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**ENGINEERING ASSESSMENT OF
INACTIVE URANIUM MILL TAILINGS**

**SPOOK SITE
CONVERSE COUNTY, WYOMING**

OCTOBER 1981

PREPARED FOR
UNITED STATES 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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Prepared for
U.S. DEPARTMENT OF ENERGY
ALBUQUERQUE OPERATIONS OFFICE
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Contract No. DE-AC04-76GJ01658

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FORD, BACON & DAVIS UTAH INC.
375 Chipeta Way
Salt Lake City, Utah 84108

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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 December 1977, entitled "Phase II - Title I Engineering Assessment of Inactive Uranium Mill Tailings, Spook Site, Converse County, Wyoming," 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 Spook 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 Dick Hornbuckle, property owner at the Spook site. Several local, county, and state agencies and private individuals also contributed information.

ABSTRACT

Ford, Bacon & Davis Utah Inc. has reevaluated the Spook site in order to revise the December 1977 engineering assessment of the problems resulting from the existence of radioactive uranium mill tailings 48 mi northeast of Casper, in Converse County, Wyoming. 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 187,000 tons of tailings at the Spook site constitutes the most significant environmental impact, although windblown tailings and external gamma radiation also are factors. The four 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 IV). Cost estimates for the four options range from about \$710,000 for stabilization in-place, to about \$1,950,000 for disposal at a distance of about 15 mi.

Three principal alternatives for the reprocessing of the Spook 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 \$40/lb of U_3O_8 by treatment in an existing conventional plant. The spot market price for uranium was \$25/lb early in 1981. Therefore, reprocessing the tailings for uranium recovery might be economically feasible if they could be treated as supplementary feed to a nearby operating mill, provided the price of uranium returns to the 1978-1979 levels.

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CHAPTER 1

SUMMARY

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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 revise 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 Spook 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 two potential practicable remedial action alternatives. Since that time, these alternatives have been judged unacceptable because of new criteria that have been proposed. In this report, the remedial action alternatives are revised as follows:

- (a) Option I - Stabilization of tailings at bottom of open pit, with a 3-m cover
- (b) Option II - Removal of tailings to an unspecified site located 5 mi from the Spook tailings site
- (c) Option III - Removal of tailings to an unspecified site located 10 mi from the Spook tailings site
- (d) Option IV - Removal of tailings to an unspecified site located 15 mi from the Spook tailings site

In addition, if uranium prices were to rise from their presently depressed levels, it could be feasible to process the Spook tailings at the Bear Creek mill, which lies only 2.5 mi north of the Spook tailings site.

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.

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)

*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. The Phase I report on the Spook site appears as Appendix I to Reference 4.

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 Spook site began on July 30, 1976, and the original Phase II - Title I Engineering Assessment was published in December 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 July 21, 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, provided 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 Spook site.

The specific scope requirements of the Title I assessment 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, perform evaluations and estimate 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 of 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 socio-economic impact based on population and land use projections.
- (o) Preparation of preliminary plans, specifications, and cost estimates for alternative corrective actions for each site.

Not all of these items received attention at the Spook site.

1.2 SITE DESCRIPTION

1.2.1 Location and Topography

The Spook millsite and tailings pile are located approximately 48 mi northeast of Casper, in Converse County, Wyoming, and approximately 32 mi northeast of Glenrock, Wyoming.

The site is located among rolling hills at an elevation of about 5,100 ft above sea level in the drainage basin of the Cheyenne River. Vegetation is comprised of sagebrush and native grasses, with cottonwood trees along the creek bottoms. The site and its relationship to the surrounding area are shown in Figure 2-1.

1.2.2 Ownership and History of Milling Operations and Processing

The Wyoming Mining and Milling Company operated on the site, which is owned by Richard T. Hornbuckle, Pearl R. Hornbuckle, Kirkwood T. Hornbuckle, and Brent B. Hornbuckle.

Western Nuclear, Inc., a subsidiary of Phelps Dodge Corporation, is presently responsible for the property.

The upgrader became operational in 1962 and ran until June 1965. Ore from the adjacent open-pit mine averaged 0.12% U_3O_8 , and about 187,000 tons were processed. (Some ore was shipped directly to a mill at Jeffrey City, Wyoming.) The ore was acid-leached and the uranium slurry was trucked 165 mi to the Western Nuclear mill at Jeffrey City for further processing.

1.2.3 Present Condition of the Site

Figure 2-5 is a descriptive map of a portion of the site as it now exists. The major structures have been removed. Concrete foundations, machine parts, timbers, overhead electrical equipment, and crusher components remain. The 187,000 tons of tailings rest on the top edge, side slope and bottom of the open-pit mine, and cover about 5 acres. They have not been stabilized and show some signs of water erosion. The most prominent features of the site are the open-pit mine and adjacent pile of mine waste and mine overburden. The pit is approximately 100 ft deep in its deepest point. Figure 2-6 is a cross-section through the tailings pile and mine pit.

About half the surface area of the tailings site is covered by weeds and native grasses. A barbed wire fence surrounds the millsite, open-pit mine, overburden, and tailings areas. A haul road runs north and south immediately to the west of the site; the road is used to haul ore from open-pit mines south of the site to a processing plant 2.5 mi to the north of the site.

1.2.4 Tailings and Soil Characteristics

The tailings are sandy in character, although no measurements of physical properties were performed. The soil on the site is a thin layer of weathered sandstone from the bedrock beneath the site.

1.2.5 Geology, Hydrology, and Meteorology

The Spook tailings pile, millsite, and the Spook mine are located on the slopes of a rolling hillside typical of the southern margin of the Powder River Basin. Bedrock is exposed in the open pit and consists of sandstones and shales of the Monument Hill unit of the Wasatch Formation. The Wasatch Formation is underlain by up to 2,000 ft of sandstones and shales of the Fort Union Formation. The shale and claystone units of the formations act as confining layers that prevent the upward and downward migration of ground waters. Although the strata at the site are virtually flat-lying, regional correlation suggests a very gentle dip of less than 1 deg to the north. A simplified stratigraphic column is shown in Figure 2-7.

The surface waters on or near the site consist of standing water in the pit during some months of the year, an interceptor ditch that diverts storm runoff around the tailings and pit, ephemeral drainage channels, and an intermittent stream south of the pit known as the Dry Fork Cheyenne River. Off-site contamination of surface waters by physical transport of tailings or by chemical leaching is unlikely. This is due to the distance of flowing surface waters from the site, the gentle hydraulic gradient, and the topography and drainage system at the site which limits almost all off-site runoff from reaching the tailings and allows only the precipitation that falls on the site to collect in the pit.

The aquifers of the Powder River Basin System are typically at different depths within the Wasatch and Fort Union Formations, and their water quality and quantity vary considerably. Most of the wells in the area are completed at depths of less than 300 ft. Some of these are flowing wells, others are pumped. In recent years, many of the shallow wells have dried out or slowed down in flow rates. During this time, mining companies have developed deep wells (greater than 1,000 ft) for use in their mining and process activities.

Regional recharge areas for the aquifers are the highland areas. Local recharge areas include higher areas such as the Cheyenne River Divide or locations where permeable formations are intercepted by surface waters. The Spook Mine pit is in permeable strata and can act as a point for ground water recharge. However, this recharge potential is small due to the limited precipitation that is trapped on the site. Should contamination occur due to the tailings, the effects would be minimal. Only stock water wells tap the nearby shallower aquifers. Furthermore, the strata of the pit are the host rock for the uranium ore of the vicinity and any contribution of radionuclides from the tailings would be far exceeded by natural sources.

The tailings are vulnerable to strong winds that are typical of the area and tend to blow from the southwest. Annual precipitation averages about 13 in. Thunderstorms are common occurrences and are sometimes accompanied by severe hail or tornado activity as well as by wind and rain.

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 these radionuclides have experienced, it appears that ^{226}Ra is 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 pile. The principal exposure results from inhalation of ^{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 pile.
- (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

Short-term radon measurements were performed by FB&DU in 1976 with continuous radon monitors supplied by ERDA⁽³⁾ at three locations in the vicinity of the Spook tailings pile. The locations and values of the 24-hr radon concentrations are shown in Figure 3-4. The highest outdoor radon concentration was measured on the pile (17 pCi/l). Background atmospheric radon at a location 2 mi from the site measured 1.1 pCi/l. Radon above the average background level was detected at 0.4 mi from the site.

1.3.1.2 Direct Gamma Radiation

The average external gamma radiation (EGR) within a few feet of the pit was about 128 $\mu\text{R/hr}$. The highest EGR level, around 650 $\mu\text{R/hr}$, was measured in the pit along a southwesterly traverse originating at the northwestern edge of the tailings pile. This high reading was also associated with a correspondingly high soil concentration of ^{226}Ra and is probably due to residual ore.

In the area surrounding the tailings, the gamma radiation rates were greater than twice background due largely to the open-pit uranium mine and mine waste. Beyond the mine and mine waste area, the gamma radiation decreased to background within 0.2 mi.

1.3.1.3 Windblown Contaminants

Prevailing winds in the area are from west-southwest. The results of the EPA gamma radiation survey around the tailings pile are shown in Figure 3-10. Figure 3-12 shows the locations and measurements of ^{226}Ra along traverses throughout the site area. Not all of the apparent contamination is due solely to the presence of the tailings; the high natural background levels of uranium and radium, and the large quantities of radioactive overburden surrounding the millsite, almost certainly contribute to elevated levels of surface contamination at some distances away from the tailings. With this qualification in mind, the boundary of the area assumed to be contaminated by tailings was drawn as shown in Figure 3-12.

1.3.1.4 Ground and Surface Water Contamination

Three water samples were taken from the Dry Fork Cheyenne River, which is an intermittent stream. All of these samples (upstream, downstream, and at the confluence with a wash that drains the southern mine waste) contained 0.1, 1.27, and 0.16 pCi/l of ^{226}Ra , respectively.⁽⁴⁾ All of these levels are below the EPA Interim Primary Drinking Water Regulations for radioactive contaminants.

A water sample from a stagnant pond south of the tailings pile just off a pile of mine waste contained 21.7 pCi/l of ^{226}Ra . However, this water has little chance of reaching the Cheyenne River. Two well water samples from wells south and east of the tailings contained 0.24 and 0.22 pCi/l of ^{226}Ra , respectively.

Considering the distance between the tailings and a flowing stream and the naturally occurring radioactivity in the area, the tailings have little potential for increasing the ^{226}Ra content of off-site water.

1.3.1.5 Soil Contamination

The leaching of radium from the tailings into the subsoil averaged 3 ft but extends from 2 to 5 ft before reaching background levels of ^{226}Ra concentration. The profile of radium concentration in the tailings was determined with a gamma probe and by core sample analyses.⁽⁴⁾

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 $\mu\text{R/hr}$ 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 (45 FR 27370) 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.*

<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 less than 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.

*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.

While these standards may undergo further revisions, 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 pile and the subsequent inhalation of radon daughters account for most of the total dose to the population from the Spook site under present conditions. The gamma radiation exposure from the Spook pile is virtually zero past 0.2 mi. There are few people who live or work within 1.5 mi of the pile, where gamma radiation is above background.

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 time 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⁽⁵⁾ earlier indicated that 13 ft of earth cover would be required to reduce the radon diffusion from the Spook tailings by 95%. Later experimental work⁽⁶⁾ 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).(7) 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 10^6 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(8) 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 tailings pile in the vicinity within 4.5 mi of the Spook site is 2.6×10^{-8} per person per year, or less than 0.02% of the average lung cancer risk due to all causes for Wyoming residents (2.1×10^{-4}). (9)

The 25-yr health effects were calculated for three population projections using the present population of 86 in the 0- to 4.5-mi area. The results for pile-induced radon and background radon for the area (0 to 4.5 mi) were as follows:

25-Year Cumulative Health Effects Within 4.5 Miles
of Edge of Pile

<u>Projected Population Growth</u>	<u>Pile-Induced RDC</u>	<u>Background RDC</u>
Constant 0.8% growth rate	0.000063	0.10
Constant 3% growth rate	0.000083	0.13
8.8% declining growth rate*	0.00013	0.20

1.3.4 Nonradioactive Pollutants

There are other potentially toxic materials in the tailings. Chemical analyses of tailings samples from auger holes in the Spook pile showed barium, chromium, and lead in concentrations between 3 and 50 ppm. The highest selenium concentration was 270 ppm, and arsenic concentration was about 90 ppm. Vanadium was present at about 26 to 350 ppm. It has been speculated that high concentrations of selenium in the overburden, resulting in correspondingly high levels of that element in the vegetation, were responsible for the deaths of cattle grazing on site about 12 to 15 yr ago.

Six water samples were taken from the vicinity of the Spook site and chemically analyzed; four samples from stagnant ponds south of the millsite, and two ground water samples from wells east and south of the site. The locations of these samples are shown in Figure 3-11 and the analyses of these samples are presented in Table 3-4. All water samples contained selenium above the EPA Interim Primary Drinking Water Regulations. In addition, some of the samples contained arsenic and cadmium above the drinking water regulations.

While there is some water contamination near the Spook mine and millsite, it is mainly due to mine waste and not mill tailings. The tailings have been deposited within the open-pit mine and precipitation which falls on the tailings is mostly confined in the pit. The possibility of seepage from the pile degrading the surface water quality is unlikely because of the distance from the tailings to flowing surface waters and other natural sources of contamination.

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

1.4 SOCIOECONOMIC AND LAND USE IMPACTS

Except for the mineral, oil, and gas exploration and development near the site, virtually all the land near the tailings site is used for grazing. A haul road just west of the site is used regularly for transporting ore to the Bear Creek uranium millsite, a few miles north of the site. The population centers closest to the site are some 30 to 40 mi south of the site. There is only one ranch house within 2 mi of the site, and there are about 90 persons living within 15 mi of the site. The land surrounding the site is all in private ownership.

There is ongoing drilling and exploration for minerals within the area. Two local mining companies intend to mine adjacent to the northern and eastern boundaries of the site.

The presence of the tailings restricts the use of the site to only a minor degree. The acreage occupied by the tailings is less than 5 acres, most of which is adjacent to an open-pit mine. This loss is minimal compared with the much larger area occupied by the open pit, mine waste, and overburden piles. If the tailings were not present, there would be virtually no change in land uses and values in the surrounding areas.

1.5 RECOVERY OF RESIDUAL VALUES

Available historical records that provide reliable data on specific mineral contents of the Spook 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. Estimates of the Spook tailings from AEC records show an average of 0.023% U_3O_8 .

There are, however, five factors that can be considered to evaluate whether reprocessing Spook 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 Spook 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 \$40/lb of U_3O_8 by treatment in an existing conventional plant. The spot market price for uranium was \$25/lb early in 1981. Therefore, reprocessing the Spook tailings for uranium recovery might be economically feasible if they were treated as supplementary feed to a nearby operating mill. Construction of reprocessing facilities for the sole purpose of reprocessing the Spook tailings would be infeasible due to the quantity and grade of the tailings.

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 the 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

There are no off-site locations other than windblown where tailings have been used, and therefore no such areas to decontaminate.

It is difficult to assess windblown contamination attributable to the tailings pile alone since there are other prevalent radioactive sources in the vicinity. The estimated boundaries of windblown tailings are shown in Figure 9-1. The cost of cleanup of the estimated 11 acres of off-site land contaminated by windblown tailings is estimated to be \$50,000, exclusive of engineering and contingency allowances.

1.8 DISPOSAL SITE SELECTION

In this report, three of the alternative remedial action options include moving the Spook tailings to unspecified disposal sites. The responsibility for disposal site selection lies with the Federal Government, with input from the State. At such time as tentative selections are made, site-specific costs may be estimated.

In each disposal option, 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 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 in the pit adjacent to the tailings site, and removal of all radioactive tailings materials to areas where these materials could be isolated from the public. The options are summarized in Table 1-2. The basis for comparison, from which the cost effectiveness of 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 pile at the bottom of the open pit and with the addition of a 3-m depth of cover. Radon exhalation would be reduced to not more than 2 pCi/m²-s above background. The tailings site would have limited future use.

Costs for tailings disposal at three unspecified sites at distances of 5, 10, and 15 mi from the Spook tailings were evaluated. Since the market for uranium is presently depressed, the possibility of reprocessing the tailings at the Bear Creek mill was not addressed, even though this might be an alternative solution if the price for uranium concentrate were to rise significantly.

1.9.2 Cost-Benefit Analyses

As summarized in Table 9-1, the total costs for the four remedial action options vary from about \$710,000 to about \$1,950,000. 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 health 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.

As indicated in Chapters 2 and 3, the mill and tailings site are located directly at the mine, and are adjoined by the open-pit mine and various piles of overburden which exhibit radioactivity levels well above the proposed standards for millsite and tailings pile stabilization. These mining wastes would continue to have an impact on the contamination levels of the site and therefore on its future utility. However, the cleanup of radioactive contamination resulting from mining operations per se is a separate problem that is not within the scope of the remedial action activities described in this report.

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 (JCC)	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)

	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>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

Option Number	Site Specific Cost (\$000)	Description of Remedial Action	Benefits	Adverse Effects
I	710	The pile would be stabilized at the bottom of the open pit with 3 m of local earth cover. Natural vegetation would be established or a riprap cover provided. On- and off-site contaminated materials would be cleaned up as necessary.	A-D,G,H	X
II	1,510	The tailings, contaminated soil and rubble would be removed by truck to an unspecified site located about 5 mi from the tailings site. The tailings site would be decontaminated and released for unlimited use.	B-F,H	--
III	1,700	Same as Option II, except tailings removed to an unspecified site located about 10 mi from the tailings site.	B-F,H	--
IV	1,950	Same as Option II, except tailings removed to an unspecified site located about 15 mi from the tailings site.	B-F,H	--

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

Definition of Adverse Effects

- X. Limited use of the tailings site

CHAPTER 1 REFERENCES

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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 Spook site, its surroundings, and the characteristics of the tailings materials present on the site.

2.1 LOCATION

The Spook millsite and tailings are located approximately 48 mi northeast of Casper in Converse County, Wyoming, and approximately 72 mi west of the Wyoming-South Dakota Border, and 32 mi northeast of Glenrock, Wyoming. Figure 2-1 is an aerial photograph of the site and Figure 2-2 shows the situation of the Spook site in relation to these locations. More specifically, the site is in parts of Sections 27 and 28, Township 38 North, Range 73 West, Sixth Principal Meridian, at 43 deg 13 min 51 sec north latitude, and 105 deg 36 min 54 sec west longitude.

2.2 TOPOGRAPHY

The site is located among rolling hills in remote ranchland at about 5,100 ft elevation above sea level. It is just north of the Dry Fork Cheyenne River and at the southern edge of the Thunder Basin National Grassland. The elevation difference between the low lands in the area and the tops of the hills averages about 200 ft. The area is dotted with mining and exploration activities, and is in the Powder River Basin uranium mining district.

The site consists of a large open pit from which the ore for the mill was taken, and of piles of overburden and mine waste material. The open-pit mine is about 100 ft deep. Figure 2-3 is a topographic map of the millsite.

There are a few cottonwood trees along the stream beds. Otherwise, the land is covered with native grasses and brush.

2.3 OWNERSHIP

The Wyoming Mining and Milling Company operated the site, which is owned by Richard T. Hornbuckle, Pearl R. Hornbuckle, Kirkwood T. Hornbuckle, and Brent B. Hornbuckle. Western Nuclear, Inc., a subsidiary of Phelps Dodge Corporation, is responsible for the property at present. A land ownership and description map prepared for DOE⁽¹⁾ is shown in Figure 2-4.

2.4 HISTORY OF MILLING OPERATIONS AND PROCESSING⁽²⁾

The upgrader at the Spook site was constructed during late 1961 and early 1962 and operated from April 1962 until June 1965. The upgrader processed ores containing too little mineral value to justify the expense of hauling the ore to the Jeffrey City mill, 165 mi away. About 200 tons of ore that averaged about 0.12% U_3O_8 were treated daily. The total feed to the upgrader was 187,000 tons. In addition to the ore processed at the upgrader, the nearby mine produced approximately 45,000 tons of higher grade ore that was trucked directly to Jeffrey City, Wyoming, for processing. Following shutdown, the upgrader and buildings were dismantled. Western Nuclear, Inc., utilized some of the equipment at the Jeffrey City mill and sold the rest to the other uranium operations.

The process and equipment used at this site were unique.⁽³⁾ Following crushing to about 0.75 in., the sandstone ore was mixed with water and sulfuric acid, pelletized, and allowed to cure for about 14 hr. The uranium was leached in false-bottom rectangular concrete tanks, the acid solution being recycled until the desired uranium concentration was attained. The pregnant solution then passed through tanks containing ion-exchange resins where the uranium was removed and the solution recycled to leach. Uranium was eluted from the resin and precipitated with ammonia to form a slurry that was trucked 165 mi to the mill at Jeffrey City for further processing.

The acid-leached residues or tailings were removed from the tanks by a front-end loader and dumped into the open-pit mine adjacent to the upgrader.

2.5 PRESENT CONDITION OF THE SITE

Figure 2-5 is a descriptive map of the site as it now exists. The original mill buildings have been removed, while concrete foundations, machine parts, timbers, overhead electrical equipment, and crusher components remain.

The tailings, covering about 5 acres, rest on the bank of the open-pit mine; some tailings can be seen on the edge of the pit and down the slope to the bottom of the pit. They have not been stabilized and gully erosion of the tailings is evident on the steep slopes of the pile. Figure 2-6 is a cross-section of the tailings pile.

About half of the surface area of the millsite and the tailings, mine, and overburden areas are covered by weeds and native grasses. A new barbed-wire fence, installed in about 1977 and still in excellent condition, surrounds the millsite, open-pit mine, overburden, and tailings area of the site.

A haul road runs north and south immediately to the west of the Spook site; the road is used to convey ore from open-pit mines 6 to 10 mi south of the Spook site to a processing plant 2.5 mi north of the site, at Bear Creek. The nearest permanent homes are at the Hornbuckle Ranch, approximately 2 mi southwest of the site.

2.6 TAILINGS AND SOIL CHARACTERISTICS

There are approximately 187,000 tons of tailings on the Spook site. Soils in the immediate vicinity of the site are primarily sandy soils developing in residuum and eolian material from the weathered sandstones of the Wasatch Formation. There are a few finer-grained units included in the area that have developed in residuum on calcareous shales.

2.7 GEOLOGY, HYDROLOGY, AND METEOROLOGY

2.7.1 Geology

The Spook site is located near the southern margin of the extensive topographic and structural basin known as the Powder River Basin. The site is geologically uncomplicated. Essentially flat-lying Tertiary Age Wasatch Formation sandstones and shales are overlain by a shallow overburden of weathered bedrock on the hill slopes. Bedrock is exposed in the Spook open-pit mine and consists of medium- to coarse-grained sandstones with claystones and carbonaceous shales. This "Monument Hill" unit is near the base of the Wasatch Formation.

Underlying the Wasatch Formation are up to 2,000 ft of sandstones and shales of the Fort Union Formation. The shale and claystone strata of the formations act as confining layers to the upward and downward migration of ground waters. Regional correlations suggest the formations dip to the north very gently (less than 1 deg). A simplified stratigraphic column of the rock formations is shown in Figure 2-7.

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 Spook tailings site is contemplated at this time.

Surface waters on or near the site consist of standing water in the pit during some months of the year, an interceptor ditch that diverts storm runoff around the tailings and pit, ephemeral hillside drainage channels, and an intermittent stream known as the Dry Fork of the Cheyenne River which is part of the

Cheyenne River Basin of the Upper Missouri River Basin. These surface waters are shown in Figure 2-8.

The tailings are on high ground and there is no potential for the inundation of tailings by floodwaters. The diversion ditch is adequate to handle all but the most severe storms. Even so, there are deep gullies cut into the steeper slopes of the tailings and there is evidence of sheet erosion on gentler slopes.

Contamination of flowing surface waters near the pile cannot occur by physical transport of the tailings in overland runoff because the intermittent drainage is almost 2 mi downstream and most of the on-site drainage is collected in the pit. There is a possibility of degradation of flowing surface water quality from surface water runoff from the mine waste piles on the site. Contamination would be slight because of the distance of the tailings from flowing surface waters and the gentle hydraulic gradient.

Surface water quality in the area is highly variable and tends to be hard and is inferior to ground water quality for domestic purposes. Livestock drink the surface waters with no known adverse effects, although some water samples taken in the area are high in arsenic, iron, and selenium.

2.7.3 Ground Water Hydrology

The Powder River Basin aquifer system is typified by several aquifers at different depths within the Wasatch and Fort Union Formations. The water quality and quantity vary considerably. The unconfined ground waters in the area include water in valley alluvium and in very shallow wells. There are no such wells in the immediate vicinity of the Spook tailings.

Because of the claystone layers in the Wasatch and Fort Union Formations, the vertical permeability of the rock section is substantially less than the horizontal permeability. Most of the wells in the area are completed in sandstone units less than 300 ft in depth. Some of these are flowing wells, others are pumped. The locations of nearby wells are shown in Figure 2-9. In Converse County there are less than 50 water wells completed at depths greater than 500 ft. Three of these wells are within 5 mi of the site and are completed in sandstones of the Fort Union Formation. There are very few private local wells in the area. The domestic ranch wells are tapping deeper aquifers, and the closest wells serve only as stock water supplies. The ground water gradient tends toward the north.

In recent years, mining companies have drilled deep wells in the area; many of the shallow wells have dried up and artesian wells have stopped flowing. At least two registered wells near the site have been affected, wells No. 12 and 16 on

Hornbuckle Ranch; well No. 16 has quit flowing, and the flow of well No. 12 has slowed substantially.⁽⁴⁾ Two nonregistered wells at depths of 300 and 700 ft are located on the site itself. These wells are used intermittently for stock watering.

Regional recharge areas include land at higher elevations such as the Black Hills to the east, the Bignorn Mountains to the west, and local high ground such as the Cheyenne River Divide. Local recharge areas primarily consist of the interception of storm runoff and stream waters by permeable formations. The Spook open-pit mine is in permeable strata and can act as a point for ground water recharge. However, its local recharge potential is small because of the limited precipitation that is trapped on the site. Even if contaminants from the tailings were to enter the ground water system, the effect would be minimal. The strata of the pit contain the host rock of uranium ore in the area, and the potential contamination from the tailings is far exceeded by these natural sources. The quality of the ground water in the region is being monitored by mining companies in the area as well as by government agencies.

Recent^(5,6) and ongoing research by the Research Institute for Geochemical and Environmental Chemistry suggests that the presence of soluble sulfate salts in the tailings greatly modifies the hydrologic environment of the pile. The principal investigator⁽⁵⁾ states that "the general trend of material transfer within the pile is from the interior to the surface where salts with the contaminants precipitate." It is not known how significant the observed migration of salts will be for tailings stabilization.

2.7.4 Meteorology

Because of its relatively high elevation, the rolling terrain of the plains is subject to persistent moderate winds that occasionally reach speeds of 30 to 40 mi/hr and usually blow from the southwest. A wind rose from the Casper airport 50 mi southwest of the site is shown in Figure 2-10.

In June 1965 a tornado touched down on the Hornbuckle Ranch and caused some structural damage to the ranch buildings and major damage to the trees along the Dry Fork Cheyenne River, including the reach near the site. Thunderstorms are common in the area and are sometimes accompanied by severe hail, wind, and rain. A 50-yr frequency rainfall of 24-hr duration would result in an estimated 3.4- to 3.8-in. rainfall at the site. Such a storm would erode steeply sloped sections of the pile. The average annual precipitation in the vicinity of the Spook site is approximately 13 in. Precipitation in late spring and summer normally comes as scattered thundershowers that can vary greatly in quantity and areal extent.⁽⁷⁾ Data from Casper indicate that during April, May, and June the probability of precipitation of 0.01 in. or more is 30%,

based on the 23-yr data preceding 1974, as reported by the U.S. Department of Commerce in 1974. Thundershowers continue as a common occurrence through September, at which time rain and snow systems of Pacific origin become the dominant storm feature. Average precipitation amounts are relatively small during the fall and winter months. The average precipitation begins to increase in early spring when heavy, wet snowfalls give way to scattered thunderstorms.

FIGURE 2-1. AERIAL PHOTOGRAPH OF SITE

360-15 12/78

FIGURE 2-2. SITE LOCATION MAP

360-15 3/81

FIGURE 2-3. TOPOGRAPHIC MAP

CONVERSE COUNTY, SPOOK SITE

BEGINNING AT A POINT N 89°53'E, 61.67 FT ALONG THE SECTION LINE AND DUE SOUTH 1579.39 FT FROM THE N.W. CORNER OF SECTION 27, T38N, R73W, 6TH PRINCIPAL MERIDIAN CONVERSE COUNTY, WYOMING, AND RUNNING THENCE N 54°39'40"W, 239.57 FT THENCE S 14°37'50"E, 237.87 FT, THENCE S 65°39'20"W, 281.13 FT, THENCE S 12°30'20"W, 185.24 FT, THENCE S 22°21'10"E, 142.62 FT, THENCE S 83°03'10"E, 379.86 FT THENCE N 0° 01' 40" E, 566.17 FT TO POINT OF BEGINNING.

CONTAINING 4.39 ACRES.

(WESTERN NUCLEAR OPERATIONAL CONTROLLER)

NOTE: ADAPTED FROM REFERENCE 1

FIGURE 2-4. LAND OWNERSHIP AND SITE DESIGNATION MAP

FIGURE 2-5. DESCRIPTIVE MAP

BASELINE
PLAN

PROFILE

FIGURE 2-6. CROSS-SECTION THROUGH PILE AT BASELINE

SYSTEM	FORMATION	THICK- NESS	CHARACTER	POSITION OF THE TAILINGS
TERTIARY	WASATCH FORMATION	0- 1500 FT	SHALES, SANDSTONES, AND CONGLOMERATES; FORMS VALLEYS SLOPES, AND ROLLING HILLS; SANDSTONES YIELD WATER	CONVERSE TAILINGS ←
	FORT UNION FORMATION	1500- 3200 FT	SHALES, SANDSTONES, OCCASIONAL COAL BEDS; FORMS ROLLING HILLS, VALLEYS AND SLOPES; SANDSTONES YIELD WATER	
CRETACEOUS	LANCE FORMATION	1000- 2900 FT	SHALES WITH SOME SANDSTONE UNITS AND OCCASIONAL COAL BEDS; FORMS VALLEYS AND SLOPES; AQUICLUDE	
	FOX HILLS SANDSTONE	125- 300 FT	SANDSTONES; FORM BENCHES; AQUIFER	
	LEWIS SHALE FORMATION	1150 FT	DARK GRAY MARINE SHALE; FORMS VALLEYS AND SLOPES; AQUICLUDE	
	MESAVERDE FORMATION	500 FT	BUFF SANDSTONES WITH INTERBEDDED SHALES; FORMS BENCHES, RIDGES, AND CLIFFS, AQUIFER	
OLDER SEDIMENTARY ROCKS				

FIGURE 2-7. SIMPLIFIED STRATIGRAPHIC COLUMN

UC360-15 12/77

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360-15 12/77

FIGURE 2-10. CASPER, WYOMING SURFACE WIND ROSE
(CUMULATIVE DATA FROM 1967 TO 1972)

360-15 12/77

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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 Spook uranium tailings pile and the resulting potential exposure to the population residing and working in the vicinity. 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 Spook 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 pile. Generally, 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 will 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 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 11 off-site soil samples for each member of the uranium decay chain, assuming equilibrium, was 1.0 pCi/g.⁽¹⁾ The samples taken within a 150-mi radius of the Spook tailings pile and the corresponding ^{226}Ra concentrations are shown in Figure 3-2. In general, the samples were not obtained in mineral-bearing soil. 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 1.2 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 and 3, respectively. Previous estimates⁽²⁾ of background ^{226}Ra and ^{232}Th were 0.9 and 0.6 pCi/g, respectively.

A background value of radon concentration was measured at one location using continuous radon monitors supplied by ERDA. An outdoor value of 1.1 pCi/l was obtained from the 24-hr sample. A previous estimate⁽²⁾ of the range of background radon concentrations was 0.5 to 1.0 pCi/l.

Background gamma ray levels, as measured 3 ft above the ground, also were determined at several locations within 0.6 mi of the site by using a calibrated and energy-compensated Geiger Mueller detector. A value of 12 $\mu\text{R/hr}$ was established as the average background level, but the values ranged from 9 to 13 $\mu\text{R/hr}$.⁽¹⁾ The contribution from cosmic rays is generally dependent upon the altitude and is approximately 6 $\mu\text{R/hr}$ in the Converse County area,⁽³⁾ or approximately 50% of the measured average background value.

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 pile into the environment is discussed in the following paragraphs.

3.4.1 Radon Gas Diffusion and Transport

Field measurements of the radon exhalation flux from the tailings, made in 1976 using the charcoal canister technique, ⁽⁴⁾ are depicted in Figure 3-3. The values ranged from 190 to 2,860 pCi/m²-s on the tailings pile. During the measurement

period the weather and soil were dry. Radon flux depends principally on radium content of tailings. In general, reported values of radon flux vary 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.

Radon gas above background, considered to be from the pile, was detected at distances up to 0.4 mi from the site. The locations and corresponding 24-hr average radon concentrations, including background, measured during this program with the continuous radon monitors are shown in Figure 3-4. The background radon concentration was 1.1 pCi/l.

Variation of radon concentration at two locations during the measurement period and the available weather data are shown in Figures 3-5 and 3-6. The sample location for Figure 3-5 is on the tailings pile. Figure 3-6 illustrates the measurements 0.4 mi northeast of the tailings pile. A diurnal variation of ^{222}Rn concentration is evident in both figures indicating the presence of a source of ^{222}Rn greater than background near the measurement location. Radon concentration measurements made near the pile during this program generally indicated increased concentrations during the night, with reduced values during the day. The increase in concentration is probably the result of an inversion condition and reduced wind velocities. High winds tend to disperse the radon and generally do not result in significantly higher measurements of radon concentration downwind from the tailings pile. Data were not recorded during high winds or rainstorms.

The radon concentration measurements are plotted in Figure 3-7 as a function of distance from the edge of the tailings pile. Model calculations were also performed with annual meteorology data to provide an additional estimate of the radon concentration in the vicinity of the pile. The FB&DU model first determines radon flux and the total radon released from the pile with diffusion theory using radium soil concentrations, and pile configurations deduced from the drilling and survey data. Then, the radon transport off pile is calculated by Gaussian diffusion⁽⁵⁾ plus wind drift conditions. The meteorology used in the calculations was based upon surface wind tabulations representative of central Wyoming during a 4-yr period from 1968 through 1971. The measured values are somewhat higher than the model results; however, the effects of the open pit, millsite contamination, and the mine overburden piles were not included in the calculations.

The model curve of radon concentration-versus-distance was used to calculate potential health effects resulting from radon diffusion from the Spook tailings.

3.4.2 Direct Gamma Radiation

Figure 3-8 shows uncorrected measurements of external gamma radiation (EGR) levels, including background, in the vicinity of the tailings pile. The 1976 measurements were taken 3 ft above ground with calibrated, energy-compensated Geiger Mueller detectors.⁽¹⁾ The 1980 measurements were taken with a 1- x 1-in. NaI(Tl) scintillometer held 3 ft above ground level. The highest EGR level, 650 $\mu\text{R/hr}$, was encountered in the pit, along a southwesterly traverse originating at the northwestern edge of the tailings pile, as shown in Figure 3-8. This high reading was associated with a correspondingly high "delta" value (see Paragraph 3.4.3 below) which is indicative of surface contamination by ^{226}Ra . The average EGR within a few hundred feet of the pile was between 100 and 200 $\mu\text{R/hr}$.

Gamma rate measurements away from the mine and millsite, taken at 100-yd intervals, reached background levels at less than 0.2 mi in all direction. These gamma radiation rate measurements are shown in Figure 3-9. The reduction of gamma radiation as a function of distance from the pile is also shown in Figure 3-9.

3.4.3 Windblown Contaminants

Another pathway results from windblown tailings. Prevailing winds are from the west-southwest at an average velocity of 14 mi/hr; however, winds within the open-pit mine where the tailings have been deposited are greatly reduced, but some resuspension of tailings particles could occur.

Figure 3-10 shows iso-exposure lines due to the residual windblown tailings as determined by the EPA.⁽⁶⁾ If scattered tailings and ore are removed from inside the 10 $\mu\text{R/hr}$ line (toward the pile), and if the pile is covered to provide essentially complete gamma shielding, then the remaining tailings outside the line (away from the pile) would produce a new gamma exposure rate, 3 ft above ground, approximately equal to 10 $\mu\text{R/hr}$. The 10 $\mu\text{R/hr}$ line shown in Figure 3-10 encloses the open-pit mine, the former millsite, and the major portions of the mine waste dumps and overburden piles. The only indicated areas of windblown contamination are south and east of the site.

Surface soil samples were taken in the area surrounding the tailings.⁽¹⁾ The sample locations and ^{226}Ra concentrations are shown in Figure 3-11. Nine soil and sediment samples contained ^{226}Ra above twice background. These samples were taken to the south and east of the site and the radioactivity appeared to be partially due to windblown contamination and to surface water runoff from the mine waste piles. The sample with the highest ^{226}Ra content (38 pCi/g) was taken from a wash east of the site. The sample with the next highest ^{226}Ra content, which was 20 pCi/g, was taken from a wash south of the

site. Contamination in these washes may be the result of drainage from the mine waste piles.

Measurements and data analyses were performed in 1980 to establish the boundary of that region around the site that 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. The scintillometer had one unshielded end directed toward the ground and was held about 1 in. above the ground surface. After obtaining an unshielded reading, a 0.5-in.-thick lead shield was placed over the unshielded end and a second reading was obtained. The difference between the unshielded and shielded readings represents the exposure at the surface at that location. A difference of about 400 counts/min between the shielded and unshielded count rates has been estimated to indicate an area with a soil concentration of about 5 pCi/g of ^{226}Ra with the meter used. The difference, called "delta", and the boundaries of the regions around the site that exceed the 5 pCi/g concentration of ^{226}Ra are estimated in Figure 3-12.

Several traverses with the shielded scintillometer were conducted across open lands adjacent to the tailings pile and were continued until a soil contamination of 5 pCi/g of ^{226}Ra was indicated. The traverses are shown in Figure 3-12 and the location of 5 pCi/g of ^{226}Ra is marked on each traverse. 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 were extended well beyond the 10 $\mu\text{R/hr}$ contour of the 1975 EPA gamma survey.⁽⁶⁾ It was assumed that not all of the apparent contamination is due solely to the presence of tailings. The high natural background levels of uranium and radium and the large quantities of overburden surrounding the millsite almost certainly contribute to elevated levels of surface contamination at some distance away from the tailings. With this complication in mind, the boundary of the area assumed to be contaminated by tailings (not ore or overburden) was drawn considerably short of what would normally be the estimated 5-pCi/g line indicated by a delta reading of 400 counts/min, as shown in Figure 3-12.

No air particulate measurements were performed at the Spook site; however, the average annual air particulate concentration of ^{226}Ra and ^{232}Th in the general area has been estimated⁽²⁾ to be 4×10^{-8} and 8×10^{-8} pCi/l, respectively.

3.4.4 Ground and Surface Water Contamination

Six surface and ground water samples were taken from the vicinity of the Spook tailings pile and analyzed for ^{226}Ra , as shown in Figure 3-11.⁽¹⁾ One sample taken from standing water south of the millsite near a mine waste pile contained 21.7 pCi/l of ^{226}Ra . Three samples were taken from pools in the bed of the Dry Fork Cheyenne River, an intermittent stream

south of the site. The middle sample taken at the confluence of the stream bed with the wash draining the southern mine waste piles contained 0.16 pCi/l of ^{226}Ra . Samples taken upstream and downstream from this location contained 0.1 pCi/l and 1.27 pCi/l of ^{226}Ra , respectively. The radioactive contamination of stream sediments was highest for the upstream sample, indicating either windblown contamination or contamination due to a source other than the Spook mine and mill. Two water samples taken from wells south and east of the site contained 0.24 and 0.22 pCi/l of ^{226}Ra , respectively. Previous measurements of ground water samples from 11 wells in the nearby Bear Creek project area⁽²⁾ yielded ^{226}Ra concentrations of 0.4 to 2.3 pCi/l. The only sample that contained more ^{226}Ra than the drinking water standard was the sample taken from the stagnant pond south of the millsite. This pond was formed by mine waste damming a shallow wash and the confined water has little chance of percolating through the waste and reaching the Dry Fork. Surface waters from the tailings pile all flow into the open-pit mine and present little potential for contamination of the Dry Fork Cheyenne River. The only possibility of water contamination from the tailings is due to ground water flow from the open-pit mine, discussed in Paragraph 2.7.3.

While small amounts of radium, not necessarily from the tailings, may be entering the Dry Fork Cheyenne River, the level of contamination is considerably below the EPA Interim Primary Drinking Water Regulations for radium contamination and is not a radium health hazard. The surface water background sampling program for the Bear Creek project⁽²⁾ yielded a dissolved ^{226}Ra concentration ranging from zero to 6.0 pCi/l, with an average of 1.8 pCi/l. Some samples were taken within 2 mi of the Spook site.

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 auger holes in and around the tailings pile and into the soil beneath it. The radioactivity profile was measured in these holes with a Geiger Mueller detector in a lead shield that collimates the radiation. Soil samples also were taken from selected holes for radiometric analyses. The locations of the holes are shown in Figure 2-5.

Typical ^{226}Ra activity profiles in the Spook tailings and subsoil are shown in Figures 3-13 and 3-14. Figure 3-13 illustrates the ^{226}Ra profile at hole SW-1 located on the western portion of the tailings pile. The profile was determined with the gamma probe. The radioactive contamination decreased to the average ^{226}Ra background concentration about 5 ft below the original surface.

Figure 3-14 is the profile of radium activity at auger hole SW-3, east of the main tailings pile. Adjacent to the former

millsite at that location, the gamma log indicated twice background radium concentration about 3.5 ft below the tailings-subsoil interface. Radium activity in the tailings ranged up to 650 pCi/g in the auger holes that were logged.

Generally, ^{226}Ra contamination ranged from 2 to 5 ft beneath the tailings-subsoil interface with an average depth of about 3 ft.

3.4.6 Off-Site Tailings Use

The remoteness of the tailings site makes it unlikely that tailings have been removed from the site for any purpose.

3.5 REMEDIAL ACTION CRITERIA

The criteria for remedial action that 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, applied to: (a) the cleanup of structures⁽⁷⁾ 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 cleanup standards (45 FR 27366) and proposed disposal standards (46 FR 2556).

3.5.1 EPA Interim and Proposed Standards

The interim cleanup standards and the proposed disposal 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 pCi/m²-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
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 ²²⁶Ra 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 are generally consistent with the NRC 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 pile. 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.(1,8) Elevated concentrations were measured to 0.4 mi from the tailings pile.
- (b) External Gamma Radiation - Gamma radiation above background is measurable to distances up to 0.2 mi from the pile, an area with no inhabitants. People on site will receive some gamma exposure until the pile is covered with sufficient material to reduce the gamma radiation. Since there is no local population within 0.2 mi of the pile, gamma radiation yields a negligible health impact.
- (c) Airborne Activity - The limited, directional spread of significant quantities of windblown tailings toward inhabited areas indicates that direct inhalation or ingestion of tailings particles may be a minor component of the total population dose. This is a general result also reported at other uranium tailings piles.(9,10) Added stabilization of the Spook tailings against wind erosion will eliminate any gradual accumulation of tailings off the site.

- (d) Water Contamination - The low ^{226}Ra activity in nearby off-site surface and ground water indicates little, if any, contamination from the tailings pile. However, the conditions at the site indicate a potential for contamination.
- (e) Subsoil Contamination - Leaching of radioactive materials into the ground beneath the pile and at the millsite is on the order of 2 to 5 ft. Water analyses do not indicate significant contamination from this pathway, however.
- (f) Physical Removal - Tailings that have been placed near a structure or used in its construction are sources of elevated gamma levels and radon daughter concentrations in the structure. No such locations are known.

Only the potential health effects from the inhalation of radon daughters (pathway a) are estimated quantitatively in this assessment, because this pathway produces the most significant exposure.^(8,10) Furthermore, the uncertainty in the estimates of the potential health effects from this pathway 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 the 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 estimates 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.⁽¹¹⁾ 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⁽¹²⁾ risk estimator for lung cancer is based only on the absolute model since the relative risk model is not considered valid.⁽¹³⁾

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:

<u>Age (yr)</u>	<u>Minimal Latent Period From Age at Exposure (yr)</u>	<u>Excess Risk at Age of Diagnosis (cancers per yr per 10⁶ person WLM)</u>
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 per 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.⁽¹⁴⁾ 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 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.⁽¹⁵⁾ 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:

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

The risk estimator used for continual exposure to gamma radiation is expressed as:⁽¹⁶⁾

$$72 \cdot \dot{D} + 0.3 \cdot \dot{D}^2 \text{ cancers per yr}/10^6 \text{ person rems/yr-continuous} \quad (3-4)$$

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 estimated using a ^{222}Rn flux of 430 pCi/m²-s for the pile, which was calculated using diffusion theory and the tailings physical properties. 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 effects calculations.

The transport of radon from the tailings pile was modeled using a Gaussian plume model, meteorology characteristics of the area, and population distribution surrounding the tailings pile as a function of the radius and direction from the center of the pile. The pile was modeled as a vertical cylinder with an area equal to the actual top and side surface areas of the pile. The height of the pile was conservatively assumed to be about 6 m.

Total predicted outdoor ^{222}Rn concentration (resulting from radon release from the pile) is shown as a function of distance from the center of the pile in a northeasterly direction in Figure 3-7. The predicted ^{222}Rn concentration at 0.1 mi from the edge of the pile is less than 1.2 times the background level.

Figure 3-15 shows the lung cancer risk per year from continuous exposure to radon as a function of distance northeast of the tailings pile. The curve shows that the risk for developing lung cancer from radon emanating from the pile is less than 1.1 times the natural occurrence from all causes at a distance of 0.1 mi from the edge of the pile and declines to the natural occurrence within 0.5 mi.

The population distribution within 4.5 mi of the edge of the pile was developed using 1980 census statistics. This distribution includes virtually all residents close enough to the pile to be noticeably exposed to radon emanating from the pile, as described in Chapter 4.

The three population projections used to estimate the cumulative health impacts attributable to the tailings pile were the 0.8% and 3% constant growth rates and the 8.8% declining growth rate, as discussed in Chapter 4. All three growth projections assume that the population is distributed in the same proportions as that reflected in Table 4-1.

Table 3-3 presents the estimated health impacts from the tailings pile for 0 to 4.5 mi from the edge of the pile, based on the estimated 1980 population distribution presented in Table 4-1. The cumulative health effects for the three growth scenarios considered for Spook are also included. In Table 3-3 the health effects from the pile radon are shown to be much less than 1% of those caused by background radon for the vicinity within 4.5 mi of the edge of the pile. These estimates do not include health effects attributable to operations at the Bear Creek mill but do include health effects among the Bear Creek mill personnel exposed to the hazard from the Spook tailings site.

3.7 NONRADIOACTIVE POLLUTANTS

The tailings pile contains other potentially toxic materials. Chemical analyses of tailings samples from auger holes in the Spook tailings pile showed barium, chromium, and lead in concentrations between 3 and 50 ppm. The highest selenium concentration measured was about 270 ppm; and the arsenic ranged as high as 90 ppm. Vanadium was present in a range of concentrations from 26 to 350 ppm.

Six water samples were taken from the vicinity of the Spook site and chemically analyzed. The analyses of these samples are presented in Table 3-4. The locations of these samples are shown in Figure 3-11. Sample A was obtained from a stagnant pond south of the millsite. Samples B, C, and D were taken from stagnant pools in the streambed of an intermittent stream south of the site. The level of contamination found in these standing waters has been increased due to evaporation. Samples E and F were taken from wells east and south of the site. All of these water samples contained selenium above the EPA Interim Primary Drinking Water Regulations, as high as 30 times the standard. Samples C and D from the streambed contained arsenic above the EPA standards. In addition, all of the samples, except sample D, contained cadmium above the EPA standards.

It has been speculated that high concentrations of selenium in the overburden, resulting in correspondingly high levels of that element in vegetation, were responsible for the deaths of cattle grazing on site about 12 to 15 yr ago.

While there appears to be contamination from the Spook site, it is mainly due to mine waste and not from mill tailings. Most of the tailings have been deposited within the open-pit mine, and precipitation that falls on the tailings is confined mainly to the pit. The possibility of seepage from the pile degrading surface water quality is unlikely because of the distance from the tailings to flowing surface waters and to the other natural sources of contamination.

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 3-3. RADON CANISTER LOCATIONS AND FLUX VALUES

FIGURE 3-4. RADON CONCENTRATION IN VICINITY OF PILE

**FIGURE 3-5. ^{222}Rn AND ATMOSPHERIC TRANSIENTS
 0.4 MI NE OF PILE ON OCTOBER 13, 1976**

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LEGEND

..... FB&D/J WEATHER STATION DATA ↗ WIND DIRECTION (UP=NORTH DOWN=SOUTH)

FIGURE 3-6. ^{222}Rn AND ATMOSPHERIC TRANSIENTS ON PILE ON OCTOBER 12, 1976

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FIGURE 3-7. REDUCTION OF OUTDOOR ^{222}Rn CONCENTRATION WITH DISTANCE FROM THE TAILINGS PILE

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FIGURE 3-8. GAMMA LEVELS 3 FT ABOVE GROUND

FIGURE 3-9. REDUCTION OF EXTERNAL GAMMA RADIATION LEVELS WITH DISTANCE FROM THE TAILINGS PILE

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FIGURE 3-11. SURFACE AND SUBSURFACE RADIUM CONCENTRATIONS

NOTE:
NUMBERS REPRESENT "DELTA"
READINGS AS EXPLAINED IN
PARAGRAPH 3.4.3.

LEGEND

- EDGE OF TAILINGS
- SUDDEN CHANGE IN SLOPE (DOWNWARD)
- OVERBURDEN AND LOW GRADE ORE PILES FROM OPEN-PIT MINE
- TRAVERSE AND MEASUREMENT POINTS
- FENCE
- DIRT ROAD

FIGURE 3-12. WINDBLOWN CONTAMINATION SURVEY

FIGURE 3-13. RADIOMETRIC PROFILE AT DRILL HOLE SW-1

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FIGURE 3-14. RADIOMETRIC PROFILE AT DRILL HOLE SW-3

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FIGURE 3-15. 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 = Protactinium-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 ($1 \text{ WL} = 1.3 \times 10^5 \text{ MeV}$ of alpha energy).
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 FROM WYOMING⁽¹⁾

<u>Isotope (Decay Chain)</u>	<u>Average Value (pCi/g)</u>	<u>Range (pCi/g)</u>
^{226}Ra (^{238}U)	0.99 ± 0.30	0.65 - 1.7
^{232}Th (^{232}Th)	1.21 ± 0.41	0.59 - 1.78
		360-15 12/77

TABLE 3-3

ESTIMATED HEALTH IMPACT FROM SPOOK TAILINGS
FOR AN AREA WITHIN 4.5 MILES OF 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	86	0.0000023	0.0036
2005 (0.8% constant growth rate)	105	0.0000028	0.0043
2005 (3% constant growth rate)	180	0.0000047	0.0075
2005 (8.8% declining growth rate)*	261	0.0000068	0.011

25-Yr Cumulative RDC Health Effects

<u>Growth Projection</u>	<u>Pile-Induced</u>	<u>Background</u>
0.8% constant growth rate	0.000063	0.10
3% constant growth rate	0.000083	0.13
8.8% declining growth rate*	0.00013	0.20

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

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TABLE 3-4

CHEMICAL ANALYSES OF CONVERSE COUNTY WATER SAMPLES (mg/l)

Sample ^a	As	Ba	Cd	Cr	V	Fe	Pb	Se
A - Standing water pond	0.034	0.031	0.023	0.001	0.001	30.0	0.059	0.162
B - Pool, 100 yd upstream from west dry wash	0.029	0.20	0.016	0.001	0.001	1.23	0.001	0.087
C - Pool 300 yd downstream from B	0.096	0.45	0.17	0.062	0.001	0.800	0.001	0.29
D - Pool south of pile	0.053	0.33	0.001	0.001	0.001	0.040	0.001	0.217
E - Artesian well	0.019	0.31	0.015	0.038	0.001	0.130	0.001	0.028
F - Well	0.001	0.19	0.024	0.001	0.001	0.007	0.001	0.019
EPA Interim Primary Drinking Water Regulations ^b	0.05	1.0	0.01	0.05	--	0.3 ^c	0.05	0.01

^aSee Figure 3-11 for locations.

^bFederal Register, Dec 24, 1975

^cRecommended limit from Manual for Evaluating Public Drinking Water Supplies, U.S. Public Health Service, 1969

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CHAPTER 4
SOCIOECONOMIC AND LAND USE IMPACTS

CHAPTER 4

SOCIOECONOMIC AND LAND USE IMPACTS

The Spook tailings and millsite are located in Converse County, Wyoming, in a remote ranching and uranium mining district.⁽¹⁾ The site is approximately 38 mi northwest of Douglas, Wyoming, the county seat. The site is reached by a private gravel road 7 mi from the nearest public access. The boundaries of Converse County are shown in Figure 4-1.

4.1 SOCIOECONOMIC BACKGROUND

Converse County is rich in history of the development of the American West. Many of the pioneer trails, including the Oregon Trail, Mormon Trail, and Pony Express, passed through the county along the North Fork of the Platte River, 30 mi south of the site.

The Spook site is situated in an area where the predominant commerce is cattle ranching, rather than agriculture. There is an abundance of wildlife in the area, including many deer and antelope.

Intensive energy resource development in the county has created new permanent jobs, which, in turn, have stimulated increased population growth. Traditionally, ranching, manufacturing, and the railroads have accounted for most of the production in Converse County. Now, however, mining and construction have definitely taken a prominent position in the socioeconomic makeup of Converse County.

Ethnically, the population of Converse County is predominantly Caucasian. Educational attainment is relatively high, considering its rural nature. Most workers are classified as farmers, farm laborers, craftsmen, managers, service workers, and clericals. Although farmers and farm laborers comprise over 20% of the workforce, they showed a consistent decline in both real numbers and as a percentage of the total workers over the period from 1940 to 1970. Traditionally, Converse County has looked to agriculture, manufacturing, and the railroads for most of its industrial output. Schools, mining, and construction have played a more important role recently in the area's economy.

The recent increase of mining and gas/oil exploration activities in the county has resulted in rapid growth, straining the community's services.

4.2 POPULATION ESTIMATES

The residential population within a 2-mi radius consists of approximately 12 people. Within 4- and 15-mi radii of the site there reside an estimated 22 and 90 people, respectively.

The Bear Creek Mill, 2.5 mi north of the Spook site, employs approximately 235 persons.

Estimates of the 1978 population in relation to the 1970 population are shown below: (2)

	<u>1970</u>	<u>1978</u>	<u>Percent Change</u>
Glenrock Area	1,555	2,700	78.2
Douglas Area	2,677	7,500	180.2
Converse County	5,938	11,700	97.0

As shown in Figure 4-2, population projections over the next 25 yr range from a constant 0.8% growth rate to an 8.8% declining growth rate. The latter would cause the population to double in about 10 yr, and would likely occur only if mineral and energy resources in the area were developed on a large scale. The most likely case is taken to be the 3% constant growth rate; this scenario would result in a maximum population of about 260 in 25 yr. An estimated population of 105 would result by using the 0.8% growth rate, which is representative of the growth in the U.S. as a whole.

For purposes of health effects calculations, the current population within a 4.5-mi radius of the tailings site, including 25% of the employees at the Bear Creek project, was estimated to be about 86. Table 4-1 shows the estimated radial and azimuthal population distribution centered on the tailings site.

4.3 LAND USE

Grazing and mineral-related activities constitute the land use in the Spook area. For example, a new uranium mill is in operation at Bear Creek, just a few miles north of the site. Recent construction of roads, deep wells, and mining facilities indicates a growth in mineral-related activities. There is continual drilling and exploration for minerals in the area. Rocky Mountain Enterprise and Kerr-McGee intend to remove uranium ore to the northern and eastern boundaries of the site. (3) Figure 4-3 reflects land use in the vicinity of the Spook site.

4.4 IMPACT OF THE TAILINGS ON LAND VALUES

The site and the areas surrounding it are all in private ownership with usage being for ranching purposes. Ranchers have leased portions of this land for mineral and oil/gas development.

The area occupied by the tailings is minimal compared with the areas of the open pit, overburden, and mine waste. However, the presence of the tailings has necessitated the fencing of the entire site which, in turn, has prevented the site from being used for livestock grazing. If the tailings were not present, there would be no change in land use and values in the surrounding area. According to nearby residents, land values for typical grazing land are approximately \$100/acre for surface rights only.⁽³⁾

FIGURE 4-1. MAP OF CONVERSE COUNTY BOUNDARIES

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FIGURE 4-2. POPULATION PROJECTIONS

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FIGURE 4-3. VICINITY LAND USE

360-15 REV 3/81

TABLE 4-1

ESTIMATED 1980 POPULATION DISTRIBUTION

<u>Distance (mi)</u>	<u>Direction</u>	<u>Population</u>
1.5	SSW	12
2.5	N	59*
3.0	S	10
4.5	WNW	5
		<hr/>
Total		86

*This is 25% of the number of employees at the Bear Creek Mine, which accounts for the fact that they are at this location about 25% of the time.

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CHAPTER 4 REFERENCES

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CHAPTER 5
RECOVERY OF RESIDUAL VALUES

CHAPTER 5

RECOVERY OF RESIDUAL VALUES

The Spook Mill operated by the Wyoming Mining and Milling Company is believed to have been the first to have operated entirely on a pelletized heap leach process. The method is described in the Phase II Engineering Assessment report.⁽¹⁾ The plant recovered about 80% of the uranium in the ore processed, leaving 187,000 tons of tailings on the site, which contain 0.023% U_3O_8 based on AEC records of plant operation. The results of analyses on a composite sample of the tailings taken in 1977 are given in Table 5-1. The analyses indicate that there are no other metals of economic significance in the tailings. The uranium analysis, at 0.013% U_3O_8 is not in good agreement with the calculated uranium content based on plant records, and indicates the need for more comprehensive sampling if serious consideration were to be given to reprocessing the tailings. The vanadium assay was 0.035% V_2O_5 . As the following analysis shows, the low concentrations of uranium and vanadium together with the small quantity of tailings on the site make the prospects unfavorable that additional metals can be recovered profitably, unless it can be done at one of the operating mills in the vicinity.

No amenability tests were performed on Spook tailings to determine the recovery of uranium or vanadium that could be achieved in a reprocessing operation. In the absence of specific testing, the estimate of uranium recovery from retreatment of the tailings is based on the graph provided by DOE's Grand Junction Office, as shown in Figure 5-1. For the purpose of this chapter it is assumed that the uranium content of 0.023% U_3O_8 indicated by AEC records is correct. It is expected that recovery of uranium by a conventional process will be about 43% or 0.20 lb U_3O_8 per ton of tailings. By pelletizing with acid and heap leaching, recovery would be about 35% or 0.16 lb per ton. By normal heap leaching, the recovery would be about 25% or 0.12 lb. At November 1980 prices of \$28/lb of U_3O_8 , the total income from uranium recovery would be \$3.40 to \$5.60/ton processed. Vanadium was not recovered from ores processed at Spook. The composite tailings sample contains 0.035% V_2O_5 . The vanadium in the Spook tailings, based on a sales price of \$3/lb for V_2O_5 and an assumed recovery rate of about 40%, would produce income of about \$0.80/ton treated, which is too low to consider recovery.

5.1 PROCESS ALTERNATIVES

There are three principal alternatives for reprocessing the Spook tailings:

- (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 ft thick. The surface of the tailings then is contoured into shallow basins to contain the leach solution. An acid solution, sometimes with oxidant added, is allowed to flow into the surface basins and 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 that can be achieved with this method is highly dependent upon the porosity, the uniformity of the ore on the pad, and the extent of channeling. Because of these factors, recovery of values is considerably lower (roughly half) than by conventional plant processes, as shown in Figure 5-1. Since there is a heap leach facility very close to the millsite, no new construction would be needed.

In the second method the ore, crushed to minus 0.75-in. size, is premixed with a strong sulfuric acid solution and pelletized before being placed for leaching. Water is percolated through the bed, and the recovered solution is processed to recover the solubilized uranium and vanadium. If vanadium is to be recovered, a higher concentration of acid is required than if the tailings are being processed only for 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 as a result of 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 depends on whether or not the pelletized tailings retain their shape or disintegrate when flooded in the leaching operation. The past history of the Spook operation indicates this should not be a problem. Recovery of values in the pelletized heap-leach process is unlikely to exceed two-thirds of that in a conventional plant.

5.1.2 Treating in an Existing Plant

For reprocessing in an existing conventional plant to be economically feasible, a mill with significant excess capacity must be located reasonably close to the present tailings site. The mill also must have a tailings disposal site with sufficient capacity to handle the additional tailings and to allow for adequate long-term stabilization. In addition to the 187,000 tons of tailings, there is a very large quantity of contaminated waste at the Spook site, mainly overburden from previous mining operations adjacent to the mill as well as the open pit.

The site has fair access. Trucks could remove material from the site at a rate of about 500 tons/day. At this rate, all tailings materials could be removed from the site in about 1.5 yr. The tailings are inclined against the steep sidewall of the pit, and not in an easy location for clean removal. There are two operating mills within about 12 mi of the Spook site, and one of these is only 2.5 mi away.

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 Spook tailings would feed a 500 ton/day plant for about 1.5 yr. Normally, amortization of a plant is based on planned operation for 10 to 20 yr. The Department of Energy's studies report large reserves of ore in the \$30/lb of U_3O_8 category in the adjacent area. The potential resources are also high. This indicates that the prospects of development of significant new reserves to augment the ore supply to such a mill are very good.⁽⁷⁾

5.2 SPOOK 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 U_3O_8 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 U_3O_8 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 U_3O_8 , representing nearly 3 times the current annual consumption rate. Projected domestic uranium supply exceeds apparent buyer requirements each year through 1985.⁽⁴⁾ Under these circumstances, no basis is evident for a turnaround in uranium prices for about 5 yr.⁽³⁾ The supply and market for uranium as estimated by the DOE Assistant Secretary for Resource Applications are 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 that time, 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⁽⁶⁾ publishes reports quarterly on various construction cost indexes. The following data are derived from this source:

	Avg Index 1977	<u>Latest Reported</u> Date (1980)	<u>Index</u>	<u>Percent Increase</u>
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 500 ton/day heap-leach facility would be about \$4.8 million. For a conventional mill of similar capacity the cost, as indicated in Figure 5-3, would be about \$6 million. If these capital costs were to be amortized on the Spook tailings only, the unit costs would be \$25.70 to \$32.10/ton, or about \$160/lb of U₃O₈ recovered. These capital costs for new plant construction simply highlight the fact that there is not a large enough supply of tailings on which to amortize construction of any processing facility. The best possibility for economic reprocessing would be as incremental feed to an existing nearby mill.

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 December 1977 Engineering Assessment report, the direct operating costs of a 500 ton/day facility were estimated at \$3.25 and \$5.80/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 the cost of heap leaching 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 plant designs, it is estimated that average mill operating costs have increased by a factor of 2.5 from the January 1977 costs to mid-1980. This would result in operating costs for Spook tailings in a new 500 ton/day conventional plant of about \$17.50/ton, or \$87.50/lb of U_3O_8 recovered (assuming 0.2 lb recovered/ton). For a heap-leach plant of the same size, the corresponding figures would be \$15.60/ton and \$97.50/lb recovered. If the tailings were processed as a small part of the feed of an existing nearby mill and were considered incremental feed not bearing capital or overhead charges the operating cost might be on the order of \$8/ton, or \$40/lb of U_3O_8 . Such treatment could become economically feasible in the near future.

5.2.4 Competitive Market Factors

The average grade ore processed in conventional mills has decreased from 0.15% U_3O_8 in 1977 to 0.11% in 1979. The average recovery rate for the industry has been $91 \pm 1\%$ 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, about 5 times as much Spook tailings material would have to be processed as would when a mill is operating on ore of the average grade treated in 1979. Thus, the volume of tailings to be stabilized is also 5 times as great. The fact that there are no mining costs is a substantial off-setting advantage. In addition, there is a good possibility that additional ore will be found in the vicinity of the site.

5.3 CONCLUSION

Based on the foregoing analysis, it is concluded that the processing of Spook tailings for the recovery of additional uranium and vanadium in connection with the tailings stabilization might be economically feasible if they could be treated as supplementary feed to a nearby operating mill, provided the price of uranium returns to the levels of 1978-1979. Erection of a new plant solely for the Spook tailings would not be practicable, as the quantity available is insufficient. For processing this material, assuming a new plant of about 500 tons/day capacity, the cost of the uranium recovered would be about \$125 to \$164/lb of U_3O_8 , depending on the process used. A comparison of costs by process method is given below.

	Conventional Plant		New Plant Heap Leach		Existing Conventional Plant	
	<u>\$/ton</u>	<u>\$/lb U₃O₈</u>	<u>\$/ton</u>	<u>\$/lb U₃O₈</u>	<u>\$/ton</u>	<u>\$/lb U₃O₈</u>
Capital Cost	32.10	160.50	25.70	160.00	0.00	0.00
Operating Cost	<u>17.50</u>	<u>87.50</u>	<u>15.60</u>	<u>97.50</u>	<u>8.00</u>	<u>40.00</u>
Total	49.60	248.00	41.30	257.50	8.00	40.00

The combination of the quantity and grade of the Spook tailings is so low that construction of facilities for reprocessing is not feasible. Vanadium recovery is unattractive and will not improve the economics of reprocessing.

The spot market price for uranium in September 1980, when these economic analyses were prepared, was \$28.50/lb of U₃O₈. Since that time, construction costs have continued to rise, while the spot market price for uranium has declined to about \$25/lb of U₃O₈ 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

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

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TABLE 5-1

ASSAY RESULTS OF SPOOK TAILINGS AND BACKGROUND SAMPLES

Percentage by Weight				
<u>Element</u>	<u>Atomic Absorption</u>	<u>Spectrographic</u>	<u>Chemical</u>	<u>AEC* Estimate</u>
Aluminum	--	>1.0	--	--
Arsenic	0.0087	--	--	--
Barium	0.0046	--	--	--
Cadmium	0.000035	--	--	--
Chromium	0.0026	--	--	--
Cobalt	0.00067	--	--	--
Copper	0.0014	<0.01	--	--
Cyanide	<0.000001	--	--	--
Iron	1.53	>1.0	--	--
Lead	0.00025	<0.01	--	--
Magnesium	--	>1.0	--	--
Manganese	--	1.0-0.01	--	--
Mercury	<0.00000002	--	--	--
Potassium	--	>1.0	--	--
Selenium	0.0262	--	--	--
Silicon	--	>1.0	--	--
Silver	0.00022	--	--	--
Sodium	--	>1.0	--	--
Titanium	--	1.0-0.01	--	--
Uranium (U ₃ O ₈)	--	--	0.013	0.023
Vanadium (V ₂ O ₅)	0.0026	1.0-0.01	0.035	--
Zinc	0.0031	--	--	--

*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)
	Sales Commitments		Est. U ₃ O ₈ To Be Available For Sale	Procure- ment of Foreign Uranium	Reported Unfilled Requirement	Total Domestic Production Potential (1+2+3)	Total Domestic Supply (1+3+4)	Apparent Buyer Requirements (1+4+5)
Year	To Domestic Buyers	To Foreign Buyers						
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 alternative 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 the Spook site, precipitation averages about 13 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
- (n) 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. Those locations where tailings have been transported off site are discussed in this chapter. 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, i.e., windblown, tailings pile, millsite, and ore storage, are considered in Chapter 9.

7.1 DATA SOURCES

The remoteness of the tailings pile makes it unlikely that tailings have been removed from the site for any purpose. R.T. Hornbuckle, the owner of the site, is unaware of any specific instance where tailings have been removed. A quonset hut and miscellaneous equipment exhibiting low-level radioactivity have been relocated to the Hornbuckle Ranch.⁽¹⁾

The gamma survey and ^{226}Ra 5-pCi/g boundary mentioned in Paragraphs 3.4.2 and 3.4.3 were the data sources for consideration of remedial action for windblown areas.

7.2 REMEDIAL ACTION FOR OFF-SITE PROPERTIES OTHER THAN WINDBLOWN

There are no off-site locations, other than windblown, where tailings have been relocated that require remedial action.

7.3 REMEDIAL ACTION FOR OFF-SITE WINDBLOWN PROPERTIES

The estimated extent of windblown tailings is indicated by the 5-pCi/g line in Figure 3-12. Decontamination of the area containing windblown tailings consists of removing 6 in. of soil. The result of this action is assumed to satisfy remedial action criteria as discussed in Paragraph 3.5.

The cost for cleanup and restoration of approximately 11 acres of off-site land contaminated by windblown tailings is estimated to be \$50,000, exclusive of engineering and contingency costs.

CHAPTER 7 REFERENCES

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CHAPTER 8
DISPOSAL SITE SELECTION

CHAPTER 8

DISPOSAL SITE SELECTION

At the time of the December 1977 engineering assessment report it was thought that the Spook tailings pile would be stabilized in place, as opposed to being transported to an off-site disposal location. No disposal sites were identified in the original report, and no effort was expended during the July 1980 field work to identify alternate disposal sites.

While disposal of the tailings at an alternative disposal site is not considered essential, it is included in this report to provide a means of comparison between the cost of stabilizing the tailings in place and that of moving them to an unspecified disposal site, as well as to facilitate comparisons between this report and similar reports for other mill tailings sites. Disposal at unspecified sites located at 5, 10, and 15 mi from the Spook tailings site was considered in this evaluation.

Presently proposed regulations require 3 m of cover for the disposal of tailings. While coarse-grained soils will occur in areas where sandstones are predominant, soils in this area are predominantly deep to moderately deep, well drained, fine loamy to fine textured soils.⁽¹⁾ The fine-grained soils in the area are a potential source for cover. Another source would be the fine-grained mining overburden/waste. This source is available where uranium-bearing sandstones are locally separated by shales, siltstones, and claystones.⁽²⁾ While most of the waste piles at the site appear to be fairly coarse grained, waste from neighboring areas may be available.

It is felt that cover material could be obtained within 2 mi of the pile from local soils.⁽³⁾ If mining waste were to be used, a closer examination of the local mines would be necessary. If a source were found, it would eliminate the necessity to disturb the local soils.

Gravels are very scarce in this area; therefore, the local mining companies build their haul roads without gravel. However, there is a gravel pit 20 mi away in Township 35 North, Range 71 West,⁽⁴⁾ and other pits are located along the North Platte River. Hauls from these pits would be from 40 to 45 mi. With an in-depth field search, local scoria pits might be found closer to the site. The relative locations of sources of cover material to actual disposal sites will impact the costs.

Transportation, site preparation, and maintenance costs are discussed more fully in Chapter 9.

The tailings may be stabilized in the open pit adjacent to their present location.

CHAPTER 8 REFERENCES

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CHAPTER 9

REMEDIAL ACTIONS AND COST-BENEFIT ANALYSES

CHAPTER 9

REMEDIAL ACTIONS AND COST-BENEFIT ANALYSES

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.

Since each state where tailings are located must participate in funding for remedial action, it is fair to assume that there will be very strong pressures to assure that costs will be limited to a moderate total.

Remedial actions designed to meet the EPA interim and proposed remedial action criteria were investigated. As outlined in Chapter 8, three unspecified disposal sites were considered and were evaluated in terms of the cost of disposal. Actual disposal sites will have specific and unique characteristics that must be considered in estimating costs, and great care must be exercised in the use of these typical cost estimates. The unspecified disposal sites have been characterized in typical terms for the purpose of estimating site development costs.

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

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

The options for disposal at the alternative sites would provide for the relocation of all tailings and contaminated materials from the tailings pile and windblown area. Thus, in all of the disposal options, the entire site and windblown area would be left free of any tailings or contaminated materials due to the tailings in excess of the allowed 5 pCi/g of ^{226}Ra above background. The area to be decontaminated at the Spook site is shown in Figure 9-1.

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

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

9.1.1 Conceptual Design

Stabilization of the Spook tailings near the present site is a viable option, due in part to the isolated location of the present tailings pile and presence of an open pit. In preparing the cost estimate for this option, the possible problem of migration of contamination via unconfined 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 be placed in the mine pit adjacent to the tailings pile. Contaminated materials from the windblown area and millsite would also be placed in the pit. The walls of the pit would be scraped to remove tailings that were spilled over the side.

The tailings would be leveled at the bottom of the pit and stabilized with a minimum of 3 m of cover material, which has been shown to be adequate under certain conditions to reduce flux to less than 2 pCi/m²-s. Existing fine-grained mine overburden would be used to stabilize the pile.

9.1.2 Costs

As shown in Table 9-1, the cost for stabilization at the Spook site is estimated to be \$710,000. Costs include disposing of all tailings and contaminated material from windblown and millsite areas at the bottom of the mine pit and covering all contaminated materials with a minimum of 3 m of cover, contouring the surface and providing a riprap cover for erosion control.

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

Options II through IV would provide for the complete removal of all tailings, millsite rubble, and windblown contaminated soil to unspecified disposal sites. The amount of subsoil to be removed depends on the depth of contamination. Removal to averages of 2 ft of subsoil beneath the tailings at the millsite and 6 in. of soil at windblown areas is assumed to reduce apparent residual radium concentration to less than the allowed 5 pCi/g above background levels.

9.2.1 Excavation and Loading of Tailings and Soils

Due to the steepness of the tailings pile spilled down the side of the open pit, excavation will be difficult and costly. The tailings that cannot be loaded at the millsite will be scraped from the side of the mine pit and loaded at the bottom of the pit.

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

No special treatments of the past excavated surface, other than establishing native grass cover at the decontaminated tailings site, are considered in this assessment.

9.2.2 Transportation of the Materials

Railroad transportation is not possible for tailings transport since there are no rail facilities in the vicinity of the tailings site.

Slurry pipeline transportation was not considered feasible due to the lack of water in the area and the small volume of materials to be transported. Similarly, the use of conveyors was considered infeasible because of the small volume of materials.

If tailings were removed at a rate of about 1,200 tons/day, working 5 days/wk, all contaminated materials could be removed in less than 8 mo. This method assumes the use of conventional 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 costs associated with hauling tailings and riprap material. Capital costs include development and maintenance of access roads whenever such roads are required.

9.2.3 Disposal at Alternative Sites

A discussion of unspecified disposal sites is given in Chapter 8. Specific disposal sites might have physical, geological, and hydrological characteristics different from those assumed. Thus, actual costs could be different from those estimated in this report.

Unspecified disposal sites are located within 15 mi of the tailings pile. Vegetation covers 40% or less in the vicinity of the site, and the average annual rainfall at all disposal areas is less than 8 in. The cost estimates for each option include the construction of 3 mi of gravel-based road surface sufficient to handle the heavy loads.

It was assumed that disposal of the tailings will be below grade. The excavation procedure would involve removing cover material for the site in a strip-mining operation, placing the tailings, and covering them with previously removed cover material to a depth of at least 3 m.

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

The estimated costs for the disposal options are shown in Table 9-1 and range from about \$1,510,000 for Option II to about \$1,950,000 for Option IV.

The range in cost is due to differences among costs associated with tailings transportation. Consequently, the overall differences among cost estimates are largely dependent on the distance from the tailings site to the disposal site.

Costs for health physics and radiological monitoring are included in individual component costs (Table 9-1, lines 1 through 5). Such costs reflect approximately 8 to 17% of the total cleanup costs (line 6).

In Options II through IV the estimated costs include cleanup of the millsite, windblown area, and tailings pile; disposing of all tailings and contaminated materials at the disposal site and covering with 3 m of cover material; and 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) resulting from the remedial action. In Chapter 3 the estimated number of health effects was determined for the Spook tailings pile in its 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 pile 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 3.6.2) to the required flux of 2 pC/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 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 numbers of potential cancer cases avoided per million dollars expended were calculated and plotted in Figure 9-2. Option I yields the maximum health benefit per unit cost, whereas Option IV yields the minimum benefit per unit cost.

9.3.2 Land Value Benefits

The remedial action options as proposed would have no effect on land value because of the remoteness of the area, the land scars on the site, and the seemingly unlimited availability of similar but untouched land in the vicinity.

FIGURE 9-1. AREA DECONTAMINATION PLAN

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

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TABLE 9-1

SUMMARY OF STABILIZATION AND DISPOSAL COSTS^a

	Options			
	I	II	III	IV
1. Tailings Site	380	160	160	160
2. Off-Site Other than Windblown	--	--	--	--
3. Off-Site Windblown	50	50	50	50
4. Transportation				
a. Capital Costs	--	100	105	110
b. Haul Costs	--	260	390	570
5. Disposal Site	--	390	390	390
6. Total Cleanup ^b (sum of lines 1 through 5)	420	950	1,100	1,280
7. Engineering Design and Construction Management (30% of the difference between lines 6 and 4b)	130	210	210	210
8. Total ^b (sum of lines 6 and 7)	550	1,160	1,310	1,500
9. Contingency (30% of line 8)	160	350	390	450
10. GRAND TOTAL ^b (sum of lines 8 and 9)	710	1,510	1,700	1,950

^aCosts are presented in thousands 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
Option Cost (million \$)	0.71	1.5	1.7	2.0
Years After Remedial Action				
25	<0.000083	0.000083	0.000083	0.000083
50	<0.00020	0.00020	0.00020	0.00020
75	<0.00032	0.00032	0.00032	0.00032
100	<0.00043	0.00043	0.00043	0.00043

B. Cost Per Potential Cancer Case Avoided (Million \$)				
Options:	I	II	III	IV
Option Cost (million \$)	0.71	1.5	1.7	2.0
Years After Remedial Action				
25	>8,554	18,072	20,482	24,096
50	>3,550	7,500	8,500	10,000
75	>2,219	4,688	5,313	6,250
100	>1,651	3,488	3,954	4,651

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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/ $\text{m}^2\text{-s}$)

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/m²-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.