevertheless, in the treatment below they are conservatively assumed to apply to the population at large.

The BEIR-III report does not discuss plateau periods. However, some data presented in the report indicate cancers are still being detected as much as 50 yr after the period of exposure. Therefore, it is reasonable to assume that a lifetime plateau to age 75 may be applicable.

The age-dependent excess risks presented in the BEIR-III report must be adjusted, when applied to the population at large, to account for the fact that the breathing rate of miners on the job is about 1.9 times greater than that of the general population.⁽¹⁵⁾ Since exposure is considered proportional to the breathing rate, the exposure (and hence the excess risk) of the general population would be smaller by this same factor.

The cumulative risk estimator is obtained from the BEIR-III data adjusted for breathing rate by determining specific cancer risks for each year following an exposure. These risks are summed for the years between age at exposure and age 75. The contribution to the cumulative risk estimator from each age group is weighted by the respective fractions of the U.S. population found in those age groups.⁽¹⁶⁾ For the lifetime plateau to age 75, no cancers were assumed to occur in the years subsequent to age 75. The following cumulative risk estimator for the population at large is obtained using a lifetime plateau to age 75 and weighting by the age distribution of the U.S. population:

$$150 \text{ cancers per yr}/10^6 \text{ person} - (\text{WLM continuous}) \quad (3-1)$$

Because of the many factors that contribute to natural biological variability and of the many differences in exposures among miners and among the population at large, this risk estimator is considered to have an uncertainty factor of about 3.

For the purpose of this assessment, equivalent working levels inside structures are determined from the radon concentration assuming a 50% equilibrium condition. This yields the following conversion factor:

$$1 \text{ pCi/l of } ^{222}\text{Rn} = 0.005 \text{ WL} \quad (3-2)$$

It is assumed that the component of indoor radon concentration due to radon originating from the pile is equal to the corresponding outdoor concentration component at that point. However, the total concentration of radon progeny is higher indoors owing to reduced ventilation, and to other sources such as building materials.

The exposure rate in terms of WLM/yr can be obtained from a continuous 0.005-WL concentration as follows:

$$(0.005 \text{ WL})(8766 \frac{\text{hr}}{\text{yr}}) [\frac{1 \text{ WLM}}{(1 \text{ WL})(170 \text{ hr})}] = 0.25 \frac{\text{WLM}}{\text{yr}} \quad (3-3)$$

The risk estimator used for continual exposure to gamma radiation is expressed as:⁽¹⁷⁾

$$72 \cdot \dot{D} + 0.8 \cdot \dot{D}^2 \text{ cancers per yr/} 10^6 \text{ person rems/yr-continuous} \quad (3-4)$$

where $\dot{D}$ is the dose rate in rem/yr. In this assessment it is assumed that a gamma exposure of 1 R in air is equivalent to a dose of 1 rem in tissue.

3.6.2 Health Effects

The health effects were calculated using a flux of 500 pCi/m²-s for the tailings piles. This value was calculated using diffusion theory, the tailings physical properties, and present conditions of the tailings piles. Even though the calculated value for radon flux appears much larger than the measured values, it is considered a more defensible estimate of the radon release rate since measurements of radon flux to date have been made only at a few points in time and give no

suggestion of the magnitude of annual variations. In the absence of this information, the conservative estimate was chosen as the basis for health effect calculations.

The transport of radon from the tailings piles was modeled using a Gaussian plume model, meteorology characteristics of the Farmington, New Mexico area, and the population distribution surrounding the tailings piles as a function of the radius and direction from the center of the site. The piles were modeled as a single vertical cylinder with an area equivalent to the surface areas of the piles. The height of the equivalent pile was assumed to be 6.4 m, a conservative estimate.

Total predicted outdoor ^{222}Rn concentration is shown in Figure 3-8, along with measured values, as a function of distance from the edge of the piles in the westerly direction. The predicted ^{222}Rn concentration at 0.1 mi from the edge of the piles is almost six times background levels but declines to near background levels within about 1 mi. The predicted radon concentration appears to be in general agreement with measured values.

Figure 3-18 shows the lung cancer risk per year from continuous exposure to radon as a function of distance west of the edge of the tailings piles. The curve shows that the risk for developing lung cancer from radon emanating from the piles is less than 3 times the natural occurrence from all causes at a distance of 0.1 mi from the edge of the site but declines to near the natural occurrence within about 1 mi.

The population distribution within 6 mi of the edge of the piles was developed using the best local statistics and other population information for the past decade. This distribution includes virtually all residents close enough to either pile to be exposed to any noticeable degree to radon emanating from the piles, as described in Chapter 4.

The three population projections used to estimate the cumulative health impacts attributable to the tailings piles are the 0.8% constant growth rate and the 2.5% and 4% declining growth rates, as discussed in Chapter 4. All three growth projections assume that the population is distributed around the site in the same proportions as those reflected in Table 4-1.

Tables 3-4 and 3-5 present the estimated health impacts from the tailings piles for 0 to 0.75 and 0 to 6 mi, respectively, from the edge of the large pile, based on the estimated 1980 population distribution presented in Table 4-1. The cumulative health effects for the three growth scenarios considered for Shiprock are also included. In Tables 3-4 and 3-5, the health effects from the pile radon are shown to be about 70% and 23% of those caused by background radon for the vicinity within 0.75 and 6 mi of the edge of the large pile, respectively.

3.7 NONRADIOACTIVE POLLUTANTS

There are other potentially toxic materials in the tailings. Chemical analyses of tailings samples from drill holes on the Shiprock tailings piles showed arsenic, barium, vanadium, and lead present in concentrations between 100 and 600 ppm. The highest selenium, cadmium, and chromium were 52 ppm, 2 ppm, and 15 ppm, respectively. Iron concentration was as high as 14,700 ppm.

Five water samples were taken from the vicinity of the Shiprock tailings piles and chemically analyzed. The locations of these samples are shown in Figure 3-13. Sample A was taken from a pond northwest of the tailings and mill area. Sample B was obtained from standing water in the San Juan River flood plain just below the bluff north of the tailings piles. Sample C was taken from the San Juan River opposite the tailings. Samples D and E were taken from the San Juan River upstream and downstream from the tailings piles, respectively. Water samples A and B, of stagnant, standing water, were above the limits of the EPA Interim Primary Drinking Water Regulations for cadmium, chromium, iron, arsenic, and selenium. In Table 3-6, concentrations of heavy metals in the Shiprock water samples are listed with the EPA Interim Primary Drinking Water Regulations.⁽⁸⁾ Samples from the San Juan River downstream from the tailings showed higher levels of iron, arsenic, barium, lead, and cadmium than the upstream Sample D; however, the addition of barium, lead, and arsenic was small and the San Juan River was still below the maximum acceptable limit for drinking water for these three elements.

On the other hand, even upstream from the tailings the San Juan River contained above the recommended drinking water levels of iron, chromium, selenium, and cadmium. Other studies also indicate high mineral content in surface waters on the Colorado Plateau. A study by Williams and Byers⁽¹⁸⁾ indicated that tributaries of the Colorado River contained up to 0.40 mg/l of selenium. Scott and Voegeli⁽¹⁹⁾ found in their study of surface waters in Colorado that 25% of the samples exceeded the EPA drinking water limit of 0.01 mg/l, some as high as 40 times the maximum level. Hence, it appears that high mineral content in surface waters, as was found in this study, is not unusual on the Colorado Plateau.

In summary, the Shiprock tailings might contribute to the nonradioactive pollution in the San Juan River; however, removal of the tailings would not materially upgrade the environmental quality of the San Juan River nor increase its potential use.

NOTE:

VERTICAL DIRECTION REPRESENTS ALPHA DECAY, HORIZONTAL DIRECTION INDICATES BETA DECAY. TIMES SHOWN ARE HALF LIVES. ONLY THE DOMINANT DECAY MODE IS SHOWN.

* ALSO GAMMA EMITTERS

FIGURE 3-1. RADIOACTIVE DECAY CHAIN OF URANIUM 238

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FIGURE 3-2. LOCATION FOR ^{226}Ra BACKGROUND SAMPLES

FIGURE 3-3. SURFACE RADIUM AND THORIUM CONCENTRATIONS

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FIGURE 3-5. RADON CONCENTRATION IN VICINITY OF PILES

LEGEND

..... SHIPROCK, NEW MEXICO DATA → WIND DIRECTION (UP=NORTH, DOWN=SOUTH)

FIGURE 3-6. ^{222}Rn AND ATMOSPHERIC TRANSIENTS AT 0.46 MI NW OF PILES ON FEBRUARY 26, 1976

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FIGURE 3-7. ^{222}Rn AND ATMOSPHERIC TRANSIENTS AT STOREROOM OF NECA OFFICE ON FEBRUARY 28, 1976

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FIGURE 3-8. REDUCTION OF OUTDOOR ^{222}Rn CONCENTRATION WITH DISTANCE FROM THE TAILINGS PILES

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- LEGEND

0 200 400 600

SCALE

FIGURE 3-9. GAMMA LEVELS 3 FT ABOVE GROUND

NOTE

1. ALL GAMMA LEVEL READINGS ARE IN $\mu\text{R/hr.}^{(1)}$

FIGURE 3-10. GAMMA LEVELS IN VICINITY 3 FT. ABOVE GROUND

FIGURE 3-11. REDUCTION OF EXTERNAL GAMMA RADIATION LEVELS WITH DISTANCE FROM THE TAILINGS PILES

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FIGURE 3-12. EPA GAMMA SURVEY SURROUNDING MILLSITE

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FIGURE 3-15. RADIOMETRIC PROFILE AT DRILL HOLE SRNM-23

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FIGURE 3-16. RADIOMETRIC PROFILE AT DRILL HOLE SRNM-15

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FIGURE 3-17. RADIUM ACTIVITY CONCENTRATION
IN CONTAMINATED SUBSOIL

FIGURE 3-18. LUNG CANCER RISK FROM CONTINUOUS EXPOSURE TO RADON

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TABLE 3-1

NOTATIONS AND ABBREVIATIONS USED IN CHAPTER 3

Isotope - A particular type of element, differing by nuclear characteristics, identified by the atomic mass number given after the element name; e.g., Radium-226.

Isotope Abbreviations:

^{238}U = Uranium-238
 ^{234}Th = Thorium-234
 ^{232}Th = Thorium-232
 ^{234}Pa = Proctactinium-234
 ^{226}Ra = Radium-226
 ^{222}Rn = Radon-222
 ^{218}Po = Polonium-218
 ^{214}Pb = Lead-214
 ^{214}Bi = Bismuth-214
 ^{40}K = Potassium-40

Radiations:

alpha particle	helium nucleus; easily stopped with thin layers of material, all energy deposited locally.
beta particle	electron; penetrates about 0.2 g/cm^2 of material.
gamma rays	electromagnetic radiation; similar to X-rays, and highly penetrating.
half-life ($T_{1/2}$)	time required for half the radioactive atoms to decay.
working level (WL)	measure of potential alpha energy per liter of air from any combination of short-lived radon daughters (1 WL = 1.3×10^5 MeV of alpha energy).
one working level month (WLM)	exposure to air containing a RDC of 1 WL for a duration of 170 hr.

TABLE 3-1 (Cont)

roentgen (R)	that quantity of gamma radiation which yields a charge deposition of 2.58×10^{-4} coul/kg air. This is equal to the energy deposition of 88 ergs/g of dry air or 93 ergs/g of tissue.
$\mu\text{R/hr}$	10^{-6} roentgen/hr.
rad	energy deposition of 100 ergs/g of material.
picocurie (pCi)	unit of activity (1 pCi = 0.037 radioactive decays/sec or 2.2 min).
MeV	unit of energy; 1 MeV = 1.6×10^{-6} erg.
rem	unit of energy deposition in man; 1 rem = 1 rad x quality factor; the quality factor = 20 for alpha particles.

Note: Also see definitions of terms in Glossary.

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TABLE 3-2

BACKGROUND RADIATION SOURCES IN SOIL IN NORTHWEST NEW MEXICO

<u>Isotope (Decay Chain)</u>	<u>Average Value (pCi/g)</u>	<u>Range (pCi/g)</u>
^{226}Ra (^{238}U)	1.7 ± 0.44	1.3 - 2.6
^{232}Th (^{232}Th)	1.0 ± 0.37	0.5 - 1.8
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TABLE 3-3

RADIOACTIVE AIRBORNE PARTICULATE CONCENTRATIONS NEAR THE SITE^a

Isotope	Most Restrictive ^b Maximum Permissible Concentration (pCi/l)	Southeast of Piles 4/27 - 4/29/74	Shiprock, New Mexico, High School 5/28 - 6/3/74	Shiprock, New Mexico, Mill Yard 4/23 - 4/30/74
238U	3 x 10 ⁻³	2.1 x 10 ⁻⁷	2.2 x 10 ⁻⁷	1.3 x 10 ⁻⁵
235U	4 x 10 ⁻³	<3.7 x 10 ⁻⁸	<9.9 x 10 ⁻⁹	5.1 x 10 ⁻⁷
234U	4 x 10 ⁻³	1.1 x 10 ⁻⁷	3.2 x 10 ⁻⁷	1.4 x 10 ⁻⁵
232Th	1 x 10 ⁻³	5.9 x 10 ⁻⁷	7.0 x 10 ⁻⁸	2.3 x 10 ⁻⁷
230Th	8 x 10 ⁻⁵	9.3 x 10 ⁻⁷	4.7 x 10 ⁻⁷	5.9 x 10 ⁻⁵
226Ra	1 x 10 ⁻³	2.7 x 10 ⁻⁶	7.2 x 10 ⁻⁷	--
210Po	7 x 10 ⁻³	--	3.4 x 10 ⁻⁶	7.3 x 10 ⁻⁵
210Pb	4 x 10 ⁻³	7.0 x 10 ⁻⁶	--	--

^aMeasurements performed by EPA-ORP, Las Vegas.

^bFrom 10 CFR 20, maximum exposure to an individual in an unrestricted area.

TABLE 3-4

ESTIMATED HEALTH IMPACT FROM SHIPROCK TAILINGS
FOR AN AREA 0 TO 0.75 MILE FROM TAILINGS EDGE

<u>Time Period</u>	<u>Population (Persons)</u>	<u>Total Pile-Induced RDC Health Effects/Yr</u>	<u>Background RDC Health Effects/Yr</u>
1980	960	0.019	0.028
2005 (0.8% constant growth rate)	1,150	0.023	0.033
2005 (2.5% declining growth rate)*	1,300	0.026	0.038
2005 (4.0% declining growth rate)*	1,550	0.031	0.045

25-Yr Cumulative RDC Health Effects

<u>Growth Projection</u>	<u>Pile-Induced</u>	<u>Background</u>
0.8% constant growth rate	0.52	0.74
2.5% declining growth rate*	0.59	0.83
4.0% declining growth rate*	0.68	1.0

*Declines linearly from its initial value to zero in 25 yr and remains constant at zero thereafter.

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TABLE 3-5

ESTIMATED HEALTH IMPACT FROM SHIPROCK TAILINGS
FOR AN AREA 0 TO 6 MILES FROM TAILINGS EDGE

<u>Time Period</u>	<u>Population (Persons)</u>	<u>Total Pile-Induced RDC Health Effects/Yr</u>	<u>Background RDC Health Effects/Yr</u>
1980	6,052	0.038	0.18
2005 (0.8% constant growth rate)	7,800	0.046	0.23
2005 (2.5% declining growth rate)*	8,150	0.051	0.23
2005 (4.0% declining growth rate)*	9,700	0.060	0.28

25-Yr Cumulative RDC Health Effects

<u>Growth Projection</u>	<u>Pile-Induced</u>	<u>Background</u>
0.8% constant growth rate	1.1	4.8
2.5% declining growth rate*	1.2	5.4
4.0% declining growth rate*	1.3	6.2

*Declines linearly from its initial value to zero in 25 yr and remains constant at zero thereafter.

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TABLE 3-6

CHEMICAL ANALYSES OF SHIPROCK WATER SAMPLES (mg/l)

Sample ^a	As	Se	Cr	Cd	Fe	Ba	Pb
A - Pond - Ore Storage Area	0.268	0.636	0.280	0.119	0.33	0.60	0.012
B - Below Bluff	0.525	0.424	<0.001	0.126	0.39	0.54	0.011
C - San Juan River Opposite Piles	0.024	0.43	0.330	0.462	1.67	0.63	0.010
D - San Juan River Upstream	0.019	0.034	0.180	0.221	1.24	0.53	0.009
E - San Juan River Downstream	0.024	0.035	0.170	0.826	1.67	0.69	0.017
EPA Interim Primary Drinking Water Regulations ^b	0.05	0.01	0.05	0.01	0.3	1.0	0.05

^aSee Figure 3-13 for locations.

^bFederal Register, Dec 24, 1975.

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CHAPTER 4
SOCIOECONOMIC AND LAND USE IMPACTS

CHAPTER 4

SOCIOECONOMIC AND LAND USE IMPACTS

The Navajo Nation is divided into political divisions called "agencies" and subdivisions called "districts", which in turn are divided into "chapters", also known as "units". Shiprock and the tailings site are located within the Shiprock Agency, which is divided into three districts (see Figure 4-1). The Shiprock Chapter, where the tailings are located, is Unit 4 of District 12.

4.1 SOCIOECONOMIC BACKGROUND

In the Navajo Nation Overall Economic Development Program of 1974, five communities were designated to be primary growth points based on their potential for various kinds of development and as centers for educational, health, and welfare services.⁽¹⁾ Shiprock, the easternmost of the five, was singled out as a key community in the industrial development of the Navajo Nation. It was the site of the Fairchild Semiconductor Facility and was expected to absorb much of the growth impact of the Navajo Irrigation Project, proposed coal gasification plants, and the Exxon uranium exploration project. However, the void left by the closing of Fairchild Semiconductor Facility has yet to be filled by other light industry in Shiprock, and the growth impacts of projects such as the Navajo Irrigation Project, the Four Corners and San Juan power plants, the Navajo mine, the WESCO gasification plant and others have been focused, instead, on the communities of Farmington and Bloomfield. The reasons for this are clear; the movement of outsiders into the Shiprock area is inhibited by the need to secure homesite leases or permission from parties enjoying customary grazing rights on the reservation.

In the Shiprock Chapter the mean educational level is slightly higher and per capita income is slightly lower than for the Navajo Nation as a whole. According to the Office of Program Development, 21% of the Navajo labor force is located in District 12 and is concentrated in the craft, operative, and household service categories. The major source of employment in the district, the Fairchild operation, closed in 1975. While operating, the plant employed 79% of the Shiprock labor force. The Navajo Tribe has a few work programs, but the major employers in Shiprock are the Federal Government and the public school system. The Navajo Irrigation Project has had a beneficial impact on employment of residents of upper and lower Fruitland west of Farmington. Many Navajos working in Utah construction and at the Arizona Public Service power plant (in the latter an estimated 900 Navajo employees out of a total of 1,100) commute to work from Bloomfield.

The type of housing in the area has evidenced a shift away from the traditional hogans to mobile homes; these are noticeable on U.S. Highway 550 between Shiprock and Farmington, and to a lesser extent on U.S. Highway 660 between Shiprock and Gallup.

4.2 POPULATION ESTIMATES

Census data and subsequent attempts to update these data must be accepted with caution. Population estimates are subject to some errors for groups of people who live in desert areas of the southwestern United States. These errors are compounded for the Navajo population because of their movements from one reservation location to another, and movements onto and off the reservation. In addition, when the Fairchild plant at Shiprock closed, approximately 1,200 workers lost their jobs. It is difficult to determine whether these workers have remained in the Shiprock Chapter, in District 12, or whether they have moved away. Tribal officials do not believe any significant shift has occurred.

The Navajo Nation Overall Economic Development Program printed the following general caution:⁽¹⁾

Demographic statistics are woefully inadequate. Data concerning Navajo population are presently only available in a generalized form, whose reliability decreases as one attempts to draw from it population density and characteristics at the smaller scales.

The Bureau of Indian Affairs, Office of Vital Records in Window Rock, Arizona, estimates the population figures for Shiprock Agency in 1980⁽²⁾ as listed in the following tabulation:

<u>Age Group</u>	<u>Population</u>
Under 16	12,198
16-24	6,945
25-34	4,824
35-44	3,192
45-64	3,211
65 and over	1,487
Total	31,857

The total population in the Shiprock Agency, comprising an area of about 4,240 mi², has apparently grown at an annual rate of about 2% from the 29,431 persons in 1976.

The population of the Shiprock Chapter, roughly corresponding to the city of Shiprock, was 7,006 according to a January 1, 1976, BIA estimate,⁽³⁾ and about 9,050 according to preliminary results of the 1980 census. The current population for the city of Shiprock is unofficially estimated to be 6,000.

As shown in Figure 4-2, three population projections were estimated for the next 25 yr. A constant 0.8% growth rate (the current overall growth rate of the United States) would result in an estimated population of 7,400 by the year 2005. The fastest growth rate presented, a 4% declining growth rate, would likely occur only if mineral and energy resources in the area were developed on a large scale. This rate would result in a Shiprock population of about 10,100 by 2005. The most probable projection is the 2.5% declining growth rate; this scenario would result in a 2005 population of about 8,350.

The current population within a 6-mi radius of the tailings site was estimated to be about 6,052. Table 4-1 shows the estimated population distribution as a function of radius and direction from the site. This table was developed by distributing the estimated Shiprock population within 6 mi of the site in proportion to the number of houses in the various areas. The population distribution in the Shiprock area is illustrated in Figure 4-3.

4.3 LAND USE

The tailings site at Shiprock continues to house offices and shops of the Navajo Engineering and Construction Authority (NECA). A new, two-story concrete structure has been built to house NECA administrative and engineering offices, and the former NECA office building has been leased to the U.S. Public Health Service. The school that trained Navajos to operate earthmoving equipment was moved from the site to Crown Point, New Mexico, in 1978.

The area directly across the San Juan River to the east and northeast of the tailings site is agricultural. A single unpaved airstrip was located immediately south of the tailings area. The area south of the site is presently used for low-density grazing. The area southwest of the site is an industrial site. Farther south and west are residential areas. The closest area to the west is unoccupied at present. The most densely occupied sections of Shiprock parallel the main traffic arteries of the area. The sections north and west of the site include a school, some commercial land (on which are two motels, a bank, and a trading post), a church, and a hospital.

Figure 4-4 reflects present land use in the vicinity of the Shiprock site.

4.4 IMPACT OF THE TAILINGS ON LAND VALUES

In order to assess land values and the impact of the tailings on them, it is necessary to consider the Navajo system of land allocation and transfer.

All land is commonly owned by the Navajo Tribe. Individuals and families enjoy primary use rights to certain lands which have been established through historic grazing or other use. Such lands are called "assignments".⁽⁵⁾

Only a very few of the total assigned lands on the reservation have legally described boundaries; i.e., no specified boundary line has been agreed upon by adjoining neighbors, and overlaps of grazing use are common. However, severe violations of the generally acknowledged boundaries are seldom tolerated.⁽⁵⁾ Since no free ownership exists within the reservation boundaries, assignees do not hold titles to the land that they use.⁽⁵⁾

This lack of a traditional monetary market for land exchanges on the Navajo Reservation makes it difficult to calculate the dollar value of the site and its environs. However, recent land exchanges by the Navajo Tribal Council, whereby they purchased off-reservation land and exchanged it for tribal land, are one indication. Other indications are recent lease payments for Navajo lands projected into land values, and comparisons with land values in the Farmington area. Also, by assigning a monetary value to sheep production per acre of land and by translating this value into capital-valued land, another cash valuation may be determined.

Using all of the above methods, and also taking into consideration the distance of the site from the highway (direct highway frontage) and the presence or absence of utilities (water, electricity, sewage, natural gas), it was estimated in 1977 that with the tailings removed the site would be valued at up to \$3,500/acre as industrially zoned land. As grazing land only, the site would be worth \$50/acre. If the tailings remain unstabilized and radon exhalation is not controlled, the site is worth approximately \$200/acre, considering the purposes for which it is being used.

Use value of the site can be estimated in less highly quantified terms. The land at the tailings site has relatively high use value because of its location on the San Juan River, its proximity to one of the best highways serving the region, its proximity to the population center, and its favorable site conditions, all of which led to its choice for location of the mill. In addition, the mere existence of buildings on the site adds to its usefulness.

The relatively slow pace of development in the area, coupled with the fact that large tracts of land, presently used

for little except grazing, are available only to the Navajos, indicates that the presence of the tailings piles has had and will have relatively small impact on land values in the Shiprock community.

NOTE:
MAP PREPARED BY OFFICE OF
NAVAJO LAND ADMINISTRATION

FIGURE 4-1. MAP OF NAVAJO POLITICAL JURISDICTIONS

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FIGURE 4-2. POPULATION PROJECTIONS

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LEGEND

SPARSELY POPULATED

LOW DENSITY POPULATION

POPULATION CENTER

U.S. HIGHWAY

STATE HIGHWAY

INDIAN RESERVATION BOUNDARY

FIGURE 4-3. MAP OF POPULATION CENTERS

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FIGURE 4-4. VICINITY LAND USE

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TABLE 4-1

ESTIMATED 1980 RESIDENT POPULATION DISTRIBUTION

Direction	Radius (mi)														Total
	0.1	0.3	0.4	0.5	0.75	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	6.0	
N	0	0	0	0	0	38	115	31	93	16	16	0	0	0	309
NNE	0	0	0	0	18	63	63	0	47	0	0	0	0	0	191
NE	0	0	0	0	10	21	35	0	0	0	0	0	0	0	66
ENE	0	0	0	0	0	50	45	62	47	78	0	0	0	0	282
E	0	0	0	0	13	13	20	0	0	31	0	78	233	434	822
ESE	0	0	0	0	0	0	0	0	0	0	0	47	0	0	47
SE	0	0	0	0	0	0	0	0	0	0	16	0	0	0	16
SSE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	0	0	0	4	0	0	0	0	0	0	0	0	0	0	4
SSW	0	0	8	0	0	0	0	0	0	0	0	0	0	0	8
SW	0	0	0	10	220	348	0	0	0	0	0	0	0	0	578
WSW	0	0	0	8	159	332	1	0	0	0	0	0	0	0	500
W	0	0	0	0	113	277	10	78	78	16	0	0	0	0	759
WNW	3	0	0	0	253	0	40	0	0	31	16	0	47	140	343
NW	38	6	0	2	75	75	75	31	140	217	155	93	0	0	907
NNW	0	0	5	5	10	20	0	16	62	62	186	171	357	326	1,220
Total	41	6	13	29	871	1,237	358	218	467	451	389	389	637	900	6,052

CHAPTER 4 REFERENCES

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CHAPTER 5
RECOVERY OF RESIDUAL VALUES

CHAPTER 5

RECOVERY OF RESIDUAL VALUES

The Shiprock tailings are in two adjoining piles. The "upper pile", as it is designated in the Phase II report,⁽¹⁾ was the last one to be used for tailings disposal. It is covered with about 0.5 to 2 ft of pit-run sand and gravel. This cover layer would have to be included in any reprocessing operation, as separation from the tailings is impracticable. This pile contains about 1,050,000 tons of tailings. Operating reports indicated that this quantity includes about 350,000 tons that were reprocessed during the period 1955 to 1960 when the plant was not recovering vanadium from the ores. Due partially to this double processing, the remaining metal concentrations in the upper pile are lower than average for the inactive sites, 0.011% uranium as U_3O_8 and 0.033% vanadium as V_2O_5 .

The "lower pile" originally contained the higher grade material resulting from plant operations before 1960 when vanadium was not being recovered. However, the remaining tailings, which amount to about 600,000 tons, have been considerably diluted by the activities of the NECA training school for operators of earthmoving equipment. The recent site cleanup and temporary tailings stabilization activities by NECA have added about 430,000 tons of contaminated soil to the lower pile, which probably cannot be cleanly separated from the tailings. Samples taken prior to this cover addition assayed 0.013% U_3O_8 and 0.026% V_2O_5 .

There are no other minerals of potential economic interest in either tailings pile. Table 5-1 shows the assay results on composite samples of both piles. The two piles together have 1,500,000 dry tons of tailings estimated to contain 0.012% U_3O_8 and 0.030% V_2O_5 . No amenability testing has been performed to determine the level of uranium and vanadium recovery that might be achieved if the Shiprock tailings were to be reprocessed in connection with a remedial action program to stabilize the tailings. In the absence of such amenability test work, the uranium recovery that could be expected from reprocessing is based on the graph provided by DOE's Grand Junction Office, as shown in Figure 5-1. It is expected that the recovery of uranium by a conventional process will be about 36%, and vanadium recovery might be 40%. This would be a recovery of 0.086 lb U_3O_8 and 0.12 lb V_2O_5 /ton.

By pelletizing the tailings with acid and heap leaching, a uranium recovery of roughly 30% or 0.072 lb U_3O_8 /ton might be achieved. By normal heap leaching the recovery would be about 20%. At November 1980 prices of \$28/lb of U_3O_8 , the total income from uranium recovery would be approximately \$1.40 to \$2.40/ton. The recoverable vanadium in the Shiprock tailings

would be worth about \$0.40/ton (at \$3/lb V₂O₅). As will be shown in the following analysis, there is virtually no prospect for profitable reprocessing of the Shiprock tailings to recover additional mineral values.

5.1 PROCESS ALTERNATIVES

There are three principal alternatives for the reprocessing of the Shiprock tailings. They are as follows:

- a) Heap leaching,
- b) Treatment at an existing mill,
- c) Reprocessing at a new conventional mill constructed for tailings reprocessing.

5.1.1 Heap Leaching

There are two process variations in use for heap leaching. In the first method, which has been used successfully to treat low-grade ore which otherwise would not warrant treatment, a pad is prepared with an impermeable layer at the bottom. A pipe drainage system is laid down and covered with gravel and sand. The tailings are deposited on this base in a layer up to about 20 feet thick, the surface being contoured into shallow basins to contain the leach solution. An acid solution, sometimes with added oxidant, is flowed into the surface basins and allowed to percolate through the bed. The solution collected is treated, usually by ion exchange or solvent extraction, to recover the uranium. When present, vanadium can be recovered in a second solvent extraction circuit. The recovery of values is considerably lower than by conventional plant processes, roughly half, as shown in Figure 5-1.

In the second procedure, the ore, crushed to minus 3/4-inch size, is premixed with a strong sulfuric acid solution and pelletized before being placed for leaching. Water is percolated through the bed, the recovered solution being processed to recover the solubilized uranium.

The pelletizing procedure involves increased handling and higher plant cost, but is likely to result in improved recovery of values over the first method described above due to better contact of the ore with the acid and improved uniformity of porosity.

Careful blending is needed to produce permeable heap leach piles. The feasibility of the pelletizing procedure is questionable, and depends on whether or not the pelletized tailings retain their shape or disintegrate when flooded in the leaching operation. This should be evaluated as part of the amenability testing.

5.1.2 Treating in an Existing Plant

For reprocessing in an existing conventional plant to be economically feasible, it is necessary that such a mill with significant excess capacity be located reasonably close to the present tailings site. The mill must also have a tailings disposal site with sufficient capacity to handle the additional tailings and allow for adequate long-term stabilization. In addition to the 1,500,000 dry tons of tailings, there are about 500,000 tons of contaminated waste at the Shiprock site. Further, contaminated soils will be generated as a result of the cleanup of land in the vicinity of the site.

The site has good access. Trucks could remove material from the site at a rate of about 4,800 tons/day. At this rate, all tailings and contaminated materials could be removed from the site in about 1.3 yr. No existing mill could devote such capacity to this low grade material on a current basis. The nearest operating mills that might be considered for possible reprocessing are over 100 mi from Shiprock. Transportation alone would cost about \$30,000,000, far more than the value of the metals in the tailings.

5.1.3 Treating in a New Plant

Construction of a new mill to reprocess the tailings would permit: (a) plant design tailored for the material to be processed; (b) siting suitable for long-term tailings stabilization; and (c) optimum plant capacity and uranium recovery. The major disadvantage is in the high cost of new plant construction.

The Shiprock tailings would feed a 2,000 ton/day plant for less than 3 yr.

Normally, amortization of a plant is based on planned operation for 10 to 20 yr. There does not appear to be any other nearby source of feed to such a plant which would materially lengthen the operating life and reduce the unit cost of plant amortization.

5.2 SHIPROCK RECOVERY ECONOMICS

The subjects discussed in this section determine the economic viability of reprocessing uranium mill tailings to recover residual mineral values.

5.2.1 Market for Uranium

The demand and price for uranium from 1976 to 1980 have gone through a rapid rise and fall cycle. Spot prices for uranium as indicated by the exchange values reported by NUEXCO⁽²⁾ rose from \$30/lb of U₃O₈ in November 1975 to \$43/lb

in November 1977 and essentially held constant until the end of 1979. The price dropped precipitously to \$28.50/lb of U₃O₈ by September 1980 and to \$25/lb early in 1981. Prices in individual long-term uranium sales contracts have varied over a broad range.

A variety of factors has contributed to this pattern, including the Three Mile Island accident and the subsequent delays in nuclear plant licensing, rapidly escalating power plant costs, and the inflexibility of uranium production operations. Total uranium inventories held by U.S. companies as of January 1, 1979 were 44,700 tons equivalent U₃O₈, representing nearly 3 times the current annual consumption rate. Projected domestic uranium supply exceeds apparent buyer requirements each year through 1985.⁽³⁾ Under these circumstances no basis is evident for a turnaround in uranium prices for about 5 yr.⁽²⁾ The supply and market for uranium as estimated by the DOE Assistant Secretary for Resource Applications is given in Table 5-2.

5.2.2 Escalation of Plant Construction Costs

The estimated construction costs of both heap leach plants and conventional mills without crushing and grinding facilities, as provided by the DOE Grand Junction, Colorado Office, were included as figures in the Phase II, Title I engineering assessment report.⁽¹⁾ The costs were adjusted to January 1977. Since then, relatively few plants have been built, and reported costs have been strongly influenced by new tailings control and stabilization requirements under NRC licenses. Recent estimates by R.B. Coleman of construction costs for conventional plants have been in the range of \$13,000 to \$30,000/ton of daily plant capacity.⁽⁴⁾ In view of the many significant site-specific problems that can influence capital costs, for this report it was decided to apply suitable escalation factors to the 1977 Grand Junction Office estimates, which are based on construction costs of many plants.

The Engineering News Record⁽⁵⁾ publishes reports quarterly on various construction cost indexes. The following data are derived from this source:

	Avg Index 1977	Latest Reported		Percent Increase
		Date (1980)	Index	
Nelson Refinery Cost Index	223	Jan	276	23.8
Chemical Engineering Plant Cost	186	Apr	234	25.4
Engineering Construction Cost (20 Cities)	240	June	298	24.2

The Producer Price Index of Industrial Commodities⁽²⁾ has increased as follows in the 1977-1980 period:

<u>Period</u>	<u>Index</u>	<u>Total Percent Increase</u>	<u>Annual Percent Increase</u>
Annual Average 1977	195.1	--	--
Annual Average 1978	209.4	7.3	7.3
Annual Average 1979	236.5	21.2	12.9
June 1980	273.0	39.9	15.4

From the above indexes, an increase in plant construction cost of 25% from January 1977 to mid-1980 has been applied as a conservative estimate. As indicated in Figure 5-2, the capital cost of a 2,000 ton/day heap leach facility would be about \$12.5 million. As indicated in Figure 5-3, the cost for a conventional mill of similar capacity would be about \$16 million. If these capital costs were to be amortized on the Shiprock tailings only, the unit costs would be \$14.30 to \$18/ton, or from \$129 to \$143/lb of U₃O₈ recovered.

5.2.3 Escalation of Plant Operating Costs

The operating costs of uranium mills appear to have risen much more steeply than construction costs. In the March 1977 engineering assessment report the direct operating costs of a 2,000 ton/day facility were estimated at \$3.10 and \$4.60/ton for heap leach and conventional acid leach mills, respectively. However, R.B. Coleman⁽⁴⁾ reports that 1980 operating costs of conventional mills are in the range of \$8.70 to \$18.40/ton.

Ranchers Exploration and Development Corporation reported their operating costs for heap leaching at Naturita, approximately a 1,200 ton/day facility, at about \$34/lb of U₃O₈ recovered, equivalent to \$20.50/ton of tailings processed. Costs of vanadium recovery were reported separately. In Figure 5-4, Grand Junction Office DOE 1977 estimates for heap leach plant operating costs are compared with Ranchers' 1978-1979 experience at Naturita. In Figure 5-5, conventional acid leach plant operating costs are compared with 1980 data reported by Coleman. The data indicate that conventional milling costs have risen by 250%, and heap leach cost is higher by a factor of 400 to 500%. However, the slope of the 1977 heap leach line is not confirmed by later information. Consequently, the dotted line in Figure 5-4 is considered more representative, and has been used as a basis of estimates.

Considering the differences in the plant designs, it is estimated that average mill operating costs have increased by a factor of 2.5 from the January 1977 data to mid-1980. This would result in operating costs for Shiprock tailings in a 2,000 ton/day conventional plant of about \$11.50/ton, or \$134/lb of U₃O₈ recovered (assuming 0.086 lb recovered/ton). For a heap leach plant of the same size the corresponding figures would be \$9.25/ton and \$128/lb recovered. In view of these operating costs, which are several times the market price, no detailed analysis of optimum plant size is warranted.

5.2.4 Competitive Market Factors

The average grade of ore processed in conventional mills has decreased from 0.15% U₃O₈ in 1977 to 0.11% in 1979. Average recovery rate for the industry has been 91+1% during this period.⁽⁶⁾ However, since tailings have been processed previously, the recoveries in reprocessing are likely to be much lower, as reflected in Figure 5-1. To produce a given quantity of uranium, nearly 10 times as much Shiprock tailings material must be processed as when a mill is operating on ore of the average grade treated in 1979. Thus, the volume of tailings to be stabilized per unit of production is correspondingly greater.

5.3 CONCLUSION

Based on the foregoing analysis, it is concluded that the processing of Shiprock tailings for the recovery of additional uranium and vanadium in connection with the tailings stabilization operations either by heap leach or conventional plant processes is not economically attractive at present market prices for these metals, nor is it likely to be so in the foreseeable future. A substantial improvement in metal recoveries over those used as a basis for this analysis and an improvement in prices by a factor of 5 to 10 would be needed to make the reprocessing economically attractive. For processing this material, assuming a plant capacity of about 2,000 tons/day, the cost of the uranium recovered would be about \$230 to \$250/lb of U₃O₈. A comparison of costs by process method is given below.

	<u>Conventional Plant</u>		<u>Heap Leach</u>	
	<u>\$/ton</u>	<u>\$/lb U₃O₈</u>	<u>\$/ton</u>	<u>\$/lb U₃O₈</u>
Capital Cost	9.70	113	7.60	106
Operating Cost	<u>11.50</u>	<u>134</u>	<u>9.25</u>	<u>128</u>
Total	21.20	247	16.85	234

The cost is, of course, very sensitive to the percent recovery of metal values, which can be only roughly estimated in the absence of amenability tests on representative samples. Capital costs might be lowered if another source of feedstock could be provided for the plant.

Vanadium recovery will not aid reprocessing economics, as the cost to recover vanadium is also estimated to far exceed its price. At an estimated \$4.50/ton cost to process the tailings for vanadium, and expected recovery of 0.12 lb/ton treated, the cost would be \$37.50/lb. The market price is presently about \$3/lb of V_2O_5 .

The spot market price for uranium in September 1980, when the economic analyses in this chapter were prepared, was \$28.50/lb of U_3O_8 . Since that time, construction costs have continued to rise, while the spot market price for uranium has declined to about \$25/lb of U_3O_8 early in 1981. These trends further reduce the economic attractiveness of tailings reprocessing.

FIGURE 5-1. URANIUM RECOVERY FROM MILL TAILINGS AS A FUNCTION OF U_3O_8 CONTENT IN TAILINGS

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FIGURE 5-2. CONSTRUCTION COSTS OF HEAP LEACHING PLANT TO REPROCESS URANIUM MILL TAILINGS (COST ADJUSTED TO JULY 1980)

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FIGURE 5-3. CONSTRUCTION COSTS OF A CONVENTIONAL URANIUM MILL TO REPROCESS TAILINGS W/O CRUSHING AND GRINDING FACILITIES OR TAILINGS STABILIZATION COSTS (COST ADJUSTED TO JULY 1980)

FIGURE 5-4. OPERATING COSTS OF HEAP LEACHING OF URANIUM MILL TAILINGS

FIGURE 5-5. OPERATING COSTS OF CONVENTIONAL MILLING
W/O CRUSHING AND GRINDING FACILITIES
TO REPROCESS TAILINGS
(COST ADJUSTED TO JULY 1980)

TABLE 5-1

ASSAY RESULTS OF COMPOSITE TAILINGS SAMPLES

<u>Element</u>	<u>Composite Upper Pile Sample, %</u>	<u>Composite Lower Pile Sample, %</u>	<u>Composite Sample Both Piles, %</u>
Spectrographic Analysis			
Aluminum	>1.0	>1.0	>1.0
Arsenic	0.783×10^{-6}	0.027×10^{-6}	0.405×10^{-6}
Calcium	>1.0	>1.0	>1.0
Boron	<0.01	<0.01	<0.01
Copper	<0.01	<0.01	<0.01
Gallium	<0.01	<0.01	<0.01
Iron	>1.0	>1.0	>1.0
Lead	0.01-1.0	0.01-1.0	0.01-1.0
Manganese	0.01-1.0	0.01-1.0	0.01-1.0
Molybdenum	0.01-1.0	0.01-1.0	0.01-1.0
Nickel	<0.01	<0.01	<0.01
Potassium	0.01-1.0	0.01-1.0	0.01-1.0
Selenium	0.356×10^{-6}	0.008×10^{-6}	0.182×10^{-6}
Silica	>1.0	>1.0	>1.0
Sodium	0.01-1.0	0.01-1.0	1.01-1.0
Titanium	<0.01	<0.01	<0.01
Chemical Analysis			
Uranium (U_3O_8)	0.011	0.013	0.012
Vanadium (V_2O_5)	0.033	0.026	0.033
<u>Plant Operating Estimate*</u>			
Uranium (U_3O_8)			0.01

*Calculated tailings assay based on plant operation

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TABLE 5-2

U.S. URANIUM SUPPLY AND MARKET SUMMARY

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	<u>Sales Commitments</u>		<u>Est. U₃O₈</u>	<u>Procure-</u>	<u>Reported</u>	<u>Total</u>	<u>Total</u>	<u>Apparent</u>
	<u>To</u>	<u>To</u>	<u>To Be</u>	<u>ment of</u>	<u>Unfilled</u>	<u>Domestic</u>	<u>Domestic</u>	<u>Buyer</u>
<u>Year</u>	<u>Domestic</u>	<u>Foreign</u>	<u>Available</u>	<u>Foreign</u>	<u>Requirement</u>	<u>Potential</u>	<u>Supply</u>	<u>Requirements</u>
	<u>Buyers</u>	<u>Buyers</u>	<u>For Sale</u>	<u>Uranium</u>		<u>(1+2+3)</u>	<u>(1+3+4)</u>	<u>(1+4+5)</u>
1980	21,500	2,000	2,600	1,800	400	26,100	25,900	23,700
1981	20,000	1,000	3,100	2,700	800	24,100	25,800	23,500
1982	19,400	1,000	4,300	2,800	1,300	24,700	26,500	23,500
1983	17,400	900	7,100	2,500	1,800	25,400	27,000	21,700
1984	16,000	500	7,800	2,500	4,000	24,300	26,300	22,500
1985	13,900	500	8,800	2,400	4,300	23,200	25,100	20,600
1986	11,200	300		1,000	9,900			22,100
1987	11,400	300		1,000	11,700			24,100
1988	10,500	300		1,000	12,000			23,500
1989	9,500	100		1,000	15,100			25,600
1990	7,300	100		1,000	14,400			22,700

Source: DOE/RA-0053

Survey of United States Uranium Marketing Activity, July 1980 (p. 17)

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CHAPTER 6
MILL TAILINGS STABILIZATION

CHAPTER 6

MILL TAILINGS STABILIZATION

In all alternate remedial actions considered in this study, the stabilization of mill tailings is required. Stabilization, as used here, means implementation of efforts to prevent the introduction of potentially harmful materials into the biosphere from the tailings. Government agencies and private industry have conducted and are conducting research to develop economical and environmentally suitable methods of stabilizing uranium mill tailings. The methods, technology, and data on stabilization that are presently available were reviewed and are described in this chapter. This information includes results from previous investigations, as well as findings of current and continuing research.

The objective of stabilizing the uranium mill tailings is to eliminate the pathways to the environment for the radioactive and other toxic particles which are described in Chapter 3. Alternatively, conditioning tailings might significantly reduce the rate at which potentially hazardous substances are released to the environment. Ideally, complete stabilization of radioactive tailings should permanently eliminate the possibilities of:

- (a) Wind and water erosion
- (b) Leaching of radioactive materials and other chemicals
- (c) Radon exhalation from the tailings
- (d) Gamma radiation emitted from the tailings

Implicit in these objectives is the additional goal of ensuring long-term stability and isolation of the tailings without the need for continued active maintenance. These objectives are consistent with those of the proposed EPA standards for inactive uranium mill tailings disposal.⁽¹⁾

6.1 PREVENTION OF WIND AND WATER EROSION

Wind and water erosion could be prevented by treating the tailings surface (surface stabilization), solidifying the bulk of the tailings (volumetric stabilization), by emplacing covers over the tailings (physical stabilization), or by establishing plant growth over the tailings (vegetative stabilization). Each of these is discussed in the following paragraphs.

6.1.1 Surface Stabilization

Surface stabilization involves applying chemicals to the surface of the tailings to form a water- and wind-resistant crust. Surface stabilizers have been used successfully as a temporary protection on portions of dikes and tailings ponds which have dried and become dusty, and in areas where water shortage or chemical imbalance in the tailings prevents the use of cover vegetation. Surface stabilizers, however, are susceptible to physical breakup and gradual degradation and may not meet the long-term requirements for permanent stabilization of uranium mill tailings.

Other complications also can arise in achieving satisfactory surface stabilization. For example, the surfaces of tailings piles seldom are homogeneous, and variables such as particle size, acidity, and moisture content affect the bonding characteristics and stability of the surface stabilizers.^(2,3) Studies are currently being conducted to assess the possibilities of conditioning uranium mill tailings to minimize their impact if they were to migrate to the biosphere.⁽⁴⁾ It is possible that some conditioning techniques may change the characteristics of the tailings such that degradation of surface stabilizers by the tailings would be minimized.

Among the substances used to form crusts on mill tailings surfaces and thus reduce their susceptibility to wind erosion are: resinous adhesives; lignosulfonates; elastomeric polymers; milk of lime; mixtures of wax, tar, and pitch; potassium and sodium silicates; and neoprene emulsions.

Tests were conducted by the Bureau of Mines⁽²⁾ using certain chemicals (e.g., Compound Sp-400 Soil Gard, and DCA-70 elastomeric polymers) on both acidic and alkaline uranium tailings. Subsequently, the chemicals DCA-70 and calcium lignosulfonate were applied to the surfaces of the inactive uranium tailings ponds and dikes at Tuba City, Arizona, in May 1968, because low moisture conditions and high costs prohibited vegetative or physical stabilization. After 4 yr, approximately 40% of the dike surface showed disruption while the crust in pond areas was affected to a lesser extent. The major disruptions were attributed to initial penetration of the stabilizer by physical means such as vehicles, people, or animals crossing the tailings surface.

In 1969, a portion of the Vitro tailings at Salt Lake City, Utah, was sprayed with tarlike material as a Bureau of Mines experiment^(5,6) to achieve surface stabilization and to reduce wind erosion. The material decomposed and exposed the tailings within 2 to 3 yr after application.

"Cut-back" asphalt and asphalt-in-water emulsions also have been tested for use in protecting soils against wind and water erosion.⁽⁷⁾ Both were shown to be effective for short

periods of time when applied as a fine spray on sandy soils. On clay soils, the film disintegrated within a few weeks of application, apparently because of expansion and contraction of the clays during cycles of wetting and drying. The film was porous, allowed infiltration of water, and did not interfere with germination of wheat, grass, or legume seeds. The film is damaged by insects and rodents, and respraying may be necessary. Three to five years after application of the asphalt treatment, the amount of dry erodible surface area in the tested soils had increased, suggesting that asphalt treatments may not be desirable under all conditions.

More recent experiments performed for DOE are attempting to establish that surface stabilizers are useful in the long term.(3,8,9,10,11) Although some asphaltic emulsions applied on tailings surfaces have degraded in less than 1 yr, covering the surface stabilizer with soil after application can extend its useful life. Nevertheless, additional data must be obtained to demonstrate long-term effectiveness of surface stabilizers.

Asphalt emulsions might be useful if mixed with a sufficient thickness of tailings or overburden material (admixing) to form a volumetric seal, as opposed to a thin coating on the tailings surface.(12) Admixing depths would have to be sufficient to minimize the potential for breakup of the volumetric seal. Recent studies have suggested that asphalt emulsion seals for uranium mill tailings may be stable for long-term applications.(11) Results of tests to determine the effects of temperature cycling (freeze-thaw), aqueous leaching, oxidation, exposure to brine solutions, and microbial attack indicate satisfactory stability of asphalt emulsions.

6.1.2 Volumetric Stabilization

Volumetric stabilization, which has been used in other mineral industry operations, involves the mixing of chemicals in sufficient quantities with tailings to produce a solidified, leach-resistant mass, much like mixing cement with sand and gravel to form concrete. The chemicals could be added in two ways: to a tailings slurry in a pipeline, or to the tailings in-situ. The in-situ method of stabilization is relatively new and research is being conducted to determine desirable materials to be added to tailings and the best techniques of application.(10,11)

One of the features claimed for this stabilization method is that all pollutant chemicals are locked in the solidified mass so they cannot be leached from the solid. Recent studies have indicated that volumetric stabilization may suffer from eventual degradation, and requires careful matching of environmental conditions, tailings, and solidifying chemicals in order to be effective.(9)

A cover material, such as soil, might be required to protect the solidified mass from wind and water erosion, depending on the substances added to the tailings. Shallow rooted vegetation can be established after soil cover has been placed over the solidified mass. However, the long-term effect of plant root penetration into the stabilized tailings is unknown but probably would be a function of the specific chemical makeup of the solidified mass. Continued research to identify the conditions under which vegetation could thrive without affecting the integrity of volumetric stabilizers is required.

6.1.3 Physical Stabilization

Physical stabilization consists of isolating the contained material from wind and water erosion by covering the tailings with some type of resistant material (e.g., rock, soil, smelter slag, broken concrete, asphalt, polymeric film, etc.).

Covers of gravel or crushed rock have been shown to be effective in preventing wind erosion and allow infiltration of water without permitting substantial erosion.⁽¹³⁾ Riprap, a cover of substantial rocks, armors the surface against erosion and may enhance growth of vegetation.^(14,15) Clays or clayey soils would be self-healing if the tailings settled, would hold moisture, and could be a key component of a stabilizing cover.

Artificial covers, such as a layer of asphalt or a synthetic membrane, could be placed over the tailings to reduce wind and water erosion. However, synthetic membrane materials containing plasticizers, e.g., polyvinyl chloride (PVC), are not suitable for exposed surface application because they are susceptible to damage by ultraviolet radiation. However, a thin synthetic sheet, although protected by soil from direct exposure, would have questionable mechanical strength and might not be able to maintain integrity in the long term.

In some arid regions, where the potential for successful vegetative stabilization is slight, physical stabilization may be the preferred alternative. In such areas, combinations of pit-run sand and gravel, soil, and riprap have been placed over the tailings and have been successful in preventing wind and water erosion.

An important component of physical stabilization is the proper treatment of the finished surface by such means as contour-grading and terracing. Broad range surface runoff control channels and grading are also imperative to assure that the tailings site is protected from erosion by rainstorms and floods. Such treatments can greatly reduce long-term maintenance requirements and costs.

Both root growth and animal burrowing may provide pathways from the stabilized tailings to the environment and are therefore of concern. Research is currently under way to evaluate various chemical biobarriers for uranium mill tailings.⁽¹¹⁾ Herbicides in the form of polymeric sheets and pellets are being tested to determine their long-term ability to prohibit root growth into the tailings through the stabilizing cover material. Apparently, polymeric sheets containing herbicide are more costly than pellets, and pellets are substantially more convenient to use.

Burrowing habits of rodents and potential methods to limit burrowing are being investigated. It is believed that mechanical barriers will be more effective and less costly than chemical barriers in excluding burrowing animals from disposed tailings.

6.1.4 Vegetative Stabilization

Vegetative stabilization involves the establishment of plant growth on the tailings or on a growing medium placed over the tailings on the premise that the root system will tend to hold the soil in place.

Criteria for plant selection provide that the plants will:⁽¹¹⁾

- (a) Be tolerant of local environmental conditions.
- (b) Have properties that will aid in erosion control.
- (c) Have propagules that are readily available.
- (d) Be relatively easy to establish.
- (e) Be perennials, or annuals with good reproductive capabilities.
- (f) Have minimal rooting depth requirements.
- (g) Be of low food value and/or palatability.
- (h) Have low value as habitat for wildlife.

Many species of plants require little or no maintenance after growth becomes established, an essential aspect of vegetative stabilization. Vegetation may be able to survive provided that:

- (a) Evapotranspiration is not excessive.
- (b) Landscapes are properly shaped.

- (c) Nontoxic soil media capable of holding moisture are provided.
- (d) Irrigation and fertilization appropriate to the area are applied to initiate growth.

Growth of vegetation at sites receiving less than 10 in. of annual precipitation and with high evapotranspiration rates requires initial irrigation and fertilization. At Shiprock, precipitation averages about 8 in. annually.

A principal disadvantage of vegetative stabilization is the possibility of uptake of radioactive elements by the plants. However, if the plants are properly selected, and if there is a sufficient depth of soil cover over the tailings, this uptake will be minimal. Barriers to root penetration are currently being evaluated.

6.2 PREVENTION OF LEACHING

Leaching into underground aquifers is one of the pathways that chemicals and radioactive materials might follow to the environment. The techniques that could be employed to control leaching from tailings piles include the following:

- (a) Employ surface, volumetric, or physical stabilization to minimize infiltration of water, which would prevent leaching of hazardous elements into underground aquifers.
- (b) Physically compact the tailings to reduce the percolation of water through the materials.
- (c) Contour the drainage area and tailings surface to minimize the potential for water to penetrate into the tailings.
- (d) For a new site, line the disposal area with a low-permeability membrane.
- (e) Condition tailings to reduce leachability or contaminant content.

Current research of various liner systems has identified eight liner materials for continued laboratory study:

- (a) Natural soil amended with sodium-saturated montmorillonite (Volclay*)
- (b) Typical local clay with an asphalt emulsion radon-suppression cover

*Registered trademark.

- (c) Typical local clay with a multibarrier radon-suppression cover
- (d) Rubberized asphalt membrane
- (e) Hydraulic asphalt concrete
- (f) Chlorosulfonated polyethylene (Hypalon*) or high-density polyethylene
- (g) Bentonite, sand and gravel mixture
- (h) Catalytic airblown asphalt membrane

Of these materials, the rubberized and hydraulic asphalts are judged to be the two most viable candidates at this time.(11)

Other studies(4) are addressing the possibility of conditioning the tailings such that if they were to leach, there would be minimal adverse impact.

6.3 REDUCTION OF RADON EXHALATION

Continuing research is directed toward reduction of radon exhalation from tailings piles.(3,8,9,16,17) While there are materials that can seal or contain the gas on a laboratory scale, their use for permanent coverage of large areas is presently being studied.

From simplified diffusion theory estimates, it can be shown that about 13 ft of dry soil(18,19) are needed to reduce radon flux by 95%, but only a few feet of soil are needed if a high moisture content in the cover material is maintained. Figure 6-1 depicts the dependence on moisture content of the effective diffusion coefficient for radon in soil. The dramatic decrease of the magnitude of the effective diffusion coefficient as the moisture content increases is responsible for the resulting reduction of radon flux.(20)

The reduction of radon exhalation flux for three soil types versus depth of cover is presented in Figure 6-2 and is based upon the theory and diffusion coefficients presented in the references cited earlier. Further research is currently under way to explore more precisely the problems associated with reducing and eliminating the exhalation of radon from radioactive tailings material. The effects of applying various surface stabilizers and varying thicknesses of stabilizing earth covers and combinations of materials are being investigated. The results may have an important impact in planning radon

*Registered trademark.

exhalation control. However, proposed NRC standards for stabilizing inactive mill tailings require a minimum of 3 m of cover over the tailings.⁽¹⁾ The 3-m cover was assumed to be sufficient to meet proposed radon release requirements in remedial action cost estimates presented in this report.

Investigations described in Paragraph 6.1 have shown that cationic asphalt emulsions can be effective in large-scale applications in reducing radon fluxes to required levels.⁽¹¹⁾

Studies of multilayer physical stabilization systems presently in progress are directed at identifying cost effective cover systems to satisfy proposed EPA standards for disposal.⁽¹⁾ These studies have indicated that, under a given set of conditions, a single-material cover would have to be up to about 24 ft (7.2 m) thick to reduce radon flux to the required 2 pCi/m²-s. In contrast, a well designed multilayer cover system of less than 8.5 ft (2.6 m) thickness under the same conditions could satisfy the radon flux requirement.

6.4 REDUCTION OF GAMMA RADIATION

A few feet of cover material have been shown to be sufficient to reduce gamma radiation to background levels.

The reduction of gamma exposure rates resulting from a packed earth covering is given in Figure 6-3.^(8,21) Two feet of cover reduce the gamma levels by about two orders of magnitude. Therefore, an average cover thickness of 3 m should reduce gamma levels from the tailings to background. Multilayer and asphalt cover systems currently under investigation have been shown to effectively attenuate gamma levels to acceptable ranges.

6.5 ASSESSMENT OF APPLICABILITY

Available data indicate that the methods previously used at the inactive sites in attempts to stabilize uranium tailings have not been totally satisfactory and that long-term solutions to uranium tailings site radiation problems have yet to be clearly demonstrated. Consequently, new or combination methods of stabilization are being evaluated. The present remedial action options include physical stabilization of the tailings with at least 3 m of well designed soil cover and 0.3 m of riprap. This action will reduce gamma radiation and wind and water erosion, substantially reduce radon exhalation, minimize infiltration, and allow reestablishment of native vegetation.

If remedial actions are taken, combinations of the methods described in this chapter for preventing erosion, leaching to ground water, radon exhalation, and gamma radiation will be implemented based on climatic, hydrogeological, economic, and demographic factors. The method of stabilizing uranium mill

tailings whereby 3 m of well-engineered cover is placed on the pile is apparently the primary method currently available that satisfies both U.S.(1) and Canadian(22) regulatory requirements.

FIGURE 6-1. EXPONENTIAL MOISTURE DEPENDENCE OF THE DIFFUSION COEFFICIENT

FIGURE 6-2. REDUCTION OF RADON EXHALATION FLUX WITH DEPTH OF COVER

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FIGURE 6-3. REDUCTION OF GAMMA EXPOSURE RATE RESULTING FROM PACKED EARTH SHIELDING

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CHAPTER 7
OFF-SITE REMEDIAL ACTION

CHAPTER 7

OFF-SITE REMEDIAL ACTION

An important objective of this engineering assessment is to estimate the cost of appropriate remedial action for those off-site properties contaminated with tailings.

Discussed in this chapter are those locations where tailings have been transported away from the designated site. Such off-site locations are classified as off-site windblown properties and off-site properties other than windblown. Costs associated with the cleanup of on-site contaminated areas are considered in Chapter 9.

7.1 DATA SOURCES

A mobile scanning unit, operated by the AEC under an interagency agreement with the EPA, performed a gamma radiation survey of the Shiprock area in 1971. Of the 558 structures scanned, nine anomalies were discovered where the radiation was significantly above background. A joint team from the EPA Office of Radiation Programs, Las Vegas, Nevada (EPA-ORP-LV) and the New Mexico Environmental Improvement Agency performed individual gamma surveys of the nine locations to determine the source of the anomalies and, if tailings, how they had been used. High and low inside and outside gamma readings were recorded. A gamma map was drawn of areas where gamma readings inside the structures exceeded 20 $\mu\text{R/hr.}$ ⁽¹⁾

The gamma survey and 5-pCi/g boundary mentioned in Paragraph 3.4.3 and personal conversations with EPA personnel⁽²⁾ were the data sources for the consideration of remedial action for windblown areas.

7.2 REMEDIAL ACTION FOR OFF-SITE PROPERTIES OTHER THAN WINDBLOWN

A follow-up survey of the anomalies⁽¹⁾ indicated five locations had tailings within 10 ft of a structure; three locations had tailings in the yard more than 10 ft from a structure, and in one location uranium ore was found and removed.

Four of the locations with tailings within 10 ft of the structure had corrected outside gamma readings ranging from 47 to 75 $\mu\text{R/hr.}$ An inside gamma reading was recorded at only one of the four locations and that reading was in the background range. The fifth location had radioactive material under the structure. The survey indicated that the material probably was uranium mine waste rather than uranium mill tailings. Before the Shiprock mill began operations, a concrete slab at this

location was used as an ore transfer station. The last time ore was stored at the ore transfer site was in late 1950. Since then, the station has been partially decontaminated and buildings have been constructed on the lot. Gamma radiation measurements inside the structure at this location showed 18 μ R/hr above background through the slab. Outside the structure, a maximum 175 μ R/hr was recorded. EPA radon daughter concentration measurements inside the structure indicated a yearly average of about 0.008 WL with a maximum of 0.02 WL.

Subsequent to the 1971 mobile survey, another commercial off-site location with high RDC has been identified.⁽³⁾ At this location, RDC measurements for 1975-1976 yielded a yearly average of about 0.04 WL and a maximum of 0.06 WL. Gamma surveys indicated that the radioactive material is probably in the walls.⁽³⁾

Costs for remedial action at off-site locations and structures were estimated to be \$200,000, exclusive of engineering and contingency allowances, based upon available information and adjusted Grand Junction off-site remedial action costs. This cost includes cleanup, backfill, restoration, and health physics and monitoring services. The estimated cost includes remedial action for the locations where definite tailings use has been identified.

7.3 REMEDIAL ACTION FOR OFF-SITE WINDBLOWN PROPERTIES

Approximately 48 acres of the windblown area surrounding the tailings piles have been cleaned up under the Shiprock Millsite Decontamination Program supervised by the EPA.⁽²⁾ In addition, the main washes to the northeast and northwest were excavated to 25 ft, at which depth radiological readings were still above background. Such a depth of excavation was considered to be sufficient, and all areas were backfilled to natural grade.

Flood plain areas of the San Juan River exhibit some radiological contamination. Due to potential hydraulic problems and instability of steep bluffs surrounding the area, it was considered impractical to attempt decontamination of flood plain areas under the Shiprock Millsite Decontamination Program.⁽²⁾

For the purposes of this report it was assumed that all material surrounding the tailings which was contaminated due to transport by wind, mill operations, or seepage has been removed and confined to the lower tailings pile under the Shiprock Millsite Decontamination Program. It is possible that dispersion of the tailings could reoccur to some degree in the future, until the tailings site decontamination is completed. Under these conditions, \$300,000, exclusive of engineering and contingency allowances, was estimated as the cost to clean up windblown areas in order to satisfy remedial action criteria as discussed in Paragraph 3.5.

CHAPTER 7 REFERENCES

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CHAPTER 8
DISPOSAL SITE SELECTION

CHAPTER 8

DISPOSAL SITE SELECTION

Several of the remedial action options considered in this engineering assessment would involve moving the Shiprock tailings to a disposal site for long-term stabilization. Potential disposal sites were located based on presently proposed regulations. With the presently proposed regulations requiring at least 3 m of cover for the long-term stabilization of tailings, possible sources of these large amounts of cover materials have been located for each of the disposal options. The locations of actual sources of cover material relative to the various disposal sites will have an impact on the costs.

8.1 CRITERIA FOR DISPOSAL

New Mexico state officials, the Indian Health Services, the Bureau of Indian Affairs, and the Navajo Environmental Protection Agency were contacted to locate possible disposal sites for the Shiprock tailings.

Originally, eight sites were considered for tailings disposal. Table 8-1 lists the name of each alternative disposal site studied and the road distance of each from the Shiprock tailings site. Of the eight sites considered, seven were selected for cost estimates and are identified as Options II through VIII. Seven additional potential disposal sites in three areas south, west, and north of the tailings site have been identified for tailings disposal and evaluated to a limited extent.(1)

Figure 8-1 shows the relative locations of the alternative disposal sites. Each of the sites included in the options was evaluated to a limited extent on the basis of hydrology, meteorology, geology, ecology, and economics. The hydrologic and meteorologic conditions were assessed with regard to such factors as wind and water erosion, water contamination, flooding and drainage characteristics, precipitation, access to bedrock, and location of confined aquifers. Special consideration was given to current land productivity (e.g., grazing), topsoil availability, drainage basin configurations, and subsurface drainage. The geologic examination addressed stability problems and soil characteristics such as evidence of slides or faults, and types of unconsolidated and bedrock materials. The ecological study evaluated land use potential, animal habitats, proximity to population centers, and aesthetic considerations. Economic considerations included preliminary estimates of support facilities such as highways, distance from the Shiprock site, and the extent of site preparation and long-term maintenance required at the site.

Returning the Shiprock tailings to the mines from which the ores were obtained is not feasible. The ore treated at the mill came from many mines scattered over a wide area, and many of these mines contributed only a few hundred tons each. Costs and logistics involved in hauling make such a proposal impractical.

8.2 DESCRIPTIONS OF DISPOSAL SITES CONSIDERED AS OPTIONS

A general description and a list of proposed alternative disposal sites follows. The sites are located at varying distances from the Shiprock tailings piles, ranging from 4 mi (Many Devils site) to 26 mi (Operating Open-Pit Coal Mines site). Most sites are demographically remote. All of the sites except for the coal mines site are within the Shiprock Chapter of the Navajo Indian Reservation.

Although the vast areas of the Navajo Reservation seem to offer unlimited locations for disposal sites, consideration of the criteria limits the number of practical locations. Continued isolation on most of the sites selected is almost assured. Physical stabilization would be accomplished with sand, gravel, and soil coverings obtained from the vicinity of the disposal areas or from more distant borrow areas. A 0.3-m-thick cover of riprap would be placed to limit erosion.

The existing vegetative cover at all sites is 20% or less, and the average annual rainfall at all sites is less than 8 in. All sites are accessible by using a combination of paved, gravel, and dirt roads. Where dirt roads are to be traversed by trucks carrying tailings, the cost estimates include the construction of a gravel-based surface sufficient to handle the heavy loads and traffic.

Disposal of the tailings within the open-pit areas of an operating coal mine was considered. At least two possible locations exist for such disposal. Both are at least 26 mi from the existing Shiprock site. One of the locations is on the Navajo Reservation; the other is on leased federal (Bureau of Land Management) property. The jurisdictional, technical, and scheduling problems (e.g., timing of the placement of the tailings to mesh with mining operations) at these two alternative disposal sites might be resolved with further study. However, these are the most expensive alternative sites due to the haul distances.

Transportation, site preparation, and maintenance costs are discussed more fully in Chapter 9. There are no railroad facilities in the area. Existing paved, gravel, or dirt roads are available to most of the sites; however, some short haul roads would have to be constructed to a few sites.

Of the alternative sites evaluated, those assigned option numbers in Table 8-1 were selected as most suitable when criteria for disposal were taken into consideration.

8.2.1 Many Devils, Site 2 (Option II)

This site is the closest to the existing Shiprock site, about 4 mi by existing roads. It is about 0.3 mi north of the gravel road that runs east from U.S. Highway 666 to an oil field near the town of Shiprock. The site is within an area used for very limited winter grazing.

For site preparation, the soil from an area of approximately 80 acres would be removed and stockpiled. The tailings then would be deposited, and stockpiled overburden and imported cover material would be used to stabilize the pile.

Soils in this area are medium- to fine-grained loams that are slightly permeable to water. They are developed in materials weathered from Mancos Shales and the interbedded sandstones. The soils are from 10 to 20 in. thick on the site, but are over 26 in. thick in the drainage area to the northwest. It is unlikely that the entire 3 m of cover could be excavated from the site itself, but the surrounding area could provide suitable materials. Alluvial terrace deposits along the Chaco and San Juan Rivers could provide materials for the gravel cap. A haul distance of up to 5 mi can be expected for the gravels.

Advantages of the site include the short haul distance from the tailings site, the favorable natural drainage characteristics, and the impermeable Mancos Shale bedrock beneath the site.

The principal disadvantage is the potential growth of the town of Shiprock in this direction, which might negate the isolation feature desired in a disposal site. Other disadvantages are the unavailability of sufficient cover materials on the site and the possible need to rip and blast into bedrock below 20 in.

8.2.2 Shiprock Campground, Site 1 (Option III)

The Navajo Tribal Park Authority has established a small campground facility near the intersection of the paved Redrock Valley Road and U.S. Highway 666, approximately 6.8 mi south of the town of Shiprock. Approximately 0.8 mi northwest of the campground is a site suitable for development into a tailings disposal site. The site is not visible from the campground and is obscured from the highway by bluffs.

If this site were selected, the soils over the naturally depressed area would be removed and stockpiled. Necessary diking would be constructed, the tailings would be deposited, and the overburden and imported cover materials would be used to stabilize the pile. The limited watershed area south of the site, away from the pile, would be graded to divert surface water.

Soils in this area are medium- to fine-grained loams which are slowly permeable. They developed in materials weathered from Mancos Shales and the interbedded sandstones. The soils are from 10 to 20 in. thick on the slopes and over 36 in. in the drainage area. It is unlikely that the entire 3 m of cover could be excavated from the site itself, but the surrounding area could provide any additional cover necessary. Since there is a large proportion of deep soils in this area, it would be easier to excavate the necessary quantities from this area than for the Many Devils site. Alluvial terrace deposits along the San Juan River could provide material for the gravel cap. A haul distance of about 7 or 8 mi can be expected for the gravels.

Advantages of this site include its easy accessibility by means of a good highway to the campground area, its natural drainage characteristics, and the impermeability of the Mancos Shale bedrock.

Disadvantages of the site include the ease of trespass because of its proximity to the campground and main highway, as well as the shallow soils on the site itself.

8.2.3 Rattlesnake, Site 5 (Option IV)

This site is located approximately 8.3 mi west of Shiprock. The tailings would be deposited against a 30-ft-high bluff in an area on a gradual plain leading to Shiprock Mountain.

An area along the bluff would be covered to a depth of approximately 20 ft with tailings and other contaminated materials and 3 m of earth cover.

Soils in this area are thin, medium-to-coarse grained, and moderately permeable. They are developed on the Gallup Sandstone, which is interbedded with the Mancos Shale in this area. While the soils near the site can be up to 36-in. deep, they may not be fine enough to provide an optimum cover. It will be necessary to haul finer-grained soils from at least 3 to 6 mi for most of the required 3 m of cover material.

Gravels could be obtained from terrace deposits along the San Juan River. Hauls of about 8 to 10 mi can be expected for the gravels. The covered pile would be contour-graded to minimize water erosion.

Advantages of this site include the limited acreage that would be disturbed and would have to be maintained, and the relatively short haul distance and easy haul conditions.

Disadvantages include the sandstone bedrock which may act as a ground water recharge area, and the limited amount of stabilization cover material available on the site.

8.2.4 Salt Creek Area, Site 8 (Option V)

This site is located 8.5 mi northeast of Shiprock, along the high side of a gentle ridge sloping into the Salt Creek Wash. In several locations in this area there are natural three-sided basin-like areas, any one of which could be used for disposal of the tailings.

The tailings would be placed in an excavated area where the natural earth and rocks would be removed to provide a dike and some of the surface cover.

Soils in this area are fine grained and slowly permeable. However, they are only from 10 to 20 in. thick. Some deeper soils may be available near the bottom of the drainages. It may be necessary to import some cover materials for this site. If terrace materials can be obtained west of the site, a haul distance of 6 mi may be expected. However, if such materials are obtained from the Shiprock area, a 9-mi haul distance can be expected.

Advantages of this site include accessibility to a highway, the poor quality of the land even for limited grazing, the natural drainage configuration that can be isolated from other surface drainage patterns, the impermeable Mancos Shale bedrock, and the lack of potential for future land use development.

Disadvantages are the lack of sufficient cover materials on the site, and the requirements that the tailings would have to be hauled through the town of Shiprock (including a left turn through a traffic signal), and up a 6% grade for 0.5 mi.

8.2.5 Oil Field, Site 6 (Option VI)

This site is located about 8.5 mi southeast of the Shiprock site and about 2 mi east of the new Shiprock airport, in an area where producing oil wells are located. There are several locations in this area with similar drainage conditions. With some excavation, these areas can be formed into basins.

The tailings would be placed on Mancos Shale bedrock, from which the surface materials would be removed for later stabilization of the pile.

Soils in the area are medium grained and moderately permeable and range from 20 to 36 in. in depth. It is unlikely that the full 3 m of cover could be obtained from the site itself. However, soils both on the ridge and down along the drainage from the site are somewhat less permeable than those on site and would probably make excellent cover material. Gravels would probably have to be trucked in from the Shiprock area, requiring a haul distance of about 10 mi.

Advantages of the potential locations at this site are their natural drainage configurations of limited watershed potential, their ability to be separated from other drainage systems, the underlying impermeable bedrock, and the proximity to stabilization materials and highways.

The principal disadvantage of the area is the limited amount of cover materials on the site.

8.2.6 Hogback, Site 4 (Option VII)

The Hogback Mountains run approximately north and south about 18 mi east of Shiprock. The Hogback site is located just west of this range, 16 mi southeast of Shiprock on a dip slope formed by the easterly dipping strata. This site is the most remote from habitation of the sites evaluated.

Soils in this area are generally medium grained, slowly permeable, and moderately deep. However, it would be necessary to provide additional cover material. The local vicinity has numerous areas of fine grained, moderately deep soils, which could provide suitable sources of cover. Gravels could be obtained from terrace deposits along the Chaco River about 4 to 5 mi from the disposal site.

Advantages of the site include its isolation from population centers, its isolated drainage system, its lack of serious water erosion features, and its lack of potential for future development.

Disadvantages of the site include the limited availability of gravel cap material, the long haul distance, and the possible adverse effects on the relatively good grazing land.

8.2.7 Operating Open-Pit Coal Mines, Site 7 (Option VIII)

The general location of these mines is approximately 26 mi east of the Shiprock tailings. Tailings and other contaminated materials would be deposited in the bottom of mined-out areas of an operating open-pit coal mine. The deposited contaminated materials would then be covered with mine overburden and the surface would be contoured and reclaimed as part of the normal mining sequence. No further stabilization would be required, as contamination would be buried deep within the mine excavation. Typical pit depths of large surface mines in the area range between 100 and 200 ft.

Advantages of the site include the facts that the tailings would be permanently buried under as much as 100 ft of overburden and that the tailings would not interfere with future land use.

Disadvantages are the necessity of obtaining approvals, the potential problems of interference with coal mining operations,

haulage over well-traveled public roads, and the high cost. In addition, some Mesa Verde coal-bearing strata have the potential to recharge aquifers underlying Farmington; therefore, the mine site would have to be studied to anticipate such a problem.

FIGURE 8-1. LOCATION OF PROPOSED DISPOSAL SITES

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TABLE 8-1

SITES EVALUATED FOR DISPOSAL OF SHIPROCK TAILINGS

<u>Site No.</u>	<u>Option No.</u>	<u>Road Distance from Shiprock (mi)</u>	<u>Site Name</u>
2	II	4.0	Many Devils
1	III	6.8	Shiprock Campground
5	IV	8.3	Rattlesnake
8	V	8.5	Salt Creek
6	VI	8.5	Oil Field
4	VII	16.0	Hogback
7	VIII	26.0	Operating Open-Pit Coal Mines
3	--	6.0	Shiprock Airport

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CHAPTER 8 REFERENCES

1. "Alternative Disposal Sites for Shiprock Tailings"; Letter from J.W. McKiernan of Sandia National Laboratories to R.H. Campbell of Uranium Mill Tailings Remedial Action Program Office, DOE; Dec 11, 1980.

CHAPTER 9

REMEDIAL ACTIONS AND COST-BENEFIT ANALYSES

CHAPTER 9

REMEDIAL ACTIONS AND COST-BENEFIT ANALYSES

Various remedial action options for the tailings on the Shiprock site were identified and investigated. The remedial actions presented are those considered to be the most realistic and practical when evaluated with regard to the present remedial action criteria, technology, and information available. Costs and benefits have been estimated and evaluated for each option considered.

The procedures for decontaminating inactive mill tailings sites have not been well established. Although remedial action criteria have been established tentatively, the methodology of satisfying such standards is still in a state of change. The position has been taken that radiological and industrial safety should be pursued to the extent necessary to satisfy remedial action criteria and to provide assurance to the public and to workers. The public should feel comfortable with the methodologies used.

Remedial actions designed to meet the EPA interim remedial action criteria were investigated. Seven possible disposal sites identified in Chapter 8 were evaluated in terms of the cost of disposal. Although each alternative disposal site has specific and unique characteristics that were considered in estimating costs, great care must be exercised in the use of these site-specific cost estimates since there are insufficient data and information to characterize the sites completely for estimating site development costs.

The process of obtaining the necessary permits and the associated costs were considered to be included in the various agency budgets and were not included in this report. Similarly, the tailings sites and the proposed disposal sites have been treated as public lands in that no acquisition costs were included.

Costs for future maintenance and radiological monitoring at the location of the tailings were not included in this estimate. Funding for such future costs was assumed to come from separate contracts administered by the Federal Government.

For the purpose of this estimate, it was assumed that under the Shiprock Millsite Decontamination Program⁽¹⁾ essentially all areas surrounding the site that were contaminated in excess of proposed EPA cleanup standards were in fact decontaminated and the resulting contaminated material consolidated on the lower tailings pile.

The options for disposal at the sites would provide for the relocation of all debris and contaminated materials from the tailings piles and off-site locations. Thus in all of the disposal options, the entire site and off-site areas would be left free of any tailings or contaminated materials in excess of the allowed 5 pCi/g of ^{226}Ra above background.

A discussion of the concepts involved in tailings stabilization and their applicability to the Shiprock site has been detailed in Chapter 6. For all disposal options, a riprap or gravel cap of 0.3 m on top of 3 m of cover material is assumed to suffice for erosion control.

9.1 STABILIZATION OF THE TAILINGS ON SITE WITH A 3-METER COVER (OPTION I)

In this section the conceptual design of the option to stabilize the Shiprock tailings is discussed, and the estimated cost of the corresponding remedial actions presented.

9.1.1 Conceptual Design

Stabilization of the Shiprock tailings on the present site is not necessarily considered to be a viable option because of the site's proximity to the town of Shiprock. This option is included to provide a means of comparison among options in this report and with similar reports for other mill tailings sites. Therefore, in preparing the cost estimate for this option, the possible problem of migration of contamination via ground water was not considered and the cost does not include the placement of a clay or synthetic liner under the tailings. The cost of this option would increase significantly if the liner were required.

Under this option the tailings would remain on site. The tailings site would be leveled, graded, and stabilized with 3 m of cover material, which has been shown under certain conditions to be adequate to reduce radon flux to less than 2 pCi/m²-s. With the cover material in place, the pile would be approximately 19 ft above natural grade.

If the Shiprock site were stabilized in place, it would have limited future use.

9.1.2 Costs

As shown in Table 9-1, the cost for stabilization at the Shiprock site is estimated to be \$13,400,000. Costs include cleaning up of off-site locations, covering all contaminated materials with 3 m of cover, contouring the surface, adding a 0.3-m-deep riprap cap, and reclaiming all areas.

9.2 REMOVAL OF TAILINGS AND ALL CONTAMINATED MATERIALS FROM THE SITE (OPTIONS II THROUGH VIII)

Options II through VIII would provide for the complete removal of all tailings, contaminated soil, existing stabilization cover, buildings, materials, and rubble from the tailings site and off-site areas to a disposal site. The amount of soil to be removed depends on the depth of contamination. Removal to depths of 3 ft below the interface under the tailings piles during the Shiprock Millsite Decontamination Program has reduced residual radium concentration to less than the allowed 5 pCi/g above background levels.⁽²⁾ Finally, the site would be backfilled to natural grade and released for unrestricted use.

9.2.1 Excavation and Loading of Tailings and Soils

Roadways established by the Navajo Engineering and Construction Authority have provided excellent access to the site. Different methods of excavation are possible, with a single-bench open-pit method being the most feasible. However, the 45,000 tons of rubble buried in the lower tailings pile may necessitate different techniques of excavation and loading than might be used for tailings and soil.

To eliminate any possible dispersion of tailings during loading and transportation operations, dust control equipment and washdown facilities would be provided.

The Shiprock site would be backfilled to natural grade. Local materials, all of which must be hauled onto the site, would be used as backfill. No special treatments of the final surface other than establishing native grass cover at the decontaminated tailings site were considered in this assessment.

9.2.2 Transportation of the Materials

Railroad transportation was not considered feasible for tailings transport since there are no rail facilities in the vicinity of the tailings or disposal sites.

Slurry pipeline technology was evaluated. While water for this method of transport is available from the San Juan River, demands for water in the area for other purposes could preclude its diversion for tailings transport. Also, because of the need to dewater at the disposal site, slurry technology is not considered feasible.

The use of conveyors in transporting the tailings and contaminated materials has been investigated briefly to assess its viability. While any conclusive statement is very dependent upon the site- and route-specific parameters, some generalizations can be made about the viability of conveyors in this application:

- (a) The longer the life of the project, the more attractive the use of conveyors becomes.
- (b) The greater the mass to be moved, the more attractive the use of conveyors becomes.
- (c) Conveyors can be more attractive in difficult terrain.

However, there are many complications involved in the use of conveyors, many of which are difficult to quantify. Public acceptance, acquisition of rights-of-way and permits within a reasonable time frame, and environmental impact are considerations that cloud the evaluation of conveyors.

With all of the factors considered, the quantity of material to be moved does not appear to warrant the use of conveyors, making transportation by truck preferable. At such time as a specific site is chosen, a detailed evaluation would disclose whether this generalization holds true for the selected site and routes.

Trucks could move the materials at the rate of about 4,800 tons/day. At this rate, working 5 days/wk, all contaminated materials could be removed in approximately 3 yr. This method assumes the use of conventional truck-trailer dump trucks. Dust control measures, such as covers and washdown facilities for the trucks, are included as capital costs associated with transportation.

Transportation costs for trucking include all hauling costs associated with tailings, necessary cover material, and riprap material. No costs are included for repair and maintenance of public roads, based on the assumption that this cost is covered by fuel tax collections. Capital costs include development of access roads and maintenance thereof whenever such roads are required.

9.2.3 Disposal at Alternative Sites

A discussion of proposed disposal sites is given in Chapter 8. Each disposal site has different physical, geological, and hydrological characteristics. However, because the Federal Government, with input from the Navajo Indian Tribe, is ultimately responsible for the selection of disposal sites, there is no assurance that any of the disposal sites considered in this report will be selected. Nevertheless, an effort was made to quantify these differences based on what limited data for each site were available and to show the costs that would result if the contaminated materials were actually disposed of at the sites discussed in Chapter 8.

All of these disposal sites are located within 26 mi of the tailings piles. Vegetation covers 20% or less of the land in the Shiprock vicinity, and the average annual rainfall at all disposal areas is less than 8 in. All sites are presently accessible by using a combination of paved, gravel, and in some cases, dirt roads. Where existing dirt roads are to be traveled by trucks carrying tailings, the cost estimates include the construction of a gravel-based surface sufficient to handle the heavy loads.

The disposal sites selected can be isolated from drainage basins naturally or by dikes and drainage ditches. At all disposal sites except site 7 (the Operating Open-Pit Coal Mines), soil depths range from 10 to 36 in. Mancos Shale rock under soil layers makes excavation difficult and expensive. Disposal of the tailings will be, for the most part, above ground, requiring transportation of cover material to the site; extensive diking and contouring for erosion control is necessary in such situations. Figure 9-1 is a schematic representation of how these disposal sites might be developed.

Disposal site costs consist of preparation of the site, placement of tailings and cover material, diking and contouring, and necessary reclamation of surface areas.

The alternative sites evaluated are shown in Table 8-1. The costs for the disposal options are shown in Table 9-1; they range from about \$25,600,000 for Option II to \$37,900,000 for Option VII.

The range in cost is due to differences among costs associated with transportation and the disposal sites. These differences are attributed to varying requirements for preparing the disposal site, protecting the disposed tailings from erosion, and hauling of tailings and cover material. Consequently, the overall cost is largely dependent on the distance from the tailings site to the disposal site, ease of excavation at the disposal site, and the availability of cover material to the disposal site.

Due to shallow soil depths in Options II through VII, expensive excavating and/or importing of cover material is required. Depositing tailings against a 30-ft-high bluff at Rattlesnake, Option IV, requires less cover material, thus reducing disposal site costs. The Open-Pit Coal Mines site, Option VIII, would be ideal for below-grade disposal. However, in spite of the savings in disposal site preparation costs, the long haul distance to the coal fields would make this option more costly than disposal at sites within 9 mi of the tailings piles.

Costs for health physics and radiological monitoring are included in individual component costs (lines 1 through 5,

Table 9-1). Such costs reflect approximately 22% of the total cleanup costs (line 6).

In Options II through VIII the estimated costs include cleanup of off-site locations and tailings piles; backfilling the former tailings site; establishing vegetative cover at and around the tailings site; covering all tailings and contaminated materials at the disposal site with 3 m of cover material; contouring the stabilized disposal site; and placing 0.3 m of riprap for erosion control.

9.3 ANALYSES OF COSTS AND BENEFITS

9.3.1 Health Benefits

Each of the remedial action alternatives considered in this chapter has an associated health benefit that would be experienced as a result of the remedial action. This health benefit is the reduction of the health effects (number of lung cancer cases). In Chapter 3, the estimated number of health effects was determined for the Shiprock tailings piles in their present condition. In order to estimate the number of health benefits attributable to particular remedial actions, the effects of those remedial actions on radon exhalation from the piles must be determined, because the health effects calculated in Chapter 3 were associated with radon daughters. While there are some benefits associated with actions such as fencing, these have not been quantified in this assessment of health benefits.

In this evaluation, the health benefit of each option is calculated from the reduction in radon exhalation that is expected for that option. In accordance with proposed requirements for stabilization of uranium mill tailings, radon fluxes were assumed to be reduced from their predicted values under present conditions (as conservatively calculated in Paragraph 3.4.1) to the required flux of 2 pCi/m²-s for Option I. In all other options, radon flux was assumed to be reduced to zero by the removal of the tailings. Since health effects are proportional to radon flux, the present health effects rate was estimated to be reduced by more than 99% with stabilization in place and by 100% with tailings removal.

The results of the determination on potential cancer cases avoided (health benefits) for each option are given as a function of time in part A of Table 9-2. The cost per potential cancer case avoided for each option is included as part B in Table 9-2.

As an alternative to the presentation in Table 9-2, the number of potential cancer cases avoided per million dollars expended was calculated and plotted in Figure 9-2. Option I yields the maximum health benefit per unit cost, whereas Option VII yields the minimum benefit per unit cost.

9.3.2 Land Value Benefits

Because all reservation land is commonly owned by the Navajo Tribe, there is no conventional valuation for Navajo properties. The lack of a traditional monetary market for land exchanges on the Navajo Reservation makes it difficult to calculate the dollar value of the site and its environs. However, recent land exchanges by the Navajo Tribal Council whereby they purchased off-reservation land and exchanged it for tribal land are one indication of value. Other indications are recent lease payments for Navajo lands projected into land values, and comparisons with land values in the Farmington area. Also, by assigning a monetary value to sheep production per acre of land and by translating this value into capital-valued land, another cash valuation may be determined.

By using the above methods, it was estimated in 1977 that the value of land in the Shiprock area used for grazing purposes, with the presence of an occasional residence, corral, or shed, was no more than \$50/acre. The value of the tailings site was estimated to be approximately \$200/acre in 1977, considering the purposes for which it was used.

The site includes 230 acres. Under Option I, stabilization on site, the value of the land covered by tailings would remain about the same as at present. The portions not covered by the tailings could increase in value to as much as \$1,000/acre; hence the total net land value of the available 158 acres could rise to as much as \$158,000.

Considering the distance of the site from the highway (direct highway frontage) and the presence or absence of utilities (water, electricity, sewage, natural gas), if the tailings were to be removed the site would be worth approximately \$3,500/acre as industrial land. Under Options II through VIII, whereby the tailings would be relocated and the site decontaminated, the net increase in property value could be as much as \$759,000.

FIGURE 9-1. SCHEMATIC OF TYPICAL TAILINGS DISPOSAL SITE

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FIGURE 9-2. POTENTIAL CANCER CASES AVOIDED
PER MILLION DOLLARS EXPENDED

TABLE 9-1

SUMMARY OF STABILIZATION AND DISPOSAL COSTS^a

	<u>I</u>	<u>II</u>	<u>III</u>	<u>IV</u>	<u>V</u>	<u>VI</u>	<u>VII</u>	<u>VIII</u>
1. Tailings Site Costs	7.4	5.2	5.2	5.2	5.2	5.2	5.2	5.2
2. Off-Site Remedial Action	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
3. Windblown Area Remedial Action	--	--	--	--	--	--	--	--
4. Transportation								
a. Capital Costs	--	0.1	0.1	0.1	0.2	0.1	0.7	0.2
b. Haul Costs	--	3.7	6.6	7.1	8.3	7.2	13.0	13.2
5. Disposal Site	--	6.4	6.3	4.9	6.0	6.0	6.0	3.3
6. Total Cleanup ^b (sum of lines 1 through 5)	7.9	16.0	18.7	17.8	20.3	19.1	25.4	22.4
7. Engineering Design and Construction Management (30% of lines 1 through 6, except line 4b)	2.4	3.7	3.6	3.2	3.6	3.6	3.7	3.7
8. Total ^b (sum of lines 6 and 7)	10.3	19.7	22.3	21.1	23.8	22.7	29.2	26.2
9. Contingency (30% of line 8)	3.1	5.9	6.7	6.3	7.1	6.8	8.7	7.9
10. GRAND TOTAL ^b (sum of lines 8 and 9)	13.4	25.6	29.0	27.4	30.1	29.5	37.9	34.1

^aCosts are presented in millions of year 1980 dollars.

^bTotals may differ from the sum of component costs because of round-off.

TABLE 9-2

POTENTIAL CANCER CASES AVOIDED
AND COST PER POTENTIAL CASE AVOIDED

A. Number of Potential Cancer Cases Avoided								
Options:	I	II	III	IV	V	VI	VII	VIII
Option Cost (million \$)	13.4	25.6	29.0	27.4	30.1	29.5	37.9	34.1
Years After Remedial Action								
25	<1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
50	<2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
75	<3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
100	<4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
B. Cost Per Potential Cancer Case Avoided (Million \$)								
Options:	I	II	III	IV	V	VI	VII	VIII
Option Cost (million \$)	13.4	25.6	29.0	27.4	30.1	29.5	37.9	34.1
Years After Remedial Action								
25	11.2	21.3	24.2	22.5	25.1	24.6	31.6	28.4
50	6.4	12.2	13.8	12.9	14.3	14.0	18.1	16.3
75	4.3	8.3	9.4	8.7	9.7	9.5	12.2	11.0
100	3.4	6.4	7.3	6.8	7.5	7.4	9.5	8.5

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CHAPTER 9 REFERENCES

1. "Phase II - Title I Engineering Assessment of Inactive Uranium Mill Tailings, Shiprock Site, Shiprock, New Mexico"; Ford, Bacon & Davis Utah Inc.; Mar 31, 1977.
2. J.M. Hans, Jr.; EPA Las Vegas, Nevada; personal communication; Dec 1980.

GLOSSARY

GLOSSARY

Terms/Abbreviations

Definitions

absorbed dose	Radiation energy absorbed per unit mass.
A-E	Architect-Engineer.
AEC	Atomic Energy Commission.
alpha particle (α)	A positively charged particle emitted from certain radioactive materials. It consists of two protons and two neutrons, hence is identical with the nucleus of the helium atom. It is the least penetrating of the common radiations (α, β, γ), hence is not dangerous unless alpha-emitting substances have entered the body.
amenability	The relative ease with which a mineral can be removed from an ore by a particular process.
anomaly (mobile gamma survey)	Any location detected by the mobile gamma survey where the recorded counts per second (c/s) from the large gamma-ray detector exceed the determined background for that area by 50 or more c/s.
aquifer	A water-bearing formation below the surface of the earth; the source of wells. A confined aquifer is overlain by relatively impermeable rock. An unconfined aquifer is one associated with the water table.
atmospheric pressure	Pressure exerted on the earth by the mass of the atmosphere surrounding the earth; expressed in inches of mercury (at sea level and 0°C, standard pressure is 29.921 in. Hg).

background radiation	Naturally occurring low-level radiation to which all life is exposed. Background radiation levels vary from place to place on the earth.
beta particle (β)	A particle emitted from some atoms undergoing radioactive decay. A negatively charged beta particle is identical to an electron. A positively charged beta particle is called a positron. Beta radiation can cause skin burns and beta emitters are harmful if they enter the body.
BEIR	Biological Effects of Ionizing Radiation.
BOM (USBOM)	Bureau of Mines.
CHES	Center for Health and Environmental Studies, Brigham Young University, Provo, Utah.
Curie (Ci)	The unit of radioactivity of any nuclide, defined as precisely equal to 3.7×10^{10} disintegrations/second.
daughter product	The nuclide remaining after a radioactive decay. A daughter atom may itself be radioactive, producing further daughter products.
diurnal	Daily, cyclic (happening each day or during the day).
dose equivalent	A term used to express the amount of effective radiation when modifying factors have been considered (the numerical product of absorbed dose and quality factor).
EPA (USEPA)	Environmental Protection Agency.
ERDA (USERDA)	Energy Research and Development Administration.

ERDA-GJO	Energy Research and Development Administration-Grand Junction Office.
erg	A basic unit of work or energy in the centimeter-gram-second system (1 erg = 7.4×10^{-8} ft-lb, or 10^{-7} joule).
external gamma radiation (EGR)	Gamma radiation emitted from a source(s) external to the body, as opposed to internal gamma radiation emitted from ingested or inhaled sources.
exposure	Related to electrical charge produced in air by ionizing radiation per unit mass of air.
exhalation	Emission of radon from earth (usually thought of as coming from a uranium tailings pile, but actually from any location).
FB&DU	Ford, Bacon & Davis Utah Inc.
fixed alpha	Particulate alpha emitting isotopes which have become imbedded in otherwise non-radioactive surfaces and which cannot be removed by standard decontamination techniques.
gamma background	Natural gamma ray activity everywhere present, originating from two sources: (1) cosmic radiation, bombarding the earth's atmosphere continually, and (2) terrestrial radiation. Whole body absorbed dose equivalent in the U.S. due to natural gamma background ranges from about 60 to about 125 mrem/yr.
gamma ray (γ)	High energy electromagnetic radiation emitted from the nucleus of a radioactive atom, with specific energies for the atoms of different elements and having high penetrating power.
GJO	Grand Junction Office.

ground water	Subsurface water in the zone of full saturation which supplies wells and springs.
health effect	Adverse physiological response from tailings (in this report, one health effect is defined as one case of cancer from exposure to radioactivity).
heap leaching	A process for removing uranium from ore, tailings, or other material wherein the material is placed on an impermeable pad and wetted with appropriate reagents. The uranium solution is collected for further processing.
HEW (USHEW)	Department of Health, Education, and Welfare.
insult	Negative impact on the environment or the health of individuals.
Interim Primary Drinking Water Regulations	Title No. 40 of the Code of Federal Regulations, Chapter 1, Part 141, dated Dec 24, 1975 and effective June 24, 1977.
iso-exposure line	A line drawn on a map to connect a set of points having the same exposure rate.
isotope	One of two or more species of atoms with the same atomic numbers (the same chemical element) but with different atomic weights. Isotopes usually have very nearly the same chemical properties, but somewhat different physical properties.
JCAE	Joint Committee on Atomic Energy.
knot	A unit of velocity, approximately equal to 1.15 mi/hr.
man-rem (person-rem)	A unit used in health physics to compare the effects of different amounts of radiation on groups

	of people. It is obtained by summing individual dose equivalent values for all people in the population.
$\mu\text{R/hr}$	Microroentgen per hour (10^{-6} R/hr).
mR/hr	Milliroentgen per hour (10^{-3} R/hr).
MeV	Million electron volts.
maximum permissible concentration (MPC)	The highest concentration in air or water of a particular radionuclide permissible for occupational or general exposure without taking steps to reduce exposure.
NAS	National Academy of Sciences.
NIOSH	National Institute for Occupational Safety and Health.
noble gas	One of the gases, such as helium, neon, radon, etc., with completely filled electron shells, which is therefore chemically inert.
NRC	Nuclear Regulatory Commission.
nuclide	A general term applicable to all atomic forms of the elements; nuclides comprise all the isotopic forms of all the elements. Nuclides are distinguished by their atomic number, atomic mass, and energy state.
ORNL	Oak Ridge National Laboratory.
ORP-LVF (EPA)	Office of Radiation Programs, Las Vegas Facility (Environmental Protection Agency).
pCi/l	Picocurie per liter (10^{-12} Ci/l)
pCi/g	Picocurie per gram (10^{-12} Ci/g)
$\text{pCi/m}^2\text{-s}$	Picocurie per square meter per second (10^{-12} Ci/m ² -s)

PHS (USPHS)	Public Health Service.
quality factor (QF)	An assigned factor that denotes the modification of the effectiveness of a given absorbed dose by the linear energy transfer.
rad	The basic unit of absorbed dose of ionizing radiation. A dose of 1 rad means the absorption of 100 ergs of radiation energy per gram of absorbing material.
radioactivity	The spontaneous decay or disintegration of an unstable atomic nucleus, usually accompanied by the emission of ionizing radiation.
radioactive decay chain	A succession of nuclides, each of which transforms by radioactive disintegration into the next until a stable nuclide results. The first member is called the parent, the intermediate members are called daughters, and the final stable member is called the end product.
radium	A radioactive element, chemically similar to barium, formed as a daughter product of uranium (^{238}U). The most common isotope of radium, ^{226}Ra , has a half-life of 1,620 yr. Radium is present in all uranium-bearing ores. Trace quantities of both uranium and radium are found in all areas, contributing to the background radiation.
radon	A radioactive, chemically inert gas. The nuclide ^{222}Rn has a half-life of 3.8 days and is formed as a daughter product of radium (^{226}Ra).
radon background	Low levels of radon gas found in air resulting from the decay of naturally occurring radium in the soil.

radon concentration	The amount of radon per unit volume. In this assessment, the average value for a 24-hr period of atmospheric radon concentrations, determined by collecting data for each 30-min period of a 24-hr day and averaging these values.
radon daughter	One of several short-lived radioactive daughter products of radon (several of the daughters emit alpha particles).
radon daughter concentration (RDC)	The concentration in air of short-lived radon daughters, expressed either in pCi/l or in terms of working level (WL).
radon flux	The quantity of radon emitted from a surface in a unit time per unit area (typical units are in pCi/m ² -s).
raffinate	The liquid part remaining after a product has been extracted in a solvent extraction process.
recharge	The processes by which water is absorbed and added to the zone of saturation of an aquifer, either directly into the formation or indirectly by way of another formation.
rem (roentgen equivalent man)	The unit of dose equivalent of any ionizing radiation which produces the same biological effect as a unit of absorbed dose of ordinary X-rays, numerically equal to the absorbed dose in rads multiplied by the appropriate quality factor for the type of radiation. The rem is the basic recorded unit of accumulated dose to personnel.
residual value	The value of minerals in tailings material.

riprap	An irregular protective layer of broken rock.
roentgen (R)	A unit of exposure to ionizing radiation. It is that amount of gamma or X-rays required to produce ions carrying 1 electrostatic unit of electrical charge, either positive or negative, in 1 cubic centimeter of dry air under standard conditions, numerically equal to 2.58×10^{-4} coulombs/kg of air.
sands	Relatively coarse-grained materials produced along with the slimes as waste products of ore processing in uranium mills (see tailings). These sands normally contain a lower concentration of radioactive material than the slimes.
scintillometer	A gamma-ray detection instrument normally utilizing a NaI crystal.
slimes	Extremely fine-grained materials mixed with small amounts of water, produced along with the sands as waste products of ore processing in uranium mills (see tailings). The highest concentration of radioactive material remaining in tailings is found in the slimes.
tailings	The remaining portion of a metal-bearing ore after the desired metal, such as uranium, has been extracted. Tailings also may contain other minerals or metals not extracted in the process (e.g., radium).
UMTRA	Uranium Mill Tailings Remedial Action
working level (WL)	A unit of radon daughter exposure, equal to any combination of short-lived radon daughters in 1 liter of air that will result in the ultimate

emission of 1.3×10^5 MeV of potential alpha energy. This level is equivalent to the energy produced in the decay of the daughter products RaA, RaB, RaC, and RaC' that are present under equilibrium conditions in a liter of air containing 100 pCi of Rn-222. It does not include decay of RaD (22-yr half-life) and subsequent daughter products.

working level month (WLM)

One WLM is equal to the exposure received from 170 WL-hours.