**PHASE II - TITLE I
ENGINEERING ASSESSMENT OF
INACTIVE URANIUM MILL TAILINGS**

**SHIPROCK SITE
SHIPROCK, NEW MEXICO**

MARCH 31, 1977

MASTER

PREPARED FOR

**U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
GRAND JUNCTION, COLORADO**

CONTRACT NO. E(05-1)-1658

BY

Ford, Bacon & Davis Utah Inc.

375 CHIPETA WAY, SALT LAKE CITY, UTAH 84108 • 801 - 583-3773

SINCE 1894

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

LEGAL NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

PHASE II - TITLE I
ENGINEERING ASSESSMENT OF
INACTIVE URANIUM MILL TAILINGS

SHIPROCK SITE
SHIPROCK, NEW MEXICO

March 31, 1977

Prepared For

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
GRAND JUNCTION, COLORADO

Contract No. E(05-1)-1658

By

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

FB&DU 130-01

87
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

FOREWORD

This report entitled, "Phase II - Title I Engineering Assessment of Inactive Uranium Mill Tailings, Shiprock Site, Shiprock, New Mexico" was prepared under the U.S. Energy Research and Development Administration (ERDA) Contract No. E(05-1)-1658. It is one of a series of reports on inactive uranium millsites that addresses the radiological problems and estimated costs of remedial measures that would reduce exposure of the general public. Chapter 1 of this report is a summary and is published under separate cover for those not requiring all the details of this report.

Ford, Bacon and Davis Utah Inc. (FB&DU) under supplemental authorization currently is investigating uranium mill tailings stabilization techniques. This research could modify some of the estimated costs in this report.

Also, FB&DU acknowledges the excellent cooperation and assistance given in this engineering assessment. Particular recognition is due the ERDA personnel of both the Germantown, Md., and Grand Junction, Co. offices and also the Union Carbide Corporation personnel of the Health Physics Division, Oak Ridge National Laboratory, who provided field radiological measurements and radon diffusion modeling. The preparation of this report could not have been accomplished without the cooperation and assistance of FB&DU's subcontractor, the Center for Health and Environmental Studies at Brigham Young University, Provo, Utah, and also of the following:

- (1) The Environmental Protection Agency for consultation, data, and information from prior surveys and studies, with notable assistance from the Office of Radiation Programs, Las Vegas, Nevada.
- (2) The Navajo Tribal Council.
- (3) Navajo Environmental Protection Commission -- Mr. Daniel Peaches, Chairman, and Mr. Harold Tso, Executive Director.
- (4) Navajo Engineering and Construction Authority.
- (5) The Indian Health Service, Office of Environmental Health, USPHA -- especially Mr. Donald W. Mantay, Senior Sanitary Engineer; and the Bureau of Indian Affairs, Navajo Area, Mr. Harold Zutxies, Environmental Service Officer.
- (6) The New Mexico Environmental Improvement Agency.
- (7) Dr. Victor E. Archer, Western Area Occupational Health Laboratory, National Institute for Occupational Safety and Health, Salt Lake City, Utah.

- (8) Local government officials, Shiprock Chapter residents and business personnel in the Shiprock neighborhood.
- (9) EG&G, Las Vegas, Nevada; Mr. Jack Doyle, for aerial photography.

ABSTRACT

Ford, Bacon and Davis Utah Inc. has performed an engineering assessment of the problems resulting from the existence of radioactive uranium mill tailings at Shiprock, New Mexico. The Phase II, Title I services include the preparation of topographic maps, the performance of core drillings and radiometric measurements sufficient to determine areas and volumes of tailings and other radium-contaminated materials, the evaluation of resulting radiation exposures of individuals and nearby populations, the investigation of site hydrology and meteorology and the evaluation and costing of alternative corrective actions.

Radon gas release from the 1.7 million tons of tailings at the Shiprock site constitutes the most significant environmental impact, although windblown tailings and external gamma radiation are also factors. The 11 alternative actions presented range from completion of the present ongoing EPA site decontamination plan (Option I), to stabilizing in-place with varying depths of cover material (Options II-IV), to removal to an isolated long-term disposal site (Options V-XI). All options include remedial action costs for off-site locations where tailings have been placed. Costs estimates for the 11 options range from \$540,000 to \$12,500,000.

Reprocessing the tailings for uranium is not economically feasible.

CONTENTS

<u>Chapter</u>	<u>Title</u>	<u>Page</u>
	Foreword	ii
	Abstract	iv
	List of Figures	xi
	List of Tables	xiv
	Glossary	xv
1	SUMMARY	
1.1	Introduction	1-1
1.1.1	Background	1-2
1.1.2	Scope of Phase II Engineering Assessment	1-3
1.2	Site Description	1-5
1.2.1	Location and Topography	1-5
1.2.2	Ownership and History of Milling Operations and Processing	1-5
1.2.3	Present Condition of the Site	1-6
1.2.4	Tailings and Soil Characteristics	1-7
1.2.5	Geology, Hydrology, and Meteorology	1-7
1.3	Radioactivity and Pollutant Impacts on the Environment	1-8
1.3.1	Radiation Exposure Pathways, Contamination Mechanisms, and Background Levels	1-8
1.3.1.1	Radon Gas Diffusion and Transport	1-9
1.3.1.2	Direct Gamma Radiation	1-9
1.3.1.3	Windblown Contaminants	1-9
1.3.1.4	Ground and Surface Water Contamination	1-10
1.3.1.5	Soil Contamination	1-10
1.3.2	Remedial Action Criteria	1-10
1.3.3	Potential Health Impact	1-11
1.3.4	Nonradioactive Pollutants	1-13

CONTENTS (Cont)

<u>Chapter</u>	<u>Title</u>	<u>Page</u>
1.4	Socioeconomic and Land Use Impacts	1-14
1.5	Recovery of Residual Values	1-14
1.6	Mill Tailings Stabilization	1-15
1.7	Off-Site Remedial Action	1-15
1.8	Long-Term Storage Site Selection	1-15
1.9	Remedial Actions and Cost-Benefit Analyses	1-16
	1.9.1 Remedial Action Options	1-16
	1.9.2 Cost-Benefit Analyses	1-17
	Chapter 1 References	1-26
2	SITE DESCRIPTION	
2.1	Location	2-1
2.2	Topography	2-1
2.3	Ownership	2-2
2.4	History of Milling Operations and Processing	2-2
2.5	Present Condition of the Site	2-3
2.6	Tailings and Soil Characteristics	2-5
2.7	Geology, Hydrology, and Meteorology	2-5
	2.7.1 Geology	2-5
	2.7.2 Surface Water Hydrology	2-5
	2.7.3 Ground Water Hydrology	2-6
	2.7.4 Meteorology	2-7
	Chapter 2 References	2-18
3	RADIOACTIVITY AND POLLUTANT IMPACT ON THE ENVIRONMENT	
3.1	Radioactive Material Characteristics	3-1
3.2	Radiation Effects	3-2
3.3	Natural Background Radiation	3-3
3.4	Radiation Exposure Pathways and Contamination Mechanisms	3-3
	3.4.1 Radon Gas Diffusion and Transport	3-4
	3.4.2 Direct Gamma Radiation	3-5
	3.4.3 Windblown Contaminants	3-6
	3.4.4 Ground and Surface Water Contamination	3-7

CONTENTS (Cont)

<u>Chapter</u>	<u>Title</u>	<u>Page</u>
	3.4.5 Soil Contamination	3-7
	3.4.6 Off-Site Tailings Use	3-8
3.5	Remedial Action Criteria	3-8
3.6	Potential Health Impact	3-9
	3.6.1 Assumptions and Uncertainties in Estimating Health Effects .	3-11
	3.6.2 Health Effects	3-12
3.7	Nonradioactive Pollutants	3-13
	Chapter 3 References	3-35
4	SOCIOECONOMIC AND LAND USE IMPACTS	
	4.1 Socioeconomic Background	4-1
	4.2 Population Estimates	4-1
	4.3 Land Use	4-3
	4.4 Impact of the Tailings on Land Values	4-4
	Chapter 4 References	4-10
5	RECOVERY OF RESIDUAL VALUES	
	5.1 Process Alternatives	5-1
	5.1.1 Heap Leaching	5-1
	5.1.2 Treating in an Existing Plant	5-2
	5.1.3 Treating in a New Mill	5-2
	5.2 Shiprock Recovery Economics	5-2
	5.2.1 Recovery	5-2
	5.2.2 Reprocessing Costs	5-3
	5.3 Assessment of Shiprock Mineral Recovery Potential	5-3
	Chapter 5 References	5-11
6	MILL TAILINGS STABILIZATION	
	6.1 Prevention of Wind and Water Erosion	6-1

CONTENTS (Cont)

<u>Chapter</u>	<u>Title</u>	<u>Page</u>
	6.1.1 Chemical Stabilization of the Surface	6-1
	6.1.2 Complete Chemical Stabilization	6-2
	6.1.3 Physical Stabilization	6-3
	6.1.4 Vegetative Stabilization . . .	6-3
	6.2 Prevention of Leaching	6-4
	6.3 Reduction of Radon Exhalation	6-4
	6.4 Reduction of Gamma Radiation	6-5
	6.5 Assessment of Applicability	6-5
	Chapter 6 References	6-8
7	OFF-SITE REMEDIAL ACTION	
	7.1 Data Sources	7-1
	7.2 Remedial Action for Structures	7-1
	7.3 Remedial Action for Open Lands	7-2
	Chapter 7 References	7-4
8	LONG-TERM STORAGE SITE SELECTION	
	8.1 Criteria for Long-Term Storage	8-1
	8.2 General Description of Disposal Site Areas	8-1
	8.3 Return to Original Mine Sources	8-2
9	REMEDIAL ACTIONS AND COST-BENEFIT ANALYSES	
	9.1 Minimal Remedial Action (Option I) . .	9-1
	9.1.1 Security and Maintenance	9-2
	9.1.2 Resulting Impacts	9-2
	9.1.3 Costs	9-2
	9.2 Stabilization of the Tailings On Site, 2-Ft Cover (Option II)	9-3
	9.2.1 Security and Maintenance	9-3
	9.2.2 Resulting Impacts	9-3
	9.2.3 Costs	9-4
	9.3 Stabilization of the Tailings On Site, 4-Ft Cover (Option III)	9-4
	9.3.1 Security and Maintenance	9-5
	9.3.2 Resulting Impacts	9-5

CONTENTS (Cont)

<u>Chapter</u>	<u>Title</u>	<u>Page</u>
	9.3.3 Costs	9-5
9.4	Stabilization of the Tailings On Site, 13-Ft Cover (Option IV)	9-5
	9.4.1 Costs	9-5
9.5	Removal of Tailings and all Contaminated Materials from the Site (Options V-XI)	9-6
	9.5.1 On-Site Structures and Facilities	9-6
	9.5.2 Excavation and Loading of Tailings and Soils	9-6
	9.5.3 Backfill	9-7
	9.5.4 Transportation of the Material	9-7
	9.5.5 Disposal and Storage at Alternative Sites	9-7
	9.5.5.1 Option V - Many Devils (Site No. 2)	9-8
	9.5.5.2 Option VI - Shiprock Campground (Site No. 1)	9-9
	9.5.5.3 Option VII - Rattlesnake (Site No. 5)	9-10
	9.5.5.4 Option VIII - Salt Creek Area (Site No. 8)	9-10
	9.5.5.5 Option IX - Oil Field (Site No. 6)	9-11
	9.5.5.6 Option X - Hogback (Site No. 4)	9-12
	9.5.5.7 Option XI - Within an Operating Open-Pit Coal Mine (Site No. 7)	9-13
9.6	Analyses of Costs and Benefits	9-14
	9.6.1 Health Benefits	9-14
	9.6.2 Land Value Benefits	9-16

Appendix

A

REMEDIAL ACTION CRITERIA

A.1	Surgeon General's Guidelines	A-1
A.2	Radiological Criteria for Decontamination of Inactive Uranium Mill Sites	A-6

CONTENTS (Cont)

<u>Appendix</u>	<u>Title</u>	<u>Page</u>
A.3	Grand Junction Remedial Action Criteria (10CFR12)	A-9
B	SHIPROCK EPA DECONTAMINATION RECOMMENDATIONS	
B.1	Recommendations for the Decontami- nation of Uranium Mill Sites on the Navajo Reservation	B-1
B.2	EPA Status Report on Evaluation of Inactive Uranium Mill Sites; March, April, and May 1976	B-9

LIST OF FIGURES

<u>Number</u>	<u>Title</u>	<u>Page</u>
2-1	Aerial Photograph of Site	2-8
2-2	Topographic Map	2-9
2-3	Descriptive Map	2-10
2-4	Cross-Section at Stations 15+00 and 24+50	2-11
2-5	Surface Drainage Patterns	2-12
2-6	Probable Direction of Ground Water Flow .	2-13
2-7	Simplified Stratigraphic Cross-Section .	2-14
2-8	Prevailing Wind Map	2-15
3-1	Radioactive Decay Chain of Uranium 238 .	3-15
3-2	Locations for ^{226}Ra Background Samples .	3-16
3-3	Radon Concentration in Vicinity of Piles	3-17
3-4	^{222}Rn and Atmospheric Transients at 0.46 Mi NW of Piles on February 26, 1976	3-18
3-5	^{222}Rn and Atmospheric Transients at Storeroom of NECA Office on February 28, 1976	3-19
3-6	Reduction of Outdoor ^{222}Rn Concentration with Distance from the Tailings Piles . .	3-20
3-7	Gamma Levels 3 Ft Above Ground	3-21
3-8	Gamma Levels in Vicinity 3 Ft Above Ground	3-22
3-9	Reduction of External Gamma Radiation Levels with Distance from the Tailings Piles	3-23
3-10	EPA Gamma Survey Surrounding Millsite . .	3-24
3-11	Surface and Subsurface Radium Concentrations	3-25
3-12	Radiometric Profile at Drill Hole SRNM-23	3-26
3-13	Radiometric Profile at Drill Hole SRNM-15	3-27

LIST OF FIGURES (Cont)

<u>Number</u>	<u>Title</u>	<u>Page</u>
3-14	Lung Cancer Risk from Continuous Exposure to Radon Diffusion	3-28
4-1	Map of Navajo Political Jurisdictions . .	4-6
4-2	Map of Population Centers	4-7
4-3	Population Projections	4-8
4-4	Vicinity Land Use Patterns	4-9
5-1	Uranium Recovery from Mill Tailings as a Function of U_3O_8 Content in Tailings .	5-5
5-2	Operating Costs of Heap Leaching of Uranium Mill Tailings Containing 0.01 to 0.05% U_3O_8 with Uranium Recovery from 20 to 35%	5-6
5-3	Operating Costs of Conventional Milling W/O Crushing and Grinding Facilities to Reprocess Tailings Containing 0.01 to 0.05% U_3O_8 with Uranium Recovery Ranging from 35 to 60%	5-7
5-4	Construction Costs of Heap Leaching Plant to Reprocess Uranium Mill Tailings Containing 0.01 to 0.05% U_3O_8 with Uranium Recovery 20 to 35%	5-8
5-5	Construction Costs of a Conventional Uranium Mill W/O Crushing and Grinding Facilities to Reprocess Tailings Containing 0.01 to 0.05% U_3O_8 with Uranium Recovery Ranging from 35 to 60%	5-9
6-1	Reduction of Radon Exhalation Flux with Depth of Cover Material	6-6
6-2	Reduction of Gamma Exposure Rate Resulting from Packed Earth Shielding . .	6-7
8-1	Proposed Disposal Sites	8-3
9-1	Radium Activity Concentration in Contaminated Subsoil	9-17
9-2	Schematic of Typical Long-Term Tailings Storage Site	9-18

LIST OF FIGURES (Cont.)

<u>Number</u>	<u>Title</u>	<u>Page</u>
9-3	Potential Cancer Cases Avoided per Million Dollars Expended	9-19

LIST OF TABLES

<u>Number</u>	<u>Title</u>	<u>Page</u>
1-1	Summary of Conditions Noted at Time of Phase I Site Visits	1-19
1-2	Summary of Remedial Action Options, Costs, and Effects	1-21
2-1	Tailings Materials	2-16
2-2	Physical Properties and pH of the Uranium Tailings Samples	2-17
3-1	Notations and Abbreviations used in Chapter 3	3-29
3-2	Background Radiation Sources in Soil in Northwest New Mexico	3-30
3-3	Radon Exhalation Flux for Shiprock Piles	3-31
3-4	Radioactive Airborne Particulate Concentrations Near the Site	3-32
3-5	Estimated Health Impact from Shiprock Tailings for an Area 0-1.5 Miles from Tailings Edge	3-33
3-6	Chemical Analyses of Shiprock Water Samples (mg/l)	3-34
5-1	Assay Results of Composite Tailings Samples	5-10
8-1	Sites Evaluated as Repositories for the Shiprock Tailings	8-4
9-1	Cost Estimate Summary	9-20
9-2	Potential Cancer Cases Avoided and Cost per Potential Cancer Case Avoided . . .	9-21

GLOSSARY

Abbreviations/Terms

Definitions

absorbed dose

Radiation energy absorbed per unit mass

A-E

Architect-Engineering

AEC

Atomic Energy Commission

alpha particle (α)

A positively charged particle emitted from certain radioactive material. 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 radiation (α, β, γ), hence is not dangerous unless alpha-emitting substances have entered the body.

amenability

The relative ease with which a mineral(s) can be removed from an ore by a particular process

anomaly (mobile gamma survey)

Any location where the recorded counts per second (c/s) exceed the determined background for that location by 50 or more c/s (as defined in EPA report EPA-520/6-74-006)

aquifer

A water-bearing formation below the surface of the earth; the source of wells

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 radia-

tion can cause skin burns and beta-emitters are harmful if they enter the body.

BEIR	Biological Effects of Ionizing Radiation
BIA	Bureau of Indian Affairs
BOM (USBOM)	Bureau of Mines
CHES	Center for Health and Environmental Studies, Brigham Young University, Provo, Utah
Ci	Curie (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 atom (parent) has undergone 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).
EGR	External gamma radiation (gamma radiation emitted from a source(s) external to the body, as opposed to internal gamma radiation emitted from ingested or inhaled sources)
EPA (USEPA)	Environmental Protection Agency
ERDA (USERDA)	Energy Research and Development Administration
ERDA-GJO	Energy Research and Development Administration-Grand Junction Office
erg	The basic unit of work or energy in the centimeter-gram-second system (One erg is equal to 7.4×10^8 ft-lb.)

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.
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	High energy electromagnetic radiation emitted from the nucleus of a radioactive atom, with specific energies for the atoms 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 to pollutants from tailings (In this report, one health effect is defined as one case of lung cancer produced from inhalation of radioactive materials.)
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
IHS	Indian Health Service

insult	Negative impact on the environment or the health of individuals
Interim Drinking Water Standards (EPA)	Title No. 40 of the Code of Federal Regulations, Chapter 1, Part 141, dated Dec 24, 1975; scheduled to become effective Jun 24, 1977
iso-exposure line	A line drawn on a map to connect all points having the same exposure rate
isotope	One of two or more 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 of Atomic Energy
knot	A unit of velocity, approximately equal to 1.15 mi/hr
μ R/hr	Microroentgen per hour
mR/hr	Milliroentgen per hour
MeV	Million electron volts
MPC	Maximum permissible concentration (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
NECA	Navajo Engineering and Construction Authority
NEPC	Navajo Environmental Protection Commission
NIOSH	National Institute for Occupational Safety and Health
NMEIA	New Mexico Environmental Improvement Agency

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
PHS (USPHS)	Public Health Service
QF	Quality factor (an assigned factor which denotes the modification of the effectiveness of a given absorbed dose by the linear energy transfer)
R	Roentgen (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)
rad	The basic unit of absorbed dose of ionizing radiation. A dose of one 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 1,600 yr. Radium is present in all uranium-bearing ores. Trace quantities of both uranium and radium are found in all areas, contributing to the gamma background.
radon	A radioactive, chemically inert gas, having a half-life of 3.8 days (^{222}Rn); formed as a daughter product of radium (^{226}Ra)
radon background	Low levels of radon gas found in an area, due to the presence of uranium or radium in the soil
radon concentration	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.)
RDC	Radon daughter concentration (the concentration in air of short-lived radon daughters, expressed usually in pCi/l; also measured in terms of working level (WL))
radon flux	The quantity of radon emitted in a unit time per unit area (typical units are in pCi/cm ² -sec)
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

(Acronyn of roentgen equivalent man)
The unit of dose 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 what remains in tailings after the uranium (or other mineral) has been removed

riprap

An irregular wall of broken rock, placed as a retaining wall, as a protection for dikes, etc.

sands

Relatively coarse-grained materials produced along with the slimes as waste products of uranium mills (see tailings). These sands normally contain less radioactive material than the slimes.

scintillometer

A radiation detection instrument used for monitoring small changes in background and for low-level radiation, normally utilizing a NaI crystal as a scintillator

slimes

Extremely fine-grained materials, mixed with small amounts of water, produced along with the sands as waste products of uranium mills (see tailings). Most of the radioactive material remaining in tailings is found in the slimes.

tailings

The remaining portion of a metal-bearing ore after the metal, such as uranium, has been extracted. Tailings also may contain other minerals or metals not extracted in the process (e.g. radium).

WL

Working level. 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.

WLM

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

CHAPTER 1

SUMMARY

CHAPTER 1

SUMMARY

1.1 INTRODUCTION

The U.S. Energy Research and Development Administration (ERDA) has contracted with Ford, Bacon & Davis Utah Inc. (FB&DU) of Salt Lake City, Utah, to provide architect-engineering services in the assessment of the problems resulting from the existence of large quantities of radioactive uranium mill tailings at the sites of inactive mills in eight western states.

A preliminary survey (Phase I) was carried out by ERDA in cooperation with EPA and the affected states and completed in October 1974. In the Summary Report⁽¹⁾, ERDA identified 17 sites in Arizona, Colorado, Idaho, New Mexico, Utah, and Wyoming for which practical remedial measures are to be evaluated. Subsequently, ERDA added five additional sites (Riverton and Converse County, Wyoming; Lakeview, Oregon; Falls City and Ray Point, Texas) to the list for a total of 22 sites. Most of these mills produced by far the greatest part of their output of uranium under contracts with the U.S. Atomic Energy Commission (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.

To date, the studies of radiation levels on and in the vicinity of these sites have been limited in scope. The data available were insufficient to permit assessment of risk to people with any degree of confidence in the conclusions reached. In addition, information on practicable measures to reduce radiation exposures and estimates of their projected costs are completely lacking. The purpose of this study is to develop the necessary information to provide a basis for decision-making for appropriate remedial actions for each of these sites.

In assessing the significance of the conditions existing at the Shiprock site, evaluations of the following factors were included:

- (a) Exhalation of radon gas from the tailings
- (b) On-site and off-site direct radiation
- (c) Land contamination from windblown tailings

(1) See end of chapter for references.

- (d) Hydrology and contamination by water pathways
- (e) Potential health impact
- (f) Potential for extraction of additional metals from the tailings

Investigation of these and other factors led to the detailed evaluation of 11 potential practical alternatives that were evaluated in detail. These may be placed within three main categories:

- (a) Minimum remedial action, which amounts to completion of the stabilization program now in progress
- (b) Stabilization designed for long-term storage of tailings in their current location
- (c) Removal of the tailings to alternative sites suitable for long-term storage and stabilization

The estimated costs of carrying out the remedial work to implement each option depend on such parameters as the degree of decontamination to be achieved, and the degree of stabilization necessary.

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 and appropriate remedial action to limit the exposure of individuals to radiation from uranium mill tailings.

Dr. William D. Rowe, testifying in behalf of the Environmental Protection Agency (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.

*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.

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 piece-meal 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 summarized the conditions at the time of the Phase I visits.⁽¹⁾ Based on the findings presented in the 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 had been selected to provide the architect-engineering (A-E) services for Phase II. ERDA's Grand Junction, Colorado, office (GJO) was authorized to negotiate and administer the terms of a contract with FB&DU. The contract was effective on June 23, 1975. The Salt Lake City Vitro site was assigned as the initial task, and work began immediately. Work on the Shiprock site began on February 3, 1976.

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 the assessment made for Title I requirements and was prepared by FB&DU and its subcontractor, the Center for Health and Environmental Studies (CHES), at Brigham Young University. The Oak Ridge National Laboratory (ORNL) at Oak Ridge, Tennessee, under separate agreement with ERDA, provided measurements of the radioactivity concentrations in the soil and water samples, gamma

surveys, and modeled the radon diffusion from the pile. The EPA staff provided the results of radiation surveys they previously had made at the Shiprock site.

The specific scope requirements of the Title I assessment are:

- (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 costs.
- (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 to which mill tailings containing radium can be moved for long-term (>50 years) storage; and once such sites are identified, perform evaluation 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) Investigation of site hydrology and meteorology.
- (l) Evaluation of recovering residual values, such as uranium and vanadium in the tailings and other residues on the sites.
- (m) Performance of demographic and land use studies. Investigation of community and area planning, and industrial and growth projections.
- (n) Evaluation of the alternative corrective actions for each site in order to arrive at recommendations, estimated costs, and socioeconomic impact based on population and land use projections.
- (o) Preparation of preliminary plans, specifications, and cost estimates for alternative corrective actions for each site.

1.2 SITE DESCRIPTION

1.2.1 Location and Topography

The Shiprock site is a 230-acre tract on the south side of the San Juan River as it passes through the town of Shiprock, New Mexico, on the Navajo Indian Reservation. This site and its relationship to the surrounding area are shown in the aerial photo in Figure 2-1, Chapter 2. The country generally is arid and desertlike, with low rolling hills and occasional steep ridges and mesas. Vegetation is sparse except for the irrigated lands which usually abut the river. The elevation of the site is about 5,000 ft above sea level.

1.2.2 Ownership and History of Milling Operations and Processing

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

Before and during the milling operations the site was leased from the Navajo Tribe. When the Foote Mineral Company's lease

expired in 1973, full control of the site reverted to the Navajo Nation.

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

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

1.2.3 Present Condition of the Site

Figure 2-3, Chapter 2, is a descriptive map of the site as it now exists. The tailings are located in two adjacent piles and cover approximately 72 acres. The upper (north) pile covers 26 acres and varies from 14 to 40 ft in height. This pile has been stabilized with from 0.5 to 2 ft of pit-run soil and gravel, and some natural plant growth has taken root. This upper pile has resisted wind erosion. The dikes built along the pile face which abuts the San Juan River have prevented the spread of the tailings to the river as a result of water erosion. The lower (south) pile occupies 46 acres and is approximately 15 ft in height. It contains the contaminated material which has been removed from the mill and the ore storage areas during recent decontamination efforts. The lower pile is not stabilized, but it is covered with material from decontamination activities of NECA on site. It is relatively flat on top and a broadcast irrigation system has been installed in an attempt to reduce wind erosion. A cross-section of the site is shown in Figure 2-4, Chapter 2.

After mill operations ceased in 1968, some of the buildings and equipment were dismantled and buried in the tailings and washes. Several buildings and building shells were left standing and still remain. At the time of this writing the old mill building was being dismantled.

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

In 1973, however, the Navajo Tribe already had authorized the Navajo Engineering and Construction Authority (NECA) to use the site as a training school to instruct Navajo students in the operation of earthmoving machinery. NECA is headquartered at the site and uses the buildings for administration, classroom, shop, and storage purposes. At the time of the EPA survey, the NECA training program was utilizing (in part) the tailings piles for practice in earthmoving techniques. Therefore, the EPA decontamination plan specified that the NECA training program would include the removal of the contaminated soil, with earthmoving equipment, from areas surrounding the piles and placement of these materials on the piles. All buildings were to be decontaminated, as well as the entry road, and parking and ore storage areas. An interim stabilization cover of 6 in. of earth was to be placed on the lower pile and containment dikes were to be constructed. The plan was based on 10 tasks involving input from the Navajo Environmental Protection Commission (NEPC), Indian Health Service (IHS), New Mexico Environmental Improvement Agency (NMEIA), as well as from the EPA and NECA as described above. As of this writing the plan is approximately 80% complete. There are several work items in the plan yet to be accomplished (i.e. fencing and off-site decontamination). These items are the essential components of Option I. (Refer to Table 1-2.)

1.2.4 Tailings and Soil Characteristics

Several types of material make up the Shiprock tailings; a combination of uranium and vanadium tailings, dike material, rubble, and stabilization cover of pit-run gravel. Bulk densities range between 82.0 and 106.8 lb/ft³. Borings and samples taken from the piles indicate that the tailings were not uniformly deposited in the tailings ponds. There are approximately 1.7 million tons of tailings on the site. As given in Table 2-1, Chapter 2, the total of all material (dikes, tailings, rubble, stabilization cover, and contaminated earth) approximates 2.2 million tons. The soil on the site is a combination of decomposed shale and a conglomerate of river-deposited sand and cobbles with a maximum dimension of up to 12 in.

1.2.5 Geology, Hydrology, and Meteorology⁽²⁾

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

Underlying much of the tailings are up to 10 ft of terrace deposits that form a layer between the Mancos Shale and the tailings. This material has been deposited over a long period of time on the benchland by the San Juan River when it flowed at a higher level. The material is poorly sorted and ranges in size from 12-in. boulders to sand and silt-size particles which are cemented together in places. The Mancos Shale directly below this alluvium is at least several hundred feet thick. A simplified stratigraphic cross-section is illustrated in Figure 2-7, Chapter 2.

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

The confined ground water aquifers underlying the site are protected against contamination by both an upward pressure gradient and thick impermeable strata, and there is no possibility of contamination of these aquifers from the tailings. There is a potential for further contamination of the terrace gravel immediately underlying the tailings piles if sufficient water is allowed to collect and percolate through sections of the piles. However, reshaping of the surface of the piles can prevent the collection of rainwater in a single area.

The strongest winds at Shiprock are from the west and northwest, and transport of material by winds from these directions is away from population centers and over farmlands. The effect of stabilization cover on the upper pile has been to reduce the deposition of the tailings off site.

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 because the radium and thorium, principal contributors to radioactive emissions, were not normally removed from the uranium ores during milling. The principal environmental radiological impact and associated health effects arise from the ^{230}Th , ^{226}Ra , ^{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.

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 the ^{222}Rn daughters. This exposure affects the lungs. For this assessment, no criteria have been established for radon concentrations in air. However, the pathway for radon and radon daughters accounts for a 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 which 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 with the ERDA-supplied continuous radon monitors at 12 locations in the vicinity of the Shiprock tailings piles. The locations and values of the radon measurements are shown in Figure 3-3, Chapter 3. One set of measurements on the upper pile indicated an average radon concentration of 12.8 pCi/l for a 24-hr period. Measurements in the NECA office and training buildings averaged about 7 pCi/l for 24 hr.

No background measurements of radon in the atmosphere were available prior to the measurements performed during this assessment. Four 24-hr measurements of atmospheric radon at locations from 0.78 to 3 mi from the tailings site indicated an average background concentration of 0.77 pCi/l.

Radon daughters measured by ORNL personnel⁽³⁾ in the NECA office building concurrently with the FB&DU measurements ranged from 0.006 to 0.02 WL.

1.3.1.2 Direct Gamma Radiation

The range of natural background values in the Shiprock area was between 6 and 13 $\mu\text{R/hr}$ as measured by ORNL. A value of 13 $\mu\text{R/hr}$ currently is being used by EPA as the average gamma radiation background level for remedial action at the Shiprock site.⁽⁴⁾ Above the surface of the tailings piles, gamma readings ranged from 30 to over 300 $\mu\text{R/hr}$. This could be reduced to near-background levels by a cover of approximately 2 ft of sand and gravel.

1.3.1.3 Windblown Contaminants

Measurements of radioactive airborne particulates were performed at several locations around the Shiprock tailings site by EPA, Office of Radiation Programs, Las Vegas Facility (ORP-LVF), during a 7-mo period in 1974.⁽⁴⁾ The concentrations of

all the isotopes measured were below the most restrictive maximum permissible concentrations given in 10CFR20.

Windblown tailings are present primarily to the southwest of the site. An isoexposure line due to residual windblown tailings is illustrated in Figure 3-10, Chapter 3.

1.3.1.4 Ground and Surface Water Contamination

Water samples were obtained from two surface locations and three locations along the San Juan River. No water was found in any of the holes drilled through the tailings piles to investigate subsoil contamination. Water from a pond near the ore storage area contained 2.0 pCi/l of dissolved ^{226}Ra . (3) A dissolved ^{226}Ra concentration of 3.5 pCi/l was measured in a water sample taken from a stagnant pond at the base of the shale bluff at the northeast corner of the tailings site. These figures compare with the EPA Drinking Water Standards of 5 pCi/l total maximum concentration of ^{226}Ra and ^{228}Ra .

1.3.1.5 Soil Contamination

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

1.3.2 Remedial Action Criteria

Radiological criteria established for this engineering assessment are divided into two general categories:

- (a) Criteria applicable to structures with tailings underneath them or within 10 ft
- (b) Criteria pertaining to the mill tailings site and open land

The criteria utilized for habitable structures are the guidelines published by the Surgeon General of the United States for use in the Grand Junction, Colorado, remedial program. These guidelines recommend graded levels (based on yearly average values) for remedial action in terms of the external gamma radiation (EGR) levels and of the indoor radon daughter concentration (RDC) levels above background found within dwellings constructed on or near uranium mill tailings. (In this usage, the word "external" refers to gamma radiation from sources outside the human body to which an individual may be exposed.)

The recommended graded levels are as follows:

<u>EGR</u>	<u>RDC</u>	<u>Recommendations</u>
Greater than 0.1 mR/hr*	Greater than 0.05 WL	Remedial action indicated
From 0.05 to 0.1 mR/hr	From 0.01 to 0.05 WL	Remedial action may be suggested
Less than 0.05 mR/hr	Less than 0.01 WL	No remedial action indicated

*1 mR/hr = 1,000 μ R/hr

The criteria for land decontamination have the objective to reducing residual gamma radiation to levels which are as low as practicable. However, topographic and economic considerations frequently preclude complete decontamination. A provisional maximum of 40 μ R/hr above background is used in such circumstances. Average background in the Shiprock area was determined in this study to be 9 μ R/hr. As a guideline for the land beyond the site, if residual gamma levels are less than 10 μ R/hr above background, the land may be released for unrestricted use. Where cleanup is necessary the radium content of the soil should be reduced to no more than twice the radium background in the area. If the radioactive tailings material is stabilized in place, the same criteria apply but control of gamma radiation would be by an earth covering. However, the area should be designated a controlled area, be fenced to limit access, and be restricted as to human occupancy. The numerical guidelines provide a basis for the engineering assessment, but are subject to review based on the overall findings of Phase II. Therefore, the cost of decontamination to different levels is included in the study.

The radium and gross alpha content of ground and surface water should meet applicable state and federal standards.

1.3.3 Potential Health Impact

Radon gas exhalation from the piles and the subsequent inhalation of radon daughters account for most of the total dose to the population in a zone of 0.5 to 1.5 mi from the Shiprock site under present conditions. The gamma radiation exposure from the piles is virtually zero past 0.4 mi. Only five houses and the NECA

training facility are within 0.5 mi from the perimeter of the piles, and the population density between 1.0 and 1.5 mi from the piles is very low.

Gamma radiation can be reduced effectively by shielding with any dense material. However, experience has shown that it is very difficult to control the movement of radon gas through porous solid 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 piles. If the diffusion path can be made long enough, then, theoretically, substantially all the radon and its daughter products can be made to decay before escaping to the atmosphere. Calculations using the techniques of Kraner, Schroeder, and Evans⁽⁵⁾ indicate that 13 ft of earth cover theoretically would be required to reduce the radon diffusion from the Shiprock tailings by 95%. This depth of cover would approximate the same amount of material as the quantity of tailings and other contaminated material on the site.

The health significance to man of long-term exposure to radiation is a subject that has been studied extensively for many years. Since the end results of long-term exposure to low-level radiation are usually diseases such as lung cancer or leukemia, which also are 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 exposed to radon and its daughters in mine air, and 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, 1 health effect = 1 case of lung cancer.) This is the basis of the health effects calculations 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 report).⁽⁶⁾ This report presents risk estimators for lung cancer derived from epidemiological studies of both uranium miners and fluorspar miners. The average of the absolute risk estimator for these two groups is: 6 cancers per year per 10^6 person-WLM exposure. The term WLM means working level month, or an exposure to a concentration of 1 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 nor with the parent radon. Because of the many factors which contribute to natural biological variability, and of the many differences between exposure conditions in mines and residences, this estimator is considered to have an uncertainty factor of about 3.

For the purpose of the mill tailings 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 measurements of radon concentrations in excess of background values, it is calculated that the radon-induced lung cancer risk due to the piles in the area within 1.5 mi from the Shiprock site is 4.5×10^{-5} per person per year, or less than half the Navajo Nation's average risk due to all causes.

The 25-yr health effects were calculated for three population projections using a present population of 2500 in the 0.5 to 1.5 mi area. There is an insignificant number of people living within 0.5 mi from the site. The results for pile-induced Rn and background Rn were as follows:

<u>Case No.</u>		<u>Cumulative 25-yr Health Effects</u>	
		<u>Pile Rn</u>	<u>Background Rn</u>
1	2.5% annual population growth	3.9	3.0
2	4% annual population growth	4.8	3.7
3	7% annual population growth	7.3	5.6

Pile-induced radon daughter health effects are approximately 130% of the background radon daughter health effects for the same area. The exposure and consequent risk will continue for so long as the radiation source remains in its present location and condition.

1.3.4 Nonradioactive Pollutants

There are other potentially toxic materials in the tailings. Chemical analyses of tailings samples from drill holes on the Shiprock tailings piles showed arsenic, barium, vanadium, and

lead in concentrations between 100 and 600 ppm. The highest selenium, cadmium, and chromium concentrations were 52 ppm, 2 ppm, and 15 ppm, respectively. Iron concentration was as high as 14,700 ppm. Samples from stagnant water in the Shiprock ore storage area contained concentrations of arsenic 10 times the maximum allowable concentration for drinking water, and selenium 60 times the maximum allowable. However, there was no measurable increase in selenium found in the San Juan River below the millsite. Samples taken upstream and downstream from the millsite indicated increased concentrations of arsenic, iron, cadmium, and lead in the river below the site. The arsenic and lead additions are small and the resulting contents in the river are below EPA drinking water standards. The cadmium and iron additions are relatively large, and the impurity levels of these two minerals upstream from the tailings are substantially above the recommended EPA drinking water standards. Consequently, removal of the tailings would not upgrade the environmental quality of the San Juan River substantially, nor increase its potential uses.

1.4 SOCIOECONOMIC AND LAND USE IMPACTS

Because all Reservation land is owned commonly by the Navajo Tribe there is no conventional valuation for Navajo properties. However, there are several criteria that might be used to assess the value of the site land. For example, recent exchanges of Tribal land for off-Reservation land is one basis. Lease payments for Navajo lands is another; comparisons with similar use off-Reservation land is another criterion. Also, even more important is that Shiprock has been designated by Tribal authorities to be one of five Navajo communities with the greatest potential for primary growth. It is expected to absorb much of the growth impact of the Navajo Irrigation Project, proposed coal gasification plants, and oil exploration and development activities. If the Tribe's efforts to attract industry succeed, the expansion of agriculture and increased mineral activity will produce pressures to develop the tailings site area for industrial and commercial use. Since the location of the tailings site is adjacent to an industrial park along the San Juan River, near U.S. Highway 666 and near the new Shiprock airport, the site would be worth from \$50/acre to \$3500/acre depending on its use.

1.5 RECOVERY OF RESIDUAL VALUES

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

There are, however, five factors that can be employed to evaluate whether reprocessing the Shiprock tailings to extract residual uranium and other 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

Based on the aforementioned criteria, reprocessing of the Shiprock tailings does not appear to be a practical economic consideration at this time.

1.6 MILL TAILINGS STABILIZATION

Present practices and technology of mill tailings stabilization are being examined. This investigation indicates that much research and development remains to be performed before complete and permanent stabilization of radioactive mill tailings can be realized.

Reasonably effective means of wind and water erosion control are available, although they will involve continued maintenance costs. Lining of containment areas or chemical solidification of the tailings are possible methods for control of leaching.

Up to this time, no attempt has been made to contain radon in a tailings pile. Although a thick earth cover is theoretically effective, it has not actually been tried. The observed variability of radon exhalation rates indicates that with better understanding of the mechanism involved, control may be possible.

1.7 OFF-SITE REMEDIAL ACTION

A mobile scanning unit performed a gamma radiation survey of the Shiprock area in 1971. Nine anomalies above the background criteria were discovered. Ore was found and removed from one location. Three locations had tailings more than 10 ft from a structure and were not considered further. Tailings were found within 10 ft of four houses and the last location was a former ore buying station. Since the mobile survey, an additional location was found with elevated gamma and working level measurements. The latter six locations will be considered for remedial action based upon more complete measurements. A sum of \$80,000 has been included in the various remedial action options to cover possible off-site remedial work.

1.8 LONG-TERM STORAGE SITE SELECTION

Seven of the alternative remedial action options include moving the Shiprock tailings to a long-term (greater than 50 yr) storage site. The sites were selected after consultation with officials of the Navajo Environmental Protection Agency, the State of New

Mexico, the Indian Health Service and the Bureau of Indian Affairs. Each site was evaluated on the basis of hydrology, meteorology, geology, ecology, economics, and proximity to population centers.

The sites referred to in Table 1-2 under Options V through XI are shown on a map in Figure 8-1, Chapter 8. In each of these options, surface material would be removed and stockpiled, and a retaining dike and diversion ditches would be constructed if necessary. The tailings would be emplaced, contoured and covered with a 2-ft cover from the stockpiled material, and fenced. One option would make use of an operating, open-pit coal mine as a long-term storage site. In all options except the coal mine, continuing maintenance would be required to repair fences and erosion of the cover material. These annual maintenance costs have been provided for by a sinking fund in costing each option.

1.9 REMEDIAL ACTIONS AND COST-BENEFIT ANALYSES

1.9.1 Remedial Action Options

The remedial options examined cover a range from: (a) simply continuing to decontaminate areas in and around structures, fencing the site, and cleaning up contaminated material at the ore storage yard (a program now in process, described in paragraph 1.2.3); to (b) removal of all radioactive materials to an area where they could be isolated from the public.

The options for which cost estimates were made include three levels of stabilization on the present site and the removal of tailings to seven possible locations, all within a 26-mi radius of the Shiprock site. The options are summarized in Table 1-2.

The base case, from which the cost and effectiveness of other remedial alternatives can be judged, is the first option examined. Option I would leave the site essentially in its present condition, or as it would remain after NECA completes the work it currently is executing under the EPA interim remedial action program. The work accomplished to date under this program has resulted in the significant consolidation of contamination associated with the site in its former condition. This option covers the additional work necessary to complete that program. It also provides for off-site remedial action and the cost of fencing the tailings. This option would reduce direct exposure. It would also temporarily reduce wind and water erosion with a 6-in. cover on the lower pile, but there would be little reduction of radon gas exhalation from the tailings.

Option II adds to Option I the costs for more completely stabilizing the upper pile and the lower pile with 2 ft of cover. Wind and water erosion of the tailings could be controlled; however, radon exhalation would be reduced very little. The site still would be unsuitable for most uses. Option III involves the reshaping of the two piles to create one pile with resultant

slopes that are less steep, and stabilization with 4 ft of cover. Option IV is the same as Option III except that 13 ft of cover would be provided.

Eight sites were evaluated as possible repositories for the tailings. Of these, the seven most promising were evaluated in detail, including preparation of cost estimates. (See Figure 8-1, Chapter 8.) The Exxon Corporation has an exploration lease from the Navajo Nation which could lead to the possible mining and processing of uranium ore on a portion of the Navajo Reservation. Within the lease area, a combined storage site might be possible both for the Shiprock tailings and the Exxon mill tailings. However, it is not possible at this time to evaluate such a speculative situation. Most of the disposal sites suggested are within the exploration area.

The two lowest cost alternative sites would make excellent repositories for the tailings. The Many Devils site rarely is used for grazing and appears to be an isolated semidump. This site has the advantage of being close to the Shiprock site, but the disadvantage of being closest to human habitation.

The Salt Creek site has all the advantages of the Many Devils site except for haul distance. It would involve very low radiation exposure to man and presently is used as grazing land.

The Hogback site in the area east of Shiprock is very isolated and would involve very low radiation to man. Its principal disadvantage is cost. The 16-mi haulage distance makes the cost about 60% more than for sites closer to Shiprock.

The option providing for the disposal of tailings in a mined-out area of an open-pit coal mine would provide a storage area which would most isolate the tailings from humans. The 26-mi haul distance is a large cost factor. In addition, site availability and the timing of placement are problems that would have to be addressed.

Security fencing around the tailings is included in all options except Option XI. Heavy-duty chainlink fencing is costed, but extensive repair or replacement costs might make alternative types of fencing worth considering.

1.9.2 Cost-Benefit Analyses

As summarized in Table 1-2, the total estimated costs for the 11 remedial action options vary from \$540,000 to \$12,500,000. Each of these costs would yield a distinct health and monetary benefit. The number of cancer cases avoided per million dollars expended for each option is given in Figure 9-3, Chapter 9. The option numbers are identified as follows:

<u>Option</u>	<u>Description</u>
I	Minimal remedial action
II	Stabilization at the Shiprock site
III	Optimized long-term stabilization at the Shiprock site, 4 ft of earth cover
IV	Long-term stabilization at the Shiprock site, 13 ft of earth cover
V	Removal to Many Devils area
VI	Removal to Shiprock Campground area
VII	Removal to Rattlesnake area
VIII	Removal to Salt Creek area
IX	Removal to Oil Field area
X	Removal to Hogback area
XI	Removal to an operating, open-pit coal mine

The curves in Figure 9-3, Chapter 9, indicate an increase in the health benefit/cost ratio with time due to the increasing number of health effects avoided.

The potential cancer cases avoided for each option and the cost per potential cancer case avoided are given in Table 9-2, Chapter 9.

TABLE 1-1
SUMMARY OF CONDITIONS NOTED AT TIME OF PHASE I SITE VISITS

	Cond. of Tailings	Cond. of Structures on Site	Mill Housing	Adequate Fencing, Posting, Security	Property Close by River or Stream	Houses- Industry w/in 1/2 Mile	Evidence of Wind Water Erosion	Possible Water Contami- nation	Tailings Removed for Pri- vate Use	Other Hazards On-site
<u>ARIZONA</u>										
Monument	U	R	N	No	No	Yes	No	No	No	No
Tuba City	U	PR-UO	E-O	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	No	No	Yes	No
Gunnison	S	B-O	N	Yes	No	Yes	No	Yes	No	No
Maybell	S	R	N	Yes	No	No	No	No	No	No
Naturita	S	PR-O	E-P	Yes	Yes	No	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	No	Yes	Yes	Yes	No	No	No
Slick Rock (UCC)	S	R	E-P	Yes	Yes	Yes	No	No	No	No
<u>IDAHO</u>										
Lowman	U	R	N	No	Yes	Yes	No	No	Yes	No
<u>NEW MEXICO</u>										
Ambrosia Lake	U	PR-O	N	Yes	No	No	Yes	No	No	No
Shiprock	P	PR-O	E-O	Yes	Yes	Yes	No	No	Yes	Yes
<u>OREGON</u>										
Lakeview	U	M-UO	N	Yes	No	Yes	Yes	No	No	No
<u>TEXAS</u>										
Falls City	P	M-UO	N	Yes	No	No	No	No	No	No
Ray Point	P	M-UO	N	Yes	No	No	No	No	No	No

TABLE 1-1 (Cont)

	Cond. of Tailings	Cond. of Structures on Site	Mill Housing	Adequate Fencing, Posting, Security	Property Close by River or Stream	Houses- Industry w/in 1/2 Mile	Evidence of Wind Water Erosion	Possible Water Contami- nation	Tailings Removed for Pri- vate Use	Other Hazards On-site
<u>UTAH</u>										
Green River	S	B-O	N	Yes	No	Yes	Yes	Yes	No	No
Mexican Hat	U	B-O	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	No	No	No	No	No	No	No

(1) S - Stabilized but requires improvement

P - Partially stabilized

U - Unstabilized.

(2) M - 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.

(3) N - None

E - Existing

O - Occupied

P - Part occupied.

TABLE 1-2
SUMMARY OF REMEDIAL ACTION OPTIONS, COSTS, AND EFFECTS

OPTION NUMBER	COST * (\$000)	DESCRIPTION OF REMEDIAL ACTION	BENEFITS	ADVERSE EFFECTS
I	540	The work plan for the decontamination of the Shiprock uranium millsite would be completed with the exception of the stabilization of the lower pile. The pile configuration would remain basically as is. NECA would continue to occupy the site and security fencing would be installed.	A B C	L M N O P Q
II	1,100	The work of Option I would be augmented by the stabilization of the lower pile by covering it with 2 ft of earth, the addition of soil stabilization cover on the upper pile on its steep slopes, the construction of containment dikes around the pile, and the rerouting of drainage around the pile in order to isolate the pile from the area of water runoff.	A B C D E	M O P Q
III	1,600	The two piles would be graded together into one pile with resulting slopes that would be less steep in order that the 4 ft stabilization cover would be more permanent and provide greater resistance to water and wind erosion. This cover would provide enough protection to reduce gamma radiation to background levels. Grading would isolate the pile hydrologically. Fencing would be required. A 4 ft of cover would reduce radon exhalation by 30%.	A B C D E G J	O P Q

*All costs are in 1976 dollars

TABLE 1-2 (Cont)

OPTION NUMBER	COST * (\$000)	DESCRIPTION OF REMEDIAL ACTION	BENEFITS	ADVERSE EFFECTS
IV	3,400	Option IV is the same as Option III except that a 13 ft cover would be provided which would reduce radon exhalation by 95%.	A D J B E C G	P Q
V	5,800	The tailings and contaminated soil and rubble would be moved by truck from the site to the general area of the Many Devils Wash and stabilized with 2 ft of cover. A 6-ft chainlink security fence would be installed. Haul distance is 4 mi.	A F B G C H D I E	M Q
VI	6,100	The tailings and contaminated soil and rubble would be moved by truck from the site to the area of Shiprock campground and stabilized with 2 ft of cover. A 6-ft chainlink security fence would be installed. Haul distance is 6.75 mi.	A F B G C H D E	M Q
VII	6,900	The tailings and contaminated soil and rubble would be moved by truck from the site to the general area of the Rattlesnake Wash oil field area. They would be stabilized with 2 ft of cover and a 6-ft chainlink security fence would be installed. Haul distance is 8.25 mi.	A F B G C H D I E	M Q
VIII	7,000	The tailings and contaminated soil and rubble would be removed by truck from the site to the general area known as the Salt Creek Wash area, north and slightly east of the town of Shiprock. They would be stabilized with 2 ft of cover and a 6-ft chainlink security fence would be installed. Haul distance is 8.5 mi.	A F B G C H D I E	M O

TABLE 1-2 (Cont)

OPTION NUMBER	COST * (\$000)	DESCRIPTION REMEDIAL ACTION	BENEFITS	ADVERSE EFFECTS
IX	7,200	The tailings and contaminated soil and rubble would be moved by truck from the site to an area approximately 8.5 haul mi south and east of Shiprock. The area is about 1 mi east of the new Shiprock airport in the vicinity of some oil field pumping and storage operations. There are several natural horseshoe-shaped basins in the area which could be adapted for long-term tailings storage. The tailings would be covered with 2 ft of earth cover and a 6-ft chainlink security fence would be installed.	A F B G C H D I E	M Q
X	12,000	The tailings and contaminated soil and rubble would be moved by truck from the site to the general area west of the base of the Hogback Mountains, southeast of the town of Shiprock. Here the tailings would be isolated. They would be stabilized with 2 ft of cover. Fencing would be required, but maintenance would be at a minimum. Haul distance is 16 mi.	A G B H C I D J E F	M Q
XI	12,500	The tailings and contaminated soil and rubble would be removed by truck from the site to an operating open-pit coal mine northeast of the site. They would be buried in the waste areas of the mine. Haul distance is 26 mi.	A G B H C I D J E K F	none

TABLE 1-2 (Cont)

NOTES *All costs are in 1976 dollars

1. For all cost options, the cost includes off-site remedial action, and decontamination of the water supply line which fed the mill water tanks.
2. For all cost options, the decontamination of the office, classroom, old shop, and one other old storage building is included.
3. For cost options No. V to XI, the cost to remove an average of 2 ft of subsoil below the tailings area is included in the basic cost. This would reduce residual radium concentrations in the subsoil to twice background values. The additional cost to reduce these concentrations to background levels are given in Chapter 9 of the report. The cost of backfill to surrounding grade levels is also included in Chapter 9.

Definitions of Benefits

- A. Off-site structures decontaminated
- B. Access to the site controlled by fencing and posting
- C. Off-site windblown tailings cleaned up
- D. Wind and water erosion controlled
- E. Gamma radiation reduced
- F. The source of gamma radiation and radon gas removed from the area
- G. No building restrictions on or near the site
- H. The prime use of the final disposal location unchanged
- I. Disposal site maintenance required only on a limited basis; no possibility of contaminating air or water supplies
- J. A reduction in rate of radon exhalation depends on thickness of cover material
- K. Maintenance and fencing eliminated

TABLE 1-2 (Cont)

Definitions of Adverse Effects

- L. Little or no decrease in gamma radiation
 - M. Little or no reduction of radon gas emissions
 - N. No wind or water erosion control
 - O. Building restriction in the vicinity
 - P. Limited use of the property
 - Q. Maintenance required indefinitely
-

CHAPTER 2
SITE DESCRIPTION

CHAPTER 1 REFERENCES

1. Summary Report, Phase I Study of Inactive Mill Sites and Tailings Piles, U.S. Atomic Energy Commission; Oct 1974.
2. L. F. Hintze and D. K. Fuhriman, "Hydrology and Geology of Uranium Tailings Site at Shiprock, New Mexico"; Center for Health and Environmental Studies, Brigham Young University, Provo, Utah; 1976.
3. F. F. Haywood, et al; Assessment of Radiological Impact of the Inactive Uranium Mill Tailings Piles at Shiprock, New Mexico; ORNL-TM-5581, in preparation.
4. EPA, Office of Radiation Programs, Las Vegas; preliminary data.
5. H. W. Kraner, G. L. Schroeder, and R. D. Evans; "Measurements of the Effects of Atmospheric Variables on Radon-222 Flux and Soil-Gas Concentrations"; The Natural Radiation Environment, J. A. S. Adams and W. M. Lowder, eds; University of Chicago Press; 1964.
6. "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation"; Report Advisory Committee on Biological Effects of Ionizing Radiation; NAS, National Research Council; p.150; Nov 1972.

CHAPTER 2

SITE DESCRIPTION

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

2.1 LOCATION

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

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

2.2 TOPOGRAPHY

The site is located in a valley formed by the San Juan River. The Chaco River enters the San Juan about 3 mi upstream from the site. The country is arid, desertlike, with low rolling hills and occasional steep ridges and mesas. Vegetation is sparse except immediately along the San Juan River. The elevation of the site is about 5,000 ft above sea level. The tailings site is approximately 75 ft higher than the San Juan River on a bench which drops sharply to the river.

The total site contains 230 acres. The 4.5-acre area which was occupied by the mill buildings is in the northwest portion of the site. The two adjoining tailings piles, located south of the mill buildings, cover approximately 72 acres. The upper pile (i.e. the north pile) is the higher of the two piles, occupies about 26 acres, ranges in depth from 14 to 40 ft, and contains 1.056 million tons of tailings (64%). The lower pile (i.e. the south pile) occupies about 46 acres to a depth averaging about 15 ft and contains 0.594 millions tons of tailings (36%).

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

Southwest of the old mill office building is a former raffinate pond area covering approximately 6 acres. This area is referred to as Area E in the EPA Minimum Remedial Action Plan (Appendix B.1).

The northeast area was used for water pumping and water storage and for purposes unrelated to the uranium milling activities. The area south of the tailings was leveled and used as an airstrip for private planes. Figure 2-2 is a topographic map of the mill and tailings portions of the site and Figure 2-3 is a descriptive map of the same area.

2.3 OWNERSHIP

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

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

2.4 HISTORY OF MILLING OPERATIONS AND PROCESSING⁽¹⁾

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

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

The uranium-vanadium ore was mostly sandstone, containing carnotite as the principal ore mineral. Ore was trucked to the mill from many small mines. During the Kerr-McGee operation (1954-1963) about 80% of the ore came from company-controlled mines in northeastern Arizona; the remaining ore processed came from other small mines mostly in northeastern Arizona and northwestern New Mexico. After the change in ownership in 1963, more than half of the ore supply came from the Uravan Mineral Belt. The average truck haul distance was about 100 mi. Another source of feed to the mill was the upgraded slime product that was the principal output of the Monument Valley plant.

The process used called for the ore to be crushed and ground to minus 35 mesh. It was then fed to the sulfuric acid leaching circuit. Leaching was in two stages, with the strong acid solution produced in the second stage recirculated to the first stage for partial neutralization by the entering ore slurry. The high con-

(1) See end of chapter for references.

centration of acid in the second stage was required for good vanadium extraction. The bulk precipitate from the Monument Valley concentrator and upgrader was added ahead of the first leaching stage. Old tailings, which contained vanadium, were processed in the second stage of leaching. Following leaching, the sands and slimes entered the countercurrent washing system in which the sands were washed in classifiers and the slimes were washed in thickeners. Uranium and vanadium were recovered from the pregnant liquors by solvent extraction. Tailings from the washing circuit were pumped to tailings ponds. Raffinate from the solvent extraction operation was disposed of by evaporation in separate holding ponds.⁽²⁾

2.5 PRESENT CONDITION OF THE SITE

The upper tailings pile was covered with from 0.5 to 2 ft of pit-run soil and gravel and has some natural plant growth. This pile is resisting wind erosion fairly well, although tailings are exposed in a few areas. Dikes were built along the upper pile face, which abuts the San Juan River, to prevent water erosion of the tailings into the river. These dikes recently have been improved.

The tailings in the lower pile have been disturbed and recontoured as a result of the training activities of NECA, and it is now the repository of contaminated material resulting from cleanup of other parts of the site. Since this material is loose and readily windblown⁽¹⁾, an irrigation system has been installed in an attempt to reduce wind erosion. Two profiles of the upper and lower piles in cross-section are shown in Figure 2-4.

The raffinate pond area was decontaminated by removing up to 18 ft of contaminated material and replacing it with clean pit-run material from the site adjacent to the river.

Many of the original mill buildings and facilities have been removed. After mill operations ceased in 1968, much of the mill equipment was dismantled and some of the highly contaminated equipment and materials were buried in the tailings. Several buildings and building shells which were left standing and still remain are shown in Figure 2-3. The Navajo Nation has contracted for the decontamination and removal of the old main mill building.

In 1973, when the property reverted to the control of the Navajo Nation, NECA occupied the former plant office and shop buildings and began operating a training school on the site to instruct Navajo students in the operation of earthmoving machinery. This school is still in operation at the present time.

In November 1973, the Navajo Tribal Chairman asked the EPA and officials of other federal agencies for assistance in stabilizing the tailings piles at Shiprock. During April 1974, the EPA conducted radiation surveys around the site to determine the extent of wind-

and water-eroded mill tailings in order to provide a basis for deriving a decontamination plan, cost estimates, and procedures. The survey results led to recommendations for decontaminating the site. These were forwarded to the Navajo Tribe in October 1974. As shown in Figure 3-10, Chapter 3, the EPA survey indicated an area of windblown tailings extending well beyond the site boundaries.

To discourage the use of the tailings piles for earthmoving practice and to attempt to reduce the radiological exposure which trainees and site workers were receiving, representatives of the Tribe, NECA, and federal and state agencies decided that the site should be decontaminated. As part of the plan, NECA would carry out the decontamination activities with the assistance of other involved organizations and agencies. These agencies included: the Navajo Environmental Protection Commission; NECA; Public Health Service; Indian Health Service; EPA, Region VI Office; EPA Office of Radiation Programs-Las Vegas Facility (ORP-LVF); and the New Mexico Environmental Improvement Agency. The Tribal Vice Chairman inaugurated this decontamination effort on January 8, 1975. The plan, prepared by EPA-ORP-LVF, was defined in "The Work Plan for the Decontamination of the Shiprock Uranium Millsite" and is contained in part in Appendix B.1 in this report. The plan was based upon available resources and consists of a 10-task program. Assignments were made to several agencies to accomplish the various tasks, with most of the tasks assigned to NECA. The status of the program as of May 1976 is described in an EPA progress report contained in Appendix B.2.

It is estimated that the work plan was 80% complete as of October 1, 1976, and that approximately 430,000 tons of material have been relocated thus far onto the lower pile by NECA in its decontamination efforts. The original objectives of the decontamination efforts were to:

- (a) Cleanup the local environs around the site to a degree that it could be used in a less restrictive manner.
- (b) Provide interim stabilization of the tailings piles in order to prevent or minimize further wind and water erosion into the local environment until permanent stabilization could be defined and applied.
- (c) Provide a technical information base which could be applied to the decontamination of other inactive millsites.
- (d) Investigate parameters which contribute to on- and off-site exposures.

If a Phase II option were decided upon involving relocation of the piles, then a substantial portion of the required work will have been completed.

2.6 TAILINGS AND SOIL CHARACTERISTICS

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

Bulk densities of tailings samples obtained in this assessment are shown in Table 2-2. The sample locations are given in Figure 2-3. These samples generally were finely ground tailings with a high clay content. The bulk densities ranged between 82.0 and 106.8 lb/ft³. Table 2-2 shows the pH of tailings samples taken from on-site test holes to be in the neutral range; therefore, no problems are expected as a result of equipment or piping facilities coming in contact with the tailings.

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

2.7 GEOLOGY, HYDROLOGY, AND METEOROLOGY

2.7.1 Geology⁽³⁾

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

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

2.7.2 Surface Water Hydrology

Downcutting by the San Juan River has left the bench on which the site is located so high that the river waters pose no threat to the tailings even in times of maximum flooding. As shown in Figure 2-5, surface tributaries drain from the south into the San Juan River near the millsite.⁽⁴⁾ The most important tributary is Dead Mans Wash, which is 0.75 mi southeast of the site. The river and the wash provide drainage for most of the area south

of the site, leaving only a fractional part of a relatively flat, square mile watershed area to drain toward the river channel at the plant site.

2.7.3 Ground Water Hydrology

The thick Mancos Shale layer in the Shiprock area is not water-bearing and overlies rocks of an aquifer system of older age. This aquifer system (Figure 2-6) extends beneath the town of Shiprock and receives its recharge from 15 mi or more west and southwest of Shiprock in the Carrizo and Chuska Mountains areas.⁽⁵⁾

Beneath the Shiprock area the water in the older aquifer system, containing high concentrations of dissolved solids, are confined under artesian pressure and rise to the surface in flowing wells.⁽⁵⁾ Thus, the confined systems are self-pressurized against contamination from surface water in the Shiprock area. Consequently, there is no possibility of downward migration of radioactive contamination through the Mancos Shale.

The Mancos Shale that underlies the Shiprock area also constitutes an effective barrier to both the upward and downward migration of ground waters. As evidenced by contaminated seeps along portions of the Mancos Shale outcropping, unconfined ground waters move through the recent alluvial gravels of the present San Juan River floodplain, but because the millsite is on the ancient bench well above the floodplain, the unconfined waters do not come in contact with the tailings. Figure 2-7 is a simplified stratigraphic cross-section of the rock formations in the Shiprock vicinity.

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

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

2.7.4 Meteorology

Limited quantitative wind data are available at the site, but comparable records are available from Farmington. Cooley, et al(5) state that strong winds are common in the area; also, the distribution and orientation of sand and dunes, and the directions of cross-beds of eolian deposits indicate regional wind patterns during recent as well as geologic time. (See Figure 2-8.) The prevailing winds are from the southwest, but strong winds and storms also occasionally come from the west and northwest. Material eroded by these winds probably would be carried to the river or the bluff area south of the millsite.

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

7

FIGURE 2-2. TOPOGRAPHIC MAP

FIGURE 2-1. AERIAL PHOTOGRAPH OF SITE

FIGURE 2-4. CROSS-SECTION AT STATIONS 15+00 AND 24+50

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

FIGURE 2-5. SURFACE DRAINAGE PATTERNS

130-01

0 10 20 30 MI

LEGEND

UNSHADED AREAS INDICATE ROCKS RECEIVING LITTLE OR NO RECHARGE

SHADED AREAS INDICATE ROCKS RECEIVING RECHARGE

MESAVERDE GROUP AND ROCKS OF THE AQUIFER SYSTEM OF INTEREST TO THIS REPORT

NOTE
FROM REFERENCE 5

FIGURE 2-6. PROBABLE DIRECTION OF GROUND WATER FLOW

130 01

FIGURE 2-7. SIMPLIFIED STRATIGRAPHIC CROSS-SECTION

NOTE:
FROM REFERENCE 5

TABLE 2-1
TAILINGS MATERIALS

<u>Material</u>	<u>Volume (yd³)</u>	<u>Weight (tons)</u>
Tailings	1,254,000	1,650,000*
Dikes	45,000	40,000
Rubble Moved to Site	20,000	20,000
Stabilization Material	24,200	20,000
Contaminated Material**	290,000	430,000
TOTAL	1,633,200	2,160,000

*Weight based on average existing field densities, which include moisture.

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

TABLE 2-2

PHYSICAL PROPERTIES AND pH OF
THE URANIUM TAILINGS SAMPLES

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

*See Figure 2-3

CHAPTER 2 REFERENCES

1. "Phase I Reports on Conditions of Inactive Uranium Millsites, Shiprock Report"; AEC; Grand Junction, Colorado; 1974.
2. R. C. Merritt; The Extractive Metallurgy of Uranium; Colorado School of Mines Research Institute; pp. 422-428; 1971.
3. L. F. Hintze and D. K. Fuhriman; "Hydrology and Geology of Uranium Tailings Site at Shiprock, New Mexico"; Center for Health and Environmental Studies, Brigham Young University, Provo, Utah; 1976.
4. U.S. Geological Survey, Chimney Rock, New Mexico - Colorado 15-Minute Quadrangle Topographic Map; 1947.
5. M. E. Cooley, J. W. Harshbarger, J. P. Ackers, and W. F. Hardt; Regional Hydrology of the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah; USGS Professional Paper 521-A, Plate 5; 1969.

CHAPTER 3

RADIOACTIVITY AND POLLUTANT IMPACT ON THE ENVIRONMENT

CHAPTER 3

RADIOACTIVITY AND POLLUTANT IMPACT ON THE ENVIRONMENT

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

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. 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 tailings ponds. The sands and slimes that remain constitute the tailings piles. Generally, as at Shiprock, the slimes constitute only 20% of solid waste material, but they may contain 80% of the radioactive elements of major concern: radium, and its daughters.

3.2 RADIATION EFFECTS

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

The biological effects of radiation are related directly 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.

3.3 NATURAL BACKGROUND RADIATION

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

Background values of radon concentrations were measured at four locations using continuous radon monitors supplied by ERDA. An average outdoor value of 0.77 pCi/l was obtained from the 24-hr samples. However, the range of the measurements extends from 0.66 to 0.98 pCi/l. One additional measurement made 5 mi south of the millsite gave an anomalously high value of 1.4 pCi/l. This value was not included in the average background.

Background gamma ray levels, as measured 3 ft above the ground, also were determined at several locations from 1.5 to 4.5 mi from the site by using a calibrated and energy compensated Geiger Mueller detector and a sodium-iodide scintillometer. A value of 9 μ R/hr was established as the average background level, but the values ranged from 6 to 13 μ R/hr.⁽¹⁾ Cosmic rays contribute to background radiation levels. The contribution from cosmic rays is generally dependent upon the altitude and is approximately 6.5 μ R/hr in the Shiprock area,⁽²⁾ or approximately 70% of the measured average background value. Currently, a value of 13 μ R/hr, established with a pressurized ion chamber, is being used as the gamma background for the remedial action under way at the Shiprock site.⁽³⁾

3.4 RADIATION EXPOSURE PATHWAYS AND CONTAMINATION MECHANISMS

As noted previously, the principal environmental radiological implications and associated health effects of uranium mill tailings are related to radionuclides of the ²³⁸U decay chain: primarily ²³⁰Th, ²²⁶Ra, ²²²Rn, and ²²²Rn daughters. Although these radionuclides occur in nature, their concentrations in tailings material are

(1) See end of chapter for references.

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, which decay from the escape of ^{222}Rn 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; 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 which can occur; however, this pathway was not significant and therefore was not considered further in this assessment.

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

3.4.1 Radon Gas Diffusion and Transport

Field measurements of the radon exhalation flux from the tailings using the charcoal canister technique⁽⁴⁾ are listed in Table 3-3. The current values range from 53 to 157 pCi/m²-s, and are significantly less than the previously reported values taken on bare Shiprock tailings which ranges from 440 to 2,200 pCi/m²-s.⁽⁵⁾ Radon flux depends principally on radium content of the tailings. In general, radon flux varies considerably from time to time at a single sampling location due in part to differing moisture, soil, and climatological factors, to major changes in pile configuration between different locations, and to the difficulty of performing such measurements.

Radon gas exhaling from the piles has been detected at 0.5

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

The measurements were made in February 1976 and in June 1976. The 4.9 pCi/l measurement at site 4 was made in February with a light wind blowing from the piles toward the measurement location. The 0.9 pCi/l value was obtained in June with the wind blowing at right angles to a line between the piles and the measurement location.

The variation of radon concentration during the measurement period and the existing weather conditions are shown in Figures 3-4 and 3-5. The sample location for Figure 3-4 is about 0.5 mi north from the edge of the piles, and the sample location for Figure 3-5 is at the storeroom of the NECA office on the site.

ORNL personnel performed WL measurements at hourly intervals for a 24-hr period in the NECA office building at the Shiprock site.⁽¹⁾ The continuous radon monitors were operated simultaneously inside and outside the building. The working level measurements are plotted in Figure 3-5 for a direct comparison of the radon and radon daughter measurements. For this set of measurements, the radon daughter concentration is 20% of the equilibrium value inside the building.

The radon concentration measurements are plotted in Figure 3-6 as a function of distance from the edge of the tailings piles. Also shown in this figure are average and maximum concentrations calculated with the ORNL model⁽¹⁾ for radon diffusion from the Shiprock tailings.

From the data and model curves a best estimate curve of radon concentration-versus-distance was formulated for Shiprock. This best estimate curve also is shown in Figure 3-6. The best estimate curve was used to calculate potential health effects resulting from radon diffusing from the Shiprock tailings.

3.4.2 Direct Gamma Radiation

The external gamma radiation (EGR) levels measured on the piles are shown in Figure 3-7.⁽¹⁾ At a few locations on the lower pile the EGR was over 300 μ R/hr. Readings on the upper pile were all below 300 μ R/hr. Measurements of EGR were taken also at 100-yd intervals on traverses in several directions away from the piles by both FB&DU and ORNL. Results of these measurements, taken with energy compensated Geiger Mueller detectors, are plotted

in Figure 3-8. Other gamma measurements were taken at locations where radon monitors were placed. These values also are shown in Figure 3-8. The decrease of EGR with distance from the edge of the piles in four directions is shown in Figure 3-9. EGR readings reach the background range at about 0.25 mi southeast of the piles and at less than 0.2 mi from the piles in the northwest, southwest, and northeast directions.

3.4.3 Windblown Contaminants

Another pathway through the environment is the result of windblown tailings deposited off the tailings site. The prevailing winds are from the southwest; however, the tailings deposition to the east and northeast appears to be limited because the upper tailings pile at the northeast side of the site is stabilized with river rock and it also tends to reduce blowing of tailings from the lower pile. In addition, the airborne tailings are dispersed to a greater extent as the fine particles are lifted over the upper pile and encounter a drop in elevation of about 90 ft at the bluff on the northeast edge of the site above the San Juan River. The greatest spread of windblown tailings is to the southeast where above background gamma radiation levels extend to 1,200 ft from the site boundary. Figure 3-10 shows the results of the EPA gamma radiation rate survey of the Shiprock site.⁽⁶⁾ Two iso-exposure rate lines are indicated in the figure: a background line, and a 10 μ R/hr line. If scattered tailings and ore were removed from inside the 10 μ R/hr line (toward the piles) and if the piles were removed or covered to provide essentially complete gamma shielding, then the tailings remaining outside the line (away from the piles) would produce a net gamma exposure rate, 3 ft above ground, approximately equal to 10 μ R/hr.

Soil samples were taken in the area surrounding the site.⁽¹⁾ The sample locations and ^{226}Ra concentrations are shown in Figure 3-11. To the southwest, west, and northwest all the surface samples contained less than twice the average ^{226}Ra concentration of 1.7 pCi/l. In the southeasterly direction, a sample taken 400 yd from the piles had four times the average ^{226}Ra background concentration. At 600 yd from the piles the ^{226}Ra concentration was less than twice the average background value. Below the bluff to the northeast concentrations ranged from 1.5 to 14 times the background value in four samples taken between the bluff and the river. This contamination probably resulted from windblown tailings prior to covering the upper pile. If the river overflows its banks into this area, the contamination would be carried downstream. There is evidence that the river floods portions of the river bottom adjacent to the piles.

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

Concentrations of radioactive airborne particulates were

measured at several locations in the Shiprock area by EPA-ORP-LVF during a 7-mo period in 1974.⁽³⁾ Table 3-4 lists some of the measured values in the mill yard, an area southeast of the piles, and at the Shiprock High School across the San Juan River from the tailings. With only one exception, all values of concentration for measured isotopes were two orders of magnitude less than the permissible limits shown. That one exception, ^{230}Th in the mill yard, was slightly below the maximum permissible limit from 10CFR20.

3.4.4 Ground and Surface Water Contamination

Two water samples were taken at the tailings site as shown in Figure 3-11. One sample, taken from a small pond in the ore storage area, had a dissolved ^{226}Ra concentration of 2 pCi/l. The other, from a stagnant pond at the base of the shale bluff at the northeast corner of the site, had a concentration of 3.5 pCi/l.⁽¹⁾ The latter site was in the flood plain of the San Juan River. Both of these samples had ^{226}Ra concentrations below the EPA Interim Drinking Water Regulations of 5 pCi/l of combined ^{226}Ra and ^{228}Ra . No water was encountered in any drill holes.

3.4.5 Soil Contamination

The amount of ^{226}Ra activity in the tailings and the extent of leaching of radium from the tailings into the soil were determined by drilling boreholes through the tailings and into the soil beneath the upper and the lower piles. The radioactivity profile was measured in these holes with a Geiger tube probe in a lead shield which collimates the radiation. Soil samples were taken with a Shelby tube sampler from selected holes for radiometric analysis. Additional holes were drilled in the mill area, ore storage area, and on the side boundaries. The locations of the boreholes are indicated in Figure 2-3, Chapter 2.

Typical radium activity profiles in Shiprock tailings and subsoil are shown in Figures 3-12 and 3-13. The variations in the radioactivity of the tailings noted in the profiles are due to variations in the methods of milling and tailings deposition. Figure 3-12 presents the profile for hole 23 on the lower pile. Soil analysis of a sample 2.5 ft below interface showed a ^{226}Ra concentration of about two times the average background value.⁽¹⁾ Other sample analyses of ^{226}Ra concentration at 1.5 ft below interface and immediately above the interface are plotted also in Figure 3-12.

Figure 3-13 is a radiometric profile of hole 15 drilled through the upper pile. A hard layer was encountered in all five holes on that pile and hole 15 was the only one where the layer was penetrated with the rock bit. The level of activity was very high (up to 4,000 pCi/g) at the bottom of the other holes immediately above the hard layer. No Shelby tube samples could be obtained so a large backhoe from the NECA school was employed to cut trenches for sampling adjacent to holes SRNM-12 and -15 at the southeast end of the upper pile where the tailings were not

as thick and the hard layer was close to the surface. The hard layer near hole SRNM 15 consisted of cemented sand and gravel conglomerate. Beneath this layer was unconsolidated cobble conglomerate. The gamma log indicated a ^{226}Ra concentration of 2.5 times the background level at a depth of 4 ft below the tailings subsoil interface. Sample analyses of ^{226}Ra concentration from the adjacent pit varied from 2 to 45 times the average background concentration in the 6 ft interval below the tailings. These values are plotted in Figure 3-13.

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

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

3.4.6 Off-Site Tailings Use

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

3.5 REMEDIAL ACTION CRITERIA

Radiological criteria established for this engineering assessment for possible remedial action applicable to uranium mill tailings are divided into two general categories: criteria applicable to structures with tailings underneath them or within 10 ft,⁽⁷⁾ and criteria pertaining to the mill tailings site and open land.⁽⁸⁾ Copies of the complete documents establishing these criteria are presented in Appendix A. Also given in Appendix A are the Grand Junction Remedial Action Criteria for Structures (10CFR12).

The criteria which apply to the structures are the guidelines published by the Surgeon General of the United States.⁽⁷⁾ These guidelines recommend the following graded levels for remedial action in terms of the EGR levels and indoor RDC levels above background found within the dwellings constructed on or near uranium mill tailings:

<u>EGR, mR/hr</u>	<u>RDC*, WL</u>	<u>Recommendation</u>
Greater than 0.1	Greater than 0.05	Remedial action indicated
From 0.05 to 0.1	From 0.01 to 0.05	Remedial action may be suggested
Less than 0.05	Less than 0.01	No remedial action indicated

*Based upon yearly average values

The radiological criteria for decontamination of inactive uranium millsites and for open areas are based upon EGR readings above background, measured 3 ft above ground. Decontamination should result in residual exposures that are as low as practicable. For this assessment the following criteria were used:

- (a) On the tailings pile:
 - (1) Removal so that residual radium concentration in the soil does not exceed twice background values.
 - (2) If removal is not practicable, tailings should be covered so that residual gamma ray levels do not exceed 0.040 mR/hr above background. The area also should be designated a control area with restricted access.
- (b) Windblown tailings in open land areas near to or adjacent to the site:
 - (1) If gamma levels are less than 0.010 mR/hr above background, the land may be released for unrestricted use.
 - (2) If gamma levels exceed 0.010 mR/hr above background, cleanup should reduce the radium soil concentration to no more than twice background.
 - (3) If tailings removal is not practicable, residual gamma levels should in any part of the area not exceed 0.040 mR/hr above background.

3.6 POTENTIAL HEALTH IMPACT

An assessment has been made of the potential health impact of the tailings piles. The six 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 path-

way and results in the largest estimated population dose.⁽⁹⁾

- (b) External Gamma Radiation - Gamma radiation is measurable to distances of 0.25 mi from the piles, which is an area void of inhabited dwellings; however, persons on site will receive some gamma exposure until the contaminated ground is cleaned and the piles are covered with sufficient material to attenuate the gamma radiation.
- (c) Airborne Activity - According to EPA data, the limited spread of significant quantities of windblown tailings, coupled with the distance between the piles and inhabited dwellings, indicates that inhalation or ingestion of tailings particles is a minor component of the total population dose. This is a general result also reported at other uranium tailings piles.^(3,10) Stabilization of the Shiprock tailings piles against wind erosion will eliminate the gradual accumulation of tailings off site and the attendant problems thereto.
- (d) Water Contamination - The low radium activity in nearby off-site surface water indicates little, if any, contamination from the tailings piles.
- (e) Subsoil Contamination - The minimal amount of leaching of radioactive materials through the tailings into the ground beneath the piles measured during this project indicates this pathway results in negligible health effects; however, seepage from ponds during mill operations and subsequent contamination of localized areas has occurred. In one area to the northwest of the raffinate ponds, deep solution migration to 18 ft was discovered previously by EPA.
- (f) Physical Removal - Tailings which have been placed near a structure or used in its construction are sources for elevated gamma levels and radon daughter concentrations in the structure. Radiation exposure to individuals living or working in these structures can be significant. The off-site remedial action is described in Chapter 7.

Only the potential health effects from the inhalation of radon daughters (pathway a) and from direct gamma radiation (pathway b), are estimated quantitatively in this assessment because they constitute the most significant pathways. Furthermore, it is assumed that the uncertainty in the estimates of the potential health effects from these pathways far exceeds the magnitude of the health effects from the other pathways.

It is extremely difficult to predict with any assurance that a specific health effect will be observed within a given time after chronic exposure to low doses of toxic material. Therefore, the usual approach to evaluation of the health impact of low-level

radiation exposures is to make projections from observed effects of high exposures on the basis that the effects are linear, using the conservative assumption of no threshold for the effects. The resulting risk estimators also have associated uncertainties due to biological variability among individuals and to unknown contributions from other biological insults which may be present simultaneously with the insult of interest. No synergistic effects are considered explicitly in this analysis. For the purpose of this engineering study, lung cancer is the potential health effect considered for RDC and all cancers are considered for EGR exposures. The health effects were estimated using both an absolute and a relative risk model.

3.6.1 Assumptions and Uncertainties in Estimating Health Effects

Since radiation exposure from ^{222}Rn daughters 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 often are expressed in terms of rems; however, estimates of the WLM-to-rem conversion factor for internal lung exposure to alpha particles from ^{222}Rn daughters vary by over an order of magnitude. 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 absolute risk estimator used in this assessment is that given in the report of the National Academy of Sciences Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR report).⁽¹¹⁾ This report presents risk estimators for lung cancer derived from epidemiological studies conducted on two groups of miners, namely:

3 cancers per year per 10^6 person-WLM exposure
for uranium miners

8 cancers per year per 10^6 person-WLM exposure
for fluorspar miners

Therefore, the average of these two values was chosen as the risk estimator for use in this study. This estimator then is:

6 cancers per year per 10^6 person-WLM exposure

A dose from a given ingestion or inhalation of radionuclides varies widely due to differences in age (infants-adults), physical size, diet, etc. This and other components of natural biological variability which exist among members of any given population, as well as the differences between exposure conditions in residences and mines, give rise to an uncertainty on the order of a factor of 3 in this parameter.⁽¹²⁾

The commitment, then, of 6 cancers per year is based upon a total population exposure of 10^6 person-WLM. If a cancer does

occur it likely will be evident during the 30-yr period following the initial exposure and latency period.(13) When the exposure is continual over an individual's lifetime, this commitment is cumulative and the risk per year increases to an ultimate value of 6 times 30, or:

180 effects per year per 10^6 person-WLM
continual annual exposure

This mathematical expression also can be interpreted in terms of the average annual risk to an individual per unit of exposure. For example, an individual with a continuous exposure of 1 WLM annually has about a 2×10^{-4} probability each year of developing lung cancer from this exposure. Several investigations have been reported recently concerning the association between lung cancer incidence and RDC exposures in miners.(12,14,15) These investigations yielded risk estimator values consistent with the risk estimator used in the present assessment. The relative risk estimator gives 150 effects per year per 10^6 person-WLM continual annual exposure.(16)

For the purposes 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:

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

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

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

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

The risk estimator⁽¹¹⁾ used for continual exposure to gamma radiation is:

100 effects per year per 10^6 person-rem
continual annual exposure

In this assessment it is assumed that a gamma exposure of 1 R in air is equivalent to a dose of 1 rem in soft tissue.

3.6.2 Health Effects

Health effects due to radon transport from the Shiprock site in its present condition are estimated using indoor radon daughter

concentrations deduced from measured outdoor radon concentrations using 1 pCi/l of ^{222}Rn = 0.005 WL, then applying the risk estimators given previously. No health effects were attributed to gamma radiation from the piles, because gamma population exposures are virtually zero within 0.25 mi surrounding the piles where the gamma radiation from the piles is greater than the background range. The estimated annual radiation-induced lung cancer risk as a function of distance from the edge of the piles is given in Figure 3-14 for prolonged continuous exposure. The curves shown in the figure are the sum of the estimated annual radiation-induced risk from Shiprock tailings plus the average lung cancer risk per year from all causes for residents of the Navajo Reservation. It is noted that the risk for developing lung cancer is double the natural occurrence risk at a distance of about 0.5 mi, and increases to roughly four times the natural occurrence at the edge of the piles.

Health effects from total population RDC exposures for the area within 1.5 mi from the tailings pile perimeter are given in Table 3-5. Beyond 1.5 mi, the radon concentration attributed to the piles is insignificant compared with the variation in the measurements of background radon concentration; therefore, the health effects were not estimated beyond that distance. Furthermore, the population in the region immediately beyond 1.5 mi is a small fraction of the population residing within the 1.5-mi band. In fact, the population is very low between 1.0 and 1.5 mi from the piles. The population was estimated using visual numeration of dwellings and businesses and applying a 5.6 occupancy factor for residences and a 10 occupancy factor for businesses. The health effect values are obtained by converting the appropriate radon concentrations in the Shiprock area 1.5 mi around the perimeter of the piles to equivalent WLM/yr and multiplying by 180 effects/yr/ 10^6 person-WLM and by the sum (population + employees/4).

Also shown in the table are health effects estimated from background radon concentrations. The pile-induced radon daughter health effects are approximately 30% greater than background values for the same area.

It should be noted that the number of health effects attributed to the zone from 1.0 to 1.5 mi from the piles is not significant due to the low population and the very small radon concentrations. If the relative risk estimator is used, then the health effects estimates are slightly smaller than the ones given in Table 3-5. The uncertainty in the health effects estimation is about a factor of 4.

Also shown in Table 3-5 are 25-yr cumulative values based on three growth rate projections. These health effects are considered in conjunction with remedial action costs in Chapter 9.

3.7 NONRADIOACTIVE POLLUTANTS

There are other potentially toxic materials in the tailings.

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

Five water samples were taken from the vicinity of the Shiprock tailings piles and chemically analyzed. The locations of these samples are shown in Figure 3-11. Sample A was taken from a pond northwest of the tailings and mill area. Sample B was obtained from standing water in the San Juan River floodplain just below the bluff north of the tailings piles. Sample C was taken from the San Juan River opposite the tailings. Samples D and E were taken from the San Juan River upstream and downstream from the tailings piles, respectively. Water samples A and B, of stagnant, standing water were above the EPA Interim Drinking Water Regulations for cadmium, chromium, iron, arsenic, and selenium. In Table 3-6, concentrations of heavy metals in the Shiprock water samples are listed with the EPA Interim Drinking Water Regulations. Comparing downstream samples with upstream Sample D indicated increases in iron, arsenic, barium, lead and cadmium to the mineral content of the San Juan River from the tailings; however, the addition of barium, lead and arsenic were small and the San Juan River was still below the maximum acceptable limit for drinking water for these three elements.

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

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

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

130-01

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

FIGURE 3-3. RADON CONCENTRATION IN VICINITY OF PILES

LEGEND

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

FIGURE 3-4. ^{222}Rn AND ATMOSPHERIC TRANSIENTS AT 0.46 MI NW OF PILES ON FEBRUARY 26, 1976

130-01

FIGURE 3-5. ^{222}Rn AND ATMOSPHERIC TRANSIENTS AT STOREROOM OF NECA OFFICE ON FEBRUARY 28, 1976

130-01

FIGURE 3-6. REDUCTION OF OUTDOOR ^{222}Rn CONCENTRATION WITH DISTANCE FROM THE TAILINGS PILES

130-01

FIGURE 3-7. GAMMA LEVELS 3 FT ABOVE GROUND

NOTE

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

LEGEND

- STATE HIGHWAY
- U.S. HIGHWAY

FIGURE 3-8. GAMMA LEVELS IN VICINITY 3 FT ABOVE GROUND

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

130-01

NOTES

1. REFERENCE: TECHNICAL NOTE ORP/LV-75-5, GAMMA RADIATION SURVEYS AT INACTIVE URANIUM MILLSITES, USEPA, LAS VEGAS, NEVADA, AUGUST 1975, FIGURE 15 PAGE 65

0 500 1000 1500 FT

7 • UNCORRECTED DIFFERENTIAL GAMMA READING - $\mu\text{R/h}$

FIGURE 3-10. EPA GAMMA SURVEY SURROUNDING MILLSITE

130-01

FIGURE 3-11. SURFACE AND SUBSURFACE RADIUM CONCENTRATIONS

FIGURE 3-12. RADIOMETRIC PROFILE AT DRILL HOLE SRNM-23

130-01

FIGURE 3-13 RADIOMETRIC PROFILE AT DRILL HOLE SRNM-15

130-01

FIGURE 3-14. LUNG CANCER RISK FROM CONTINUOUS EXPOSURE TO RADON DIFFUSION

130-01

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.

TABLE 3-1 (Cont)

Working Level (WL)	- measure of potential alpha energy per liter of air from any combination of short-lived radon daughters (1 WL = 1.3×10^5 MeV of alpha energy).
One Working Level Month (WLM)	- WLM-Exposure to air containing a RDC of 1 WL for a duration of 170 hr.
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.
μ 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.

TABLE 3-2

BACKGROUND RADIATION SOURCES IN SOIL IN NORTHWEST NEW MEXICO

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

TABLE 3-3

RADON EXHALATION FLUX FOR SHIPROCK PILES

<u>Sample</u>	<u>Location (June 1976)</u>	<u>Rn Flux (pCi/m²-s)</u>
1	Near Hole 33	61
2	Near Hole 26	142
3	Near Hole 11	53
4	Near Hole 17	84
5	Near Hole 10	88
6	Near Center of Upper Pile	157
Average		98

TABLE 3-4

RADIOACTIVE AIRBORNE PARTICULATE CONCENTRATIONS NEAR THE SITE^a

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

^aMeasurements performed by EPA-ORP, Las Vegas^bFrom 10CFR20, Maximum exposure to an individual in an unrestricted area

TABLE 3-5

ESTIMATED HEALTH IMPACT FROM SHIPROCK TAILINGS
FOR AN AREA 0 - 1.5 MILES FROM TAILINGS EDGE

<u>Time Period</u>	<u>Population (Persons)</u>	<u>Employees (Persons)</u>	<u>Total Pile-Induced Health Effects Per Year</u>	<u>Total Background Radon Health Effects^a Per Year</u>
1975	2,500	200	0.1	0.1
2000 (2.5% annual growth)	4,625	370	0.2	0.2
2000 (4% annual growth)	6,675	534	0.3	0.2
2000 (7% annual growth)	13,575	1,086	0.6	0.5
25-yr Cumulative Health Effect (2.5% growth)			3.9	3.0
25-yr Cumulative Health Effect (4% growth)			4.8	3.7
25-yr Cumulative Health Effect (7% growth)			7.3	5.6

^a For the purposes of this assessment, background radon is defined as that generated away from the tailings piles.

TABLE 3-6

CHEMICAL ANALYSES OF SHIPROCK WATER SAMPLES (mg/l)

<u>Sample^a</u>	<u>As</u>	<u>Se</u>	<u>Cr</u>	<u>Cd</u>	<u>Fe</u>	<u>Ba</u>	<u>Pb</u>
A - Pond-Ore Storage Area	0.268	0.636	0.280	0.119	0.33	0.60	0.012
B - Below Bluff	0.525	0.424	<0.001	0.126	0.39	0.54	0.011
C - San Juan River Opposite Piles	0.024	0.043	0.330	0.462	1.67	0.63	0.010
D - San Juan River Upstream	0.019	0.034	0.180	0.221	1.24	0.53	0.009
E - San Juan River Downstream	0.024	0.035	0.170	0.826	1.67	0.69	0.017
EPA Drinking Water Standard ^b	0.05	0.01	0.05	0.01	0.3	1.0	0.05

^aSee Figure 3-11 for locations

^bFederal Register, Dec 24 1975

CHAPTER 3 REFERENCES

1. F. F. Haywood, et al; "Assessment of Radiological Impact of the Inactive Uranium Mill Tailings Piles at Shiprock, New Mexico"; ORNL-TM-5581 (in preparation).
2. D. T. Oakley; "Natural Radiation Exposure in the United States"; EPA Report ORP/SIO 72-1; Jun 1972.
3. J. M. Hans, Jr.; "Decontamination of the Shiprock, New Mexico Uranium Mill Site"; ORP-LV-76-12 (in preparation); EPA, Office of Radiation Programs, Las Vegas, Nevada.
4. M. Money and B. Heaton; Health Physics; Vol 31; p. 456; 1976.
5. D. E. Bernhardt, F. B. Johns, and R. F. Kaufmann; "Radon Exhalation from Uranium Mill Tailings Piles"; EPA Technical Note, ORP-LV-75-7(A); 1975.
6. R. L. Douglas and J. M. Hans, Jr.; "Gamma Radiation Surveys at Inactive Uranium Mill Sites"; EPA Technical Note, ORP-LV-75-5; Aug 1975.
7. Office of the U. S. Surgeon General, Department of Health, Education and Welfare; Jul 1970.
8. EPA/ORP; "Radiological Criteria for Decontamination of Inactive Uranium Mill Sites, Phase I"; Washington, D.C.; Dec 1974.
9. F. F. Haywood, et al; "Assessment of Radiological Impact of the Abandoned Uranium Mill Tailings Pile at Salt Lake City, Utah"; ORNL-TM-5251 (in preparation).
10. A. J. Breslin and H. Glaubergerman; "Uranium Mill Tailings Study"; AEC Technical Memorandum, HASL-64-14; Jul 1964.
11. "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation"; Report Advisory Committee on Biological Effects of Ionizing Radiation; NAS, National Research Council; Nov 1972.
12. W. Jacobi; "Interpretation of Measurements in Uranium Mines: Dose Evaluation and Biomedical Aspects"; NEA Conference, Sudbury, Ontario, Canada; Oct 3-8, 1976.
13. R. H. Johnson, Jr., et al; "Assessment of Potential Radiological Health Effects from Radon in Natural Gas"; EPA-520/1-73-004; EPA; Nov 1973.

CHAPTER 3 REFERENCES (Cont)

14. J. Sevc, K. Kunz, and V. Placek; Health Physics; Vol 30; p. 433; 1976.
15. R. M. Fry; "Radon and Its Hazards"; NEA Conference, Sudbury, Ontario, Canada; Oct 3-8, 1976.
16. J. Silhanek; EPA, ORP Washington, D.C.; private communication; Mar 1977.
17. H. Siegle; Indian Health Service; private communication; Oct 1976.
18. K. T. Williams and H. G. Byers; "Occurrence of Selenium in the Colorado River and Some of its Tributaries"; Industrial Engineering Chemistry Analytical Edition; 7: pp. 431-432; 1935.
19. R. C. Scott and P. T. Voegli, Sr; "Radiochemical Analyses of Ground and Surface Water in Colorado, 1954-1961"; Colorado Water Conservation Board Basic-Data Report No. 7; 1967.

CHAPTER 4
SOCIOECONOMIC AND LAND USE IMPACTS

CHAPTER 4

SOCIOECONOMIC AND LAND USE IMPACTS

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

4.1 SOCIOECONOMIC BACKGROUND

In the Navajo Nation Overall Economic Development Program, five communities were designated to be primary growth points based on their potential for various forms of development and as centers for educational, health, and welfare services.⁽¹⁾ Shiprock is the easternmost of the five, and was singled out as a key community in the industrial development of the Navajo Nation. It was the site of the Fairchild Semiconductor Facility and is currently an administrative center. Shiprock is expected to absorb much of the growth impact of the Navajo Irrigation Project, proposed coal gasification plants, and the Exxon uranium exploration project.

The social and economic conditions of the Shiprock Chapter given in this assessment⁽²⁾ are based primarily on Wistisen, et al.⁽³⁾ In the Shiprock Chapter the mean education level is slightly higher and per capita income is slightly lower than for the Navajo Nation as a whole. The type and condition of housing in the Chapter vary considerably from trailers, to hogans, and to government housing. According to the Office of Program Development, 21% of the Navajo labor force is located in District 12 and is concentrated in the craft, operative, and household service categories. The major source of employment in the district was the Fairchild operation which closed in 1975. While operating, the plant employed 79% of the Shiprock labor force. In spite of the closure there remains considerable optimism about the future of Shiprock due to the mineral wealth of the area and proposals for agricultural and industrial development.

4.2 POPULATION ESTIMATES

The 1970 census data and subsequent attempts to update these data must be accepted with caution. Population estimates are subject to some errors for groups of people who live in desert areas of the southwestern United States. These errors

⁽¹⁾ See end of chapter for references.

are compounded for the Navajo population because of their movements from one Reservation location to another, and movements onto and off the Reservation. In addition, when the Fairchild plant at Shiprock closed, approximately 1,200 workers lost their jobs. It is difficult to determine whether these workers have remained in the Shiprock Chapter, in District 12, or whether they have moved away. Tribal officials do not believe any significant shift has occurred.

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

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

The Bureau of Indian Affairs (BIA) estimates that in 1975 there were 28,714 persons living in the Shiprock Agency, of which 48% were under 16 yr of age. The figures for the Shiprock Chapter vary greatly. Boyle⁽⁴⁾ (for 1973) estimates a population of 8,635, and Wistisen et al⁽³⁾ (for 1975) place the figure at 6,814. For the purposes of this assessment a figure of 2,500 was used as the population on which to base health effects. This estimate was established by counting residences within 1.5 mi of the site using aerial photographs and multiplying by a factor of 5.6 (average family size). The areas of population concentration are shown in Figure 4-2. The concentration, basically, follows the San Juan River.

In addition to the uncertain estimate of base population, the rates used to project growth vary considerably. Ordinarily, the rate of growth is built up of three components: birth rates, death rates, and migration rates. Each of these rates is either unavailable or unreliable for subdivisions as small as a Chapter, let alone a town, and thus the composite growth rate is subject to a sizeable error. In adopting rates for the projections presented here, several considerations were included. First, Shiprock has been designated as one of five major economic growth centers on the Reservation. Second, Shiprock is the largest Reservation community near much of the Navajo Irrigation Project and Exxon exploration area. Third, Shiprock is in an area where the traditional herding and agriculture occupations cannot absorb all of the population growth occurring. Hence, it is likely that many people will migrate to community centers. Thus, rates of growth of the chapter and town of Shiprock will be at least as large or larger than those for the Navajo Reservation as a whole.

In this report, three rates of growth are employed: 2.5% assumes minimal industrial and commercial growth and minimal impact from the Navajo Irrigation Project and the Exxon exploration; 4% assumes that at least one of the factors will have an

impact or that several factors will have a moderate effect; (3) 7% assumes that more than one factor will have a substantial effect. (5)

The Shiprock population projection factors are presented in Figure 4-3. The curves represent three steady rates of growth and three declining rates of growth beginning in 1976. To obtain the population projections for a given year, the appropriate 1976 population is multiplied by the population factors for the year in question.

The slowest growth rate (a steady rate of 2.5%) indicates that in the year 2026 there will be 3.27 times as many residents in the Shiprock Chapter as at present, regardless of the base population. If the most rapid growth is assumed, there will be 25.7 persons for every one there now. For the next 25 yr, the steady 4% rate appears to be the most reasonable, even though the steady 7% rate may be the best for the next few years.

Assumptions of a steady rate of growth may be highly unrealistic. The rate of growth will decline and approach zero by some future date late in this century or early in the next. (6) A major limiting factor to growth on the Reservation is water availability. Even if all deferred rights were called upon, this scarce resource will limit population growth severely. Any growth by agriculture or industry will restrict population growth even further, because water which otherwise might be used for culinary purposes would be needed for irrigation and industry.

Also presented in Figure 4-3 are estimates of growth at a steady rate for 10 yr, and declining to zero growth at 50 yr. This is referred to as a "declining rate of growth".

It is not clear whether any of the population projections of Figure 4-3 are an adequate basis on which to base population concentrations near the Shiprock millsite; nevertheless, both the declining 4% and the declining 7% projections indicate that there will be pressures on the community to expand its commerce, industry, services, and residential areas. The population may double over the next 50 yr, or it may triple or quadruple in that time.

4.3 LAND USE

The tailings site at Shiprock is one of two Navajo Nation uranium tailings sites currently being used for other purposes. The former plant office, some buildings, and the tailings piles have been used by the Navajo Engineering and Construction Authority (NECA) since 1973 as its main office, shop, and training center to train Navajos to operate earthmoving equipment. Instructors spend four nights a week living in trailers at the site. The students are on site during the daylight hours during their 12-wk course.

The area directly across the San Juan River to the east and northeast of the tailings site is agricultural. A single unpaved runway airstrip was located immediately south of the tailings area. The area south of the site is presently used for low-density grazing. The area southwest of the site is an industrial site. Farther south and west are residential areas. The closest area to the west is unoccupied at present. (See Figure 4-4.) The most densely occupied sections of Shiprock parallel the main traffic arteries of the area. The sections north and west of the site include a school, some commercial land (including two motels, a bank, and a trading post), a church, and a hospital.

At present the tailings site is a prime area for development and is a logical site for expanded industry. The presence of the tailings could hinder the location of new businesses nearby; however, there is no lack of vacant land in the vicinity for an industrial project. The principal limitations on development in the Shiprock area are water, assignment of land rights to individuals, and other factors. The Navajo Tribal Council projects an additional 10,000 jobs in the relatively near future for Shiprock. According to all projections, the Shiprock area undoubtedly will experience considerable growth in the next decade. Consequently, indications are that the available land in the Shiprock area will become valuable.

4.4 IMPACT OF THE TAILINGS ON LAND VALUES

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

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

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

This lack of a traditional monetary market for land exchanges on the Navajo Reservation makes it difficult to calculate the dollar value of the site and its environs. However, recent land exchanges by the Navajo Tribal Council whereby they purchased off-Reservation land and exchanged it for Tribal land is one indication. Another indication is the recent lease payments for Navajo lands projected into land values. Comparisons with land values in the Farmington area give an indication of the

worth of the Shiprock site. Also, by assigning a monetary value to sheep production per acre of land, and by translating this value into capital-valued land, another cash valuation may be determined.

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

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

FIGURE 4-1. MAP OF NAVAJO POLITICAL JURISDICTIONS

130-01

LEGEND

SPARSELY POPULATED

LOW DENSITY POPULATION

POPULATION CENTER

U.S. HIGHWAY

STATE HIGHWAY

INDIAN RESERVATION BOUNDARY

FIGURE 4-2. MAP OF POPULATION CENTERS

130-01

FIGURE 4-3. POPULATION PROJECTIONS

130-01

FIGURE 4-4. VICINITY LAND USE PATTERNS

130 01

CHAPTER 4 REFERENCES

1. Office of Program Development; The Navajo Nation; "The Navajo Nation Overall Economic Development Program", Window Rock, Arizona: The Navajo Tribe; 1974.
2. J. L. England; "Baseline Data and Land Use Impact of the Shiprock Uranium Mill Tailings Site"; Center for Health and Environmental Studies, Brigham Young University, Provo, Utah; 1976.
3. M. Wistisen, R. Parsons, and A. Larsen; A Study to Identify Potentially Feasible Small Businesses for the Navajo Nation, Vols I and II; Center for Business and Economic Research, Brigham Young University, Provo, Utah; 1975.
4. G. Boyle; Economic Status of the Navajo on the Reservation, 1969; University of New Mexico; Albuquerque, New Mexico; 1973.
5. R. G. Faich, Director of Research; Navajo Research and Statistics Center; Window Rock, Arizona; personal communication with Dr. J. L. England, Brigham Young University, Provo, Utah; 1976.
6. J. Echols; Population vs the Environment: A Crisis of too Many People; American Scientist, Vol 64; pp. 165-173; 1976.

CHAPTER 5
RECOVERY OF RESIDUAL VALUES

CHAPTER 5

RECOVERY OF RESIDUAL VALUES

The principal purpose of this chapter is to address questions such as the following:

- (a) Do the Shiprock tailings piles represent a future uranium resource?
- (b) Should the piles be reprocessed before stabilization?
- (c) Is there any likelihood that once stabilized the piles would be disturbed again?

The feasibility of economic recovery at each millsite is a function of:

- (a) Total mineral recovery
- (b) Reprocessing costs
- (c) Market price

5.1 PROCESS ALTERNATIVES

Three proposed alternative methods of treating uranium tailings to recover uranium are: (a) placing the tailings on a prepared pad and heap leaching, (b) treating at an existing mill, and (c) treating at a new conventional mill.

5.1.1 Heap Leaching

In heap leaching, the mill tailings are placed on an impermeable pad for leaching with appropriate reagents. The pregnant solution is collected in the pad drainage system and processed for uranium recovery.

The percent of uranium recovery for both heap leach and conventional mill operation is given in Figure 5-1.⁽¹⁾ Because it is difficult to obtain optimum conditions for metal extraction in heap leaching, the uranium recovery using the heap leach method is only about 56% of a conventional mill operation. However, the construction costs of a heap leaching facility are only about 80% of the costs for a conventional uranium mill. The operating costs for a heap leach plant are also lower than for a conventional mill for plants below 2,000 tons/day.

⁽¹⁾ See end of chapter for references.

The heap leaching site must be an acceptable tailings disposal site that can be readily stabilized and maintained as discussed in Chapter 8.

5.1.2 Treating in an Existing Plant

In order to consider reprocessing the tailings in an existing conventional mill, it is necessary that a mill with excess milling capacity be reasonably close to the tailings sites. There are six existing uranium mills that are between 140 and 160 mi from Shiprock. Four of these have capacities exceeding 2,000 ton/day.

Reprocessing of mill tailings at an existing uranium mill must be economically feasible and lower in cost than other acceptable remedial alternatives. The mill must have available excess capacity and the tailings must be amenable to the existing treatment process. Finally, the active mill tailings disposal site should be able to handle safely the additional tailings and to allow ready stabilization and maintenance of the tailings piles.

The major advantages of treating the uranium in an existing mill are the elimination of the construction costs of a new mill and the consolidation of two tailings piles.

5.1.3 Treating in a New Mill

The advantages of treating the tailings in a new mill are: (a) the process would be designed specifically for the tailings (crushing and/or grinding circuit may not be needed), (b) the millsite would be chosen to assure a safe and relatively low-cost disposal of the tailings, and (c) a conventional uranium mill would provide a higher recovery over a heap leaching facility. (See Figure 5-1.)

The major disadvantage of a new conventional uranium mill is the construction costs, which are about 25% higher than a heap leaching facility.

5.2 SHIPROCK RECOVERY ECONOMICS

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

5.2.1 Recovery

The Shiprock tailings piles contain 1.7 million tons of tailings as determined from company records.⁽¹⁾ However, the piles also contain about 300,000 to 500,000 tons of stabilization material, rubble and other contaminated material that has been mixed with the tailings. It would be difficult to separate all of this material from the tailings.

Auger samples from the upper and lower tailings piles were combined into three composite samples: the upper pile, the lower pile and the combined piles. The analyses of these composite samples are presented in Table 5-1.

These assays indicate uranium content of the two piles as follows:

<u>File</u>	<u>% U₃O₈</u>	<u>Total Tons of Tailings</u>	<u>Lb U₃O₈ Contained</u>
Upper	0.011	1,056,000	232,300
Lower	0.013	594,000	154,400
Total	0.012	1,650,000	386,700

Further sampling would be necessary before reprocessing could be considered. Operating company records indicate that the 1.7 million tons of tailings contain an average of 0.01% U₃O₈ or 340,000 lb U₃O₈ which is in substantial agreement with the above findings.

5.2.2 Reprocessing Costs

Reprocessing costs include the operating and construction costs of any new facilities.

A range of operating costs for both heap leaching and conventional uranium mills as a function of plant capacity are shown in Figures 5-2 and 5-3.⁽¹⁾ The operating costs of heap leach plants range from \$2.65 to \$4.45/ton. The operating costs of conventional uranium mills range from \$2.70 to \$8.50/ton, depending on the nature of the ore and the size of the plant.

Plots of construction costs of heap leach facilities and conventional uranium mills as a function of plant capacity are shown in Figures 5-4 and 5-5.⁽¹⁾ The construction costs of a heap leach plant range from \$2.8 to \$27 million for a 500- to 5,000-ton/day uranium mill, while a conventional mill costs from \$3.5 to \$33 million. The construction costs of a conventional uranium mill are about 25% higher than those of a heap leach facility of the same capacity.

5.3 ASSESSMENT OF SHIPROCK MINERAL RECOVERY POTENTIAL

Using Figures 5-1 through 5-5, the breakeven cost of recovery for the Shiprock piles can be calculated as follows:

	<u>U₃O₈ Recover- able (lb)</u>	<u>Operating Costs (\$M)</u>	<u>Construction Costs* (\$M)</u>	<u>Total Cost (\$M)</u>	<u>Cost/ lb (\$)</u>
Heap leach	80,100	5.9	3.8	9.7	122
Conventional	140,500	11.6	4.7	16.3	116
Haulage to Existing Mill	140,500	11.6	23.1**	35.0	249

*For a 500-ton/day facility

**Transportation cost for 140 mi at \$0.10/ton-mi

From the economic evaluation of the reprocessing of the Shiprock tailings it can be seen that none of the three proposed options are presently economically feasible. The lowest cost for reprocessing appears to be \$116/lb in a conventional mill. This value is based on current dollars and includes no interest costs, inflation costs nor allowance for profit.

While it is always possible that technological improvements may be developed to improve the basis for estimation of production costs used herein, it is unlikely that they will be of such magnitude as to significantly affect the conclusions based upon the experience in the uranium industry over the last 25 years.

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

130-01

FIGURE 5-2. OPERATING COSTS OF HEAP LEACHING OF URANIUM MILL TAILINGS CONTAINING 0.01 TO 0.05% U_3O_8 WITH URANIUM RECOVERY FROM 20 TO 35% (COST ADJUSTED TO JANUARY 1977)

130-01

FIGURE 5-3. OPERATING COSTS OF CONVENTIONAL MILLING W/O CRUSHING AND GRINDING FACILITIES TO REPROCESS TAILINGS CONTAINING 0.01 TO 0.05% U_3O_8 WITH URANIUM RECOVERY RANGING FROM 35 TO 60% (COST ADJUSTED TO JANUARY 1977)

FIGURE 5-4.

CONSTRUCTION COSTS OF HEAP LEACHING PLANT TO REPROCESS URANIUM MILL TAILINGS CONTAINING 0.01 TO 0.05% U_3O_8 WITH URANIUM RECOVERY 20 TO 35% (COST ADJUSTED TO JANUARY 1977)

130-01

FIGURE 5-5. CONSTRUCTION COSTS OF A CONVENTIONAL URANIUM MILL W/O CRUSHING AND GRINDING FACILITIES TO REPROCESS TAILINGS CONTAINING 0.01 TO 0.05% U_3O_8 WITH URANIUM RECOVERY RANGING FROM 35 TO 60%
(COST ADJUSTED TO JANUARY 1977)

130-01

TABLE 5-1

ASSAY RESULTS OF COMPOSITE TAILINGS SAMPLES

Element	Composite Upper Pile Sample, %	Composite Lower Pile Sample, %	Composite Sample Both Piles, %
Spectrographic Analysis			
Aluminum	>1.0	>1.0	>1.0
Arsenic	0.783×10^{-6}	0.027×10^{-6}	0.405×10^{-6}
Calcium	>1.0	>1.0	>1.0
Boron	<0.01	<0.01	<0.01
Copper	<0.01	<0.01	<0.01
Gallium	<0.01	<0.01	<0.01
Iron	>1.0	>1.0	>1.0
Lead	0.01-1.0	0.01-1.0	0.01-1.0
Manganese	0.01-1.0	0.01-1.0	0.01-1.0
Molybdenum	0.01-1.0	0.01-1.0	0.01-1.0
Nickel	<0.01	<0.01	<0.01
Potassium	0.01-1.0	0.01-1.0	0.01-1.0
Selenium	0.356×10^{-6}	0.008×10^{-6}	0.182×10^{-6}
Silica	>1.0	>1.0	>1.0
Sodium	0.01-1.0	0.01-1.0	0.01-1.0
Titanium	<0.01	<0.01	<0.01

Chemical Analysis

Uranium (U_3O_8)	0.011	0.013	0.012
Vanadium (V_2O_5)	0.033	0.026	0.033

Plant Operating Estimate^a

Uranium (U_3O_8)	0.01
----------------------	------

^aCalculated tail assay based on plant operation

CHAPTER 5 REFERENCES

1. ERDA-GJO; private communication.

CHAPTER 6
MILL TAILINGS STABILIZATION

CHAPTER 6

MILL TAILINGS STABILIZATION

In most of the alternative remedial actions which have been considered, the stabilization of mill tailings is a required process. Government agencies and private industry have carried out limited research to develop economical and environmentally suitable methods of uranium tailings site stabilization. All present methods, technology, and research data on stabilization that are available were reviewed to determine the best approach. In addition, experiments are being conducted to determine the relative effectiveness of various stabilization techniques.

The objective of stabilizing the uranium mill tailings is to eliminate the pathways to the environment of the radioactive and other toxic particles as described previously in Chapter 3. 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

6.1 PREVENTION OF WIND AND WATER EROSION

Wind and water erosion can be prevented by chemical stabilization of the surface, complete chemical stabilization, physical stabilization, and vegetative stabilization.

6.1.1 Chemical Stabilization of the Surface

This process involves applying chemicals to the surface of the tailings to form a water- and wind-resistant crust. Chemical 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 prevent the use of cover vegetation. Chemical surface stabilizers, however, are susceptible to physical breakup and gradual degradation and will not meet the long-term requirements for the Shiprock tailings piles.

Other complications also can arise in achieving satisfactory chemical stabilization in that the surfaces of tailings piles seldom are homogeneous, and variables such as particle size

and moisture content affect the bonding characteristics of the chemical stabilizers.⁽¹⁾

Tests were conducted by the Bureau of Mines⁽¹⁾ 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 lignolsulfonate 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 to achieve surface stabilization and to reduce wind erosion. The attempt was unsuccessful because the material decomposed and the tailings were exposed within 2 to 3 yr.

Since no chemical sealant has been used successfully to stabilize uranium tailings for more than a few years, this method has not been considered in the various stabilization alternatives presented in Chapter 9.

6.1.2 Complete Chemical Stabilization

This process which has been used in other mineral industry operations involves the addition of chemicals in sufficient quantities to a slurry to produce a chemical reaction which solidifies the slurry. Chemicals may be added in two ways: to a slurry pipeline, and in situ. The in situ method of stabilization is relatively new and extensive research is required in each individual situation to define the optimum chemical addition to produce the desired results.

One of the features claimed for this stabilization method is that all pollutant chemicals are locked in the solidified slurry and chemicals cannot be leached from the solid.

The cost of this stabilization method is expensive for the chemicals alone. A cover material, such as gravel, would be required to protect the solidified slurry from wind and water erosion. It is not known whether vegetation can be established after topsoil and other soil cover have been spread over the solidified slurry. This probably would be a function of the

⁽¹⁾ See end of chapter for references.

specific chemical makeup of the solidified slurry and would require research to identify the conditions under which vegetation could thrive.

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, etc.) Thin covers of concrete or asphaltic materials have been shown to break down over relatively short periods of time; and starting within a few years after application, continuing maintenance is required. A concrete covering sufficiently thick and properly reinforced would be relatively permanent and maintenance-free, but the cost would be prohibitive for large areas.

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. Such treatments can reduce greatly long-term maintenance costs.

6.1.4 Vegetative Stabilization

This method involves the establishment of vegetative cover on the tailings or on a growing medium placed over the tailings.

Many species of plants are self-regenerating and require little or no maintenance after growth becomes established. Vegetation can survive providing that:

- (a) Evapotranspiration is not excessive
- (b) Landscapes are properly shaped
- (c) Nontoxic soil mediums capable of holding moisture are provided
- (d) Irrigation and fertilization appropriate to the area are applied

Growth of vegetation at sites receiving less than 10 in. of annual precipitation and with high evapotranspiration rates requires irrigation and fertilization. At Shiprock, rainfall averages 8 in. annually. Consequently, vegetative stabilization at the site would not be reliable. However, even in desert areas some sparse volunteer vegetation has established itself on stabilized and unstabilized piles.

One potential problem in the use of vegetative stabilization is the possibility of pickup of radioactive elements by the plants. The effect of this mechanism has not been considered in the present assessment.

6.2 PREVENTION OF LEACHING

Leaching into underground aquifers is one of the several pathways that chemicals and radioactive materials might take into the environment. There is little direct evidence that migration of radioelements from the Shiprock tailings is likely to constitute a problem. The techniques which could be employed to control leaching include the following:

- (a) Line the storage area with an impermeable membrane (Bentonitic clays and various plastic materials commonly are used for this purpose).
- (b) Employ chemical stabilization to prevent leaching into underground aquifers (This is the same stabilization system discussed in paragraph 6.1.2).
- (c) Physically compact the tailings to reduce the percolation of water through the materials.
- (d) Contour the tailings surface, then employ appropriate chemicals (discussed in paragraph 6.1.1) to seal the surface, thus preventing water from penetrating and destabilizing the tailings.

Since aquifers are not threatened at the Shiprock site, prevention of leaching is not essential.

6.3 REDUCTION OF RADON EXHALATION

Little research has been directed toward reduction of radon exhalation from tailings piles. While there are materials that can seal or contain the gas in small quantities, none of these are suitable for permanent coverage of large areas.

From simplified diffusion theory estimates, about 13 ft of dry soil^(2,3) 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 illustrates curves of the reduction of radon exhalation flux for three soil types versus depth of cover based upon the theory and diffusion coefficients presented in the above references. Research is 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 chemical 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 exhalation control.

6.4 REDUCTION OF GAMMA RADIATION

A few feet of cover material are sufficient to reduce gamma radiation to acceptable levels.

The reduction of gamma exposure rates resulting from a packed earth covering is given in Figure 6-2.⁽⁴⁾ Two feet of cover reduces the gamma levels by about two orders of magnitude. Therefore, an average cover of 2 ft should reduce gamma levels to less than 10 μ R/hr above background.

6.5 ASSESSMENT OF APPLICABILITY

Available data indicate that none of the methods used thus far to stabilize uranium tailings sites has been a totally satisfactory solution to uranium tailings site radiation problems. Some of the methods examined have exhibited short-term advantages, but no economical long-term solutions have become apparent. Consequently, new methods of stabilization may have to be developed and additional engineering research may be required.

FIGURE 6-1. REDUCTION OF RADON EXHALATION FLUX WITH DEPTH OF COVER

130-01

NOTE:
FROM REFERENCE 4

FIGURE 6-2. REDUCTION OF GAMMA EXPOSURE RATE
RESULTING FROM PACKED EARTH SHIELDING

130-01

CHAPTER 6 REFERENCES

1. "Methods and Costs for Stabilizing Fine Sized Mineral Wastes"; Bureau of Mines Report, RI7896; 1974.
2. A. B. Tanner; "Radon Migration in the Ground - A Review"; The Natural Radiation Environment; J. A. D. Adams and R. W. Lowder, eds; University of Chicago Press; 1964.
3. H. W. Kraner, G. L. Schroeder, and R. D. Evans; "Measurements of the Effects of Atmospheric Variables of Radon-222 Flux and Soil-Gas Concentrations"; The Natural Radiation Environment; J. A. D. Adams and R. W. Lowder, eds; University of Chicago Press; 1964.
4. K. J. Schiager; "Analysis of Radiation Exposures on or Near Uranium Mill Tailings Piles"; Radiation Data Report 15; 1974.

CHAPTER 7
OFF-SITE REMEDIAL ACTION

CHAPTER 7

OFF-SITE REMEDIAL ACTION

Two closely related objectives of this engineering assessment are to identify those structures and land areas off-site where tailings are located and, based upon the Surgeon General's guidelines and on criteria established for this assessment, to estimate the costs of appropriate remedial action.

Some tailings have been transported off the site by individuals, others by wind and water erosion.

For the purposes of this report, the tailings that have eroded off the tailings piles to surrounding land areas both on and off the site are considered in this chapter.

7.1 DATA SOURCES

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

The EPA gamma survey for windblown tailings and the EPA work plan were the data sources for consideration of the remedial action for open land areas.

7.2 REMEDIAL ACTION FOR STRUCTURES

Uranium ore was found and removed from one property, and three locations had tailings in the yard more than 10 ft from a structure. Five locations had tailings within 10 ft.

Four of the locations with tailings within 10 ft of the structure had corrected outside gamma readings ranging from 47 to 75 $\mu\text{R/hr}$. An inside gamma reading was recorded at only one of the four locations and that reading was in the background range. The other location, No. 41600, had radioactive material under the structure. The survey indicated that the material probably was uranium mine waste rather than uranium mill tailings. Before the Shiprock mill began operations, a concrete slab at this location was used as an ore transfer station. During World War II many small loads of uranium ore were being delivered to this station from the many small mines in the area. At the station the loads of ore were deposited on the concrete

slab, then reloaded onto larger trucks for hauling to mills located off the Navajo Reservation. The last time ore was stored at the ore transfer site was in late 1950. Since then, the station has been partially decontaminated and buildings have been constructed on the lot. Gamma radiation measurements inside the structure at this location showed 18 $\mu\text{R/hr}$ above background through the slab. Outside the structure, a maximum 175 $\mu\text{R/hr}$ was recorded. EPA radon daughter concentration measurements inside the structure indicated a yearly average of about 0.008 WL with a maximum of 0.02 WL.

Subsequent to the 1971 mobile survey another commercial off-site location with high RDC has been identified.⁽¹⁾ At this location, No. 41775, RDC measurements for 1975-1976 yielded a yearly average of about 0.04 WL and a maximum of 0.06 WL. Gamma surveys indicate the radioactive material is probably in the walls.⁽¹⁾

For the purposes of this engineering assessment costs of \$80,000 have been estimated for remedial action off-site. The costs include the structures for which the need for remedial action may be anticipated. An extended series of measurements, such as required in the full application of the Grand Junction Remedial Action Criteria, might reduce the actual number of locations included in the remedial action.

7.3 REMEDIAL ACTION FOR OPEN LANDS

The extent of windblown tailings is indicated by the EPA data in Figure 3-10, Chapter 3. Decontamination of windblown tailings consists of removing the off-pile contaminated soil and returning it to the tailings piles. Although the Phase II criteria (Appendix A-2) state that the area for windblown soil removal is determined by residual gamma radiation of no more than 10 $\mu\text{R/hr}$, costs are included to remove contaminated soil to reduce gamma readings to background as is proposed in the EPA work plan. (See Appendix B.) The cost for this additional work is only \$5,000 and is included in all options. The depth of the soil to be removed varies from 2 in. at the outside soil removal boundary to 2 ft at the edge of the tailings piles.

Where the upper pile parallels, but is higher than the San Juan River, there is evidence of contamination along portions of the Mancos Shale outcropping. Also, some of the tailings have been carried by wind and water into several of the small gullies or washes that separate the pile from the river. The rough topography of the drainage ways makes recovery action very costly. However, if the tailings and contaminated material

⁽¹⁾ See end of chapter for references.

are to be relocated from the present site to an alternative site, then these drainage ways should be decontaminated to the extent practicable.

During the mill's operation, water was supplied by a water line which originated at a well approximately 0.25 mi north of the ore storage area. The trench dug for this line is back-filled with contaminated material. The estimated cost to remove this material is \$10,000; the task is considered in all of the cost options of Chapter 9.

CHAPTER 7 REFERENCE

1. J. M. Hans, Jr.; "Decontamination of the Shiprock, New Mexico Uranium Mill Site"; EPA-ORP-LV-76-12 (in preparation).

CHAPTER 8

LONG-TERM STORAGE SITE SELECTION

CHAPTER 8

LONG-TERM STORAGE SITE SELECTION

In seven of the alternative remedial actions which are considered in this assessment, the Shiprock tailings would be moved to a site more isolated from the populace. For convenience, long-term (greater than 50 yr) storage sites for tailings are referred to in this report as disposal sites.

8.1 CRITERIA FOR LONG-TERM STORAGE

New Mexico state officials, the Indian Health Service, the Bureau of Indian Affairs, and the Navajo Environmental Protection Agency were contacted to locate possible disposal sites for the Shiprock tailings. In all, eight disposal sites were considered and a reconnaissance survey was made of each, but only seven are described in detail. (See Figure 8-1.)

Each site was evaluated on the basis of hydrology, meteorology, geology, ecology and economics. The hydrologic and meteorologic conditions were assessed with regard to such factors as wind and water erosion, water contamination, flooding and drainage characteristics, precipitation, access to bedrock, and location of confined aquifers. The geologic examination addressed stability problems and soil characteristics such as evidence of slides or faults, and types of unconsolidated and bedrock materials. The ecological study evaluated land use potential, animal habitats, proximity to population centers, and aesthetic considerations. Economic considerations included preliminary estimates of support facilities such as highways, distance from the Shiprock site, and the extent of site preparation and long-term maintenance required at the site.

8.2 GENERAL DESCRIPTION OF DISPOSAL SITE AREAS

Of the eight sites listed in Table 8-1, seven were selected for cost estimate studies. These sites are indicated by asterisks in the tables. These locations are relatively close to the existing site yet are demographically remote. All of the sites selected are on Navajo Nation land and within the Shiprock Chapter, except for the coal mine site.

The Shiprock area is one of the expanding population centers within the Navajo Nation and the selection of these sites bears that fact in mind. Storing the tailings in the Shiprock area in the wrong place could result in a future situation similar to the present problem unless they are placed in such a manner that access is limited, radioactive materials are contained and the radiation is reduced significantly.

In addition to the site selection criteria given in paragraph 8.1, consideration was given to current land productivity (e.g.

grazing), topsoil availability, drainage basin configurations, and subsurface drainage.

Although the vast areas of the Navajo Nation seem to offer unlimited locations for long-term storage sites, consideration of the criteria limits the number of locations that are practical. Continued isolation on most of the sites selected is almost assured. Physical stabilization would be accomplished with sand, gravel, and soil coverings from the storage area. Volunteer vegetation of the stabilized piles would occur with the passage of time by natural processes.

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

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

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

8.3 RETURN TO ORIGINAL MINE SOURCES

The return of tailings to the mines from which the ores were obtained is impractical. The ores processed at the plant came from many mines scattered over a wide area. The average haul to the Shiprock mill was over 100 mi. Many of these mines contributed only a few hundred tons and some of them are still active. Others have collapsed long ago.

FIGURE 8-1. PROPOSED DISPOSAL SITES

130-01

TABLE 8-1

SITES EVALUATED AS REPOSITORIES FOR THE SHIPROCK TAILINGS

<u>Site Name</u>	<u>Site Identification Number</u>
Shiprock Campground 6.75 mi S-W from pile	1*
Many Devils 4.0 mi S-E from pile	2*
Shiprock Airport 6.0 mi S-E from pile	3
Hogback 16.0 mi S-E from pile	4*
Rattlesnake 8.25 mi W from pile	5*
Oil Field 8.5 mi S-E from pile	6*
Operating Open-Pit Coal Mines 26.0 mi E from pile	7*
Salt Creek 8.5 mi S-E from pile	8*

*Alternative disposal sites selected for cost studies

CHAPTER 9

REMEDIAL ACTIONS AND COST-BENEFIT ANALYSES

CHAPTER 9

REMEDIAL ACTIONS AND COST-BENEFIT ANALYSES

Various remedial actions for the tailings were identified and investigated. The alternatives presented are those considered to be the most realistic and practical when evaluated in regard to the present technology, equipment, and transportation facilities available. Remedial measures for the site can be separated into three basic categories:

- (1) Minimal remedial action
- (2) Stabilization at the Shiprock site
- (3) Removal of tailings and stabilization at alternative sites

Several of the remedial measures are common to all the alternative approaches costed; these measures were considered in estimating the total cost of each option. For example, in nearly all of the options, fencing would be required around the tailings. Unless specified otherwise, the standard fencing included in all options is 6-ft-high chainlink fence with three strands of barbed wire along the top. Also, radiation warning signs would be displayed prominently on the fence, gates, and in other appropriate areas and facilities. The off-site remedial action described in Chapter 7 is included in all options.

Another measure considered in all options except the minimal remedial action is the stabilization of the tailings with at least 2 ft of pit-run earth, sand, and gravel. This action would greatly reduce gamma radiation and wind and water erosion.

Long-term maintenance also would be required for most of the options. The maintenance would generally include periodic inspection and repair of fences, signs, and stabilizing cover.

Provision for the annual maintenance costs for an extended period of time is included in the form of a sinking fund which at 7% annual interest would provide the money necessary for projected inspection and maintenance functions.

9.1 MINIMAL REMEDIAL ACTION (OPTION I)

The principal objective of this option is to complete the appropriate remaining on-site and off-site work specified in the EPA decontamination plan recommendations to NECA. Appendix B of this report contains the EPA recommendations and a progress report describing the status of the ongoing decontamination efforts by NECA as of May 1976. This option provides for only the effort necessary to maintain the site and prevent further

serious deterioration. It does not provide for long-term stabilization.

The 10 main tasks recommended in the EPA original plan are shown in Figure B-2, Appendix B. Those remaining tasks to be addressed or modified in this option are as follows:

- (a) Task 1c -- Obtain permission to decontaminate areas immediately adjacent to the site.
- (b) Tasks 4e, 5c -- Decontaminate the interiors and exteriors of those buildings to remain on-site.
- (c) Tasks 7, 8 -- Decontaminate Areas B and A. (See Figure B-1, Appendix B.)
- (d) Task 9 -- Cover the lower tailings pile with 6 in. of clean material.
- (e) Task 10 -- Install security fencing.

The areas A and B would be decontaminated to background gamma levels.

9.1.1 Security and Maintenance

The tailings area would be fenced, and radiation warning signs would be posted prominently. Gates would be installed to allow access to inspection and maintenance crews and equipment.

A continuing program of periodic inspection and maintenance would be required to ensure that the fence, gates, and warning signs remain secure, and that the structural integrity of the piles remains intact. Operation of a sprinkler system as necessary to prevent further wind erosion is a part of the maintenance program.

9.1.2 Resulting Impacts

Under this option the eventual release of some radioactive materials from the tailings piles could occur, although not to the extent that has occurred in the past. The projected exposure of the public to contamination is described in Chapter 3, paragraph 3.4.

The use of existing buildings and appropriate areas by NECA could continue; however, the property would be restricted to prevent new construction on it and it would have limited future use.

9.1.3 Costs

As shown in Table 9-1, at \$540,000 this is the lowest cost option. The major cost components are as follows:

(a) Engineering (10% of item b)	\$ 25,000
(b) Remedial Action	250,000
(c) Environmental Assessment and EIS preparation	20,000
(d) Contingency (15% of items a, b, and c)	45,000
(e) Sinking Fund	<u>200,000</u>
Total Cost	\$540,000

The sinking fund at 7% annual interest will provide \$14,000 for the annual inspection and maintenance required.

9.2 STABILIZATION OF THE TAILINGS ON SITE, 2-FT COVER (OPTION II)

In addition to the actions taken in Option I, the lower tailings pile would be contoured, then covered with a minimum of 2 ft of pit-run earth, sand, and gravel which are available on the site at 0.5-mi haul distance. The cover then would be appropriately contoured to minimize wind and water erosion.

The stabilization cover on the upper pile would be increased to 2 ft. This material would be placed and graded to form ridges, structured at right angles to the slope to prevent water erosion. The steep slopes of the upper pile would be covered with riprap material for better control of wind and water erosion.

Adequate dikes would also be installed around the edges of the piles, and the natural drainage of the area would be routed around the isolated piles. No attempt would be made to vegetate the stabilized pile, nor would irrigation be required.

9.2.1 Security and Maintenance

The comments of paragraph 9.1.1 also are applicable in this option.

9.2.2 Resulting Impacts

Stabilization as proposed in Option II would be more effective than Option I in preventing the spread of tailings by wind and water. The 2 ft of cover material would reduce the gamma radiation to near background levels, but probably would not significantly reduce the exhalation of radon (no more than 25%). The greater depth of stabilization cover would offer greater resistance to wind and water erosion and the added riprap would increase stability of the piles, decreasing maintenance requirements versus Option I. However, the steep slopes of the sides of the upper tailings pile could be expected to require continuing maintenance.

The site would have limited use due to the physical presence of the piles and the associated radiation.

9.2.3 Costs

As shown in Table 9-1, the cost of this option is estimated at \$1,100,000. The major components are as follows:

(a) Engineering (9% of item b)	\$ 66,000
(b) Remedial Action	731,000
(c) Environmental Assessment and EIS preparation	20,000
(d) Contingency (15% of items a, b, and c)	123,000
(e) Sinking Fund	<u>160,000</u>
Total Cost	\$1,100,000

The sinking fund at 7% interest would provide approximately \$11,000 a year for inspection and maintenance. The expected maintenance of the two piles would be less than that of Option I by some \$3,000/yr.

9.3 STABILIZATION OF THE TAILINGS ON SITE, 4-FT COVER (OPTION III)

In addition to the actions taken in Option II, this option includes the contouring of both piles into one by moving the top portion of the upper pile onto the lower pile to reduce slope angles. The earth cover then could be applied more easily and would withstand water and wind erosion more successfully. The cost of this procedure is estimated to be less than covering the two piles without reducing the existing slopes.

The entire consolidated pile would be covered with 4 ft of pit-run earth, sand, and gravel yielding an approximate radon reduction of 60%. No dikes would surround the pile, but drainage ways would be formed so that natural runoff from the uphill area towards the site would flow around the stabilized pile. Careful attention would be given to the sides of the pile where the wind and water erosion potential are the greatest. At the base of the pile, 2-ft thick riprap would be placed to a height of 3 ft above the surrounding ground. The surface of the pile would be finish-graded to form rows of terraces at right angles to the surface slope. The terraces would be approximately 3 ft wide and 14 in. high, and should help to contain surface runoff from the pile. No attempt would be made to revegetate the stabilized pile, nor would irrigation be required.

9.3.1 Security and Maintenance

With the engineering and construction work (placement of stabilization and riprap) completed satisfactorily, inspection and maintenance, although required, would be reduced compared to Options I and II. However, the same level of attention to fence and warning signs still would be required.

9.3.2 Resulting Impacts

Stabilization as proposed would prevent the spread of tailings by wind or water and would reduce gamma radiation to near background; furthermore, the radon exhalation would be reduced by about 60% (see Figure 6-1, Chapter 6). The tailings area would be restricted to prevent building construction on it.

9.3.3 Costs

As shown in Table 9-1, the estimated cost for Option III is \$1,600,000. The major cost components are as follows:

(a) Engineering (8% of item b)	\$ 92,000
(b) Remedial Action	1,153,000
(c) Environmental Assessment and EIS preparation	20,000
(d) Contingency (15% of items a, b, and c)	190,000
(e) Sinking Fund	<u>145,000</u>
Total Cost	\$1,600,000

The sinking fund at 7% interest would provide \$10,000 for the expected maintenance.

9.4 STABILIZATION OF THE TAILINGS ON SITE, 13-FT COVER (OPTION IV)

This option is identical to Option III except 13 ft of cover material is applied to the consolidated pile. This is expected to reduce the radon exhalation by about 95% as compared with about 60% in Option III.

9.4.1 Costs

As shown in Table 9-1, the estimated cost for this option is \$3,400,000, which includes all factors described in paragraph 9.3. The major components are as follows:

(a) Engineering (7% of item b)	\$ 180,000
--------------------------------	------------

(b) Remedial Action	\$2,630,000
(c) Environmental Assessment and EIS preparation	20,000
(d) Contingency (15% of items a, b, and c)	425,000
(e) Sinking Fund	<u>145,000</u>
Total Cost	\$3,400,000

Costs are included for obtaining a portion of the cover material from off-site locations if required.

9.5 REMOVAL OF TAILINGS AND ALL CONTAMINATED MATERIALS FROM THE SITE (OPTIONS V-XI)

These seven options provide for the complete removal of all tailings, contaminated soil, buildings, materials, and rubble from the site to a long-term storage area. However, the office, classroom, and shop buildings would be decontaminated and remain on the site.

To comply with decontamination criteria for tailings piles (as described in Chapter 3, paragraph 3.5), the contaminated soils beneath the piles must be removed. The amount of soil to be removed depends on the depth of contamination, which is indicated in Figure 9-1 for the Shiprock site. In this figure, radium concentration is given as a function of depth below the interface. The approximate cost to remove and dispose of the subsoil for the tailings removal options is also presented. The removal of an average of 2 ft of subsoil beneath the tailings area would assure that the residual concentration in the remaining soil is less than twice the background value of 1.7 pCi/l.

9.5.1 On-Site Structures and Facilities

It is assumed that the old mill building will have been removed by the time this work begins. The office, classroom building, and two old shop buildings would be decontaminated and remain on site. The new shop building, erected early in 1976, is free of any radioactive contamination and rests on a clean fill area.

9.5.2 Excavation and Loading of Tailings and Soils

The excavation and loading of the tailings and soil can be performed by normal front-end, scoop-loading, crawler-type tractors or by other borrow removal equipment. Heavy earth-moving vehicles and trucks can operate with ease on and around the site.

Some of the old mill equipment already is buried within the tailings; consequently, a heavy-duty motor crane and low-

bed trucks would be required to move this material to a storage site.

To eliminate further tailings dispersion during loading and transportation operations, site and road dust control equipment and washdown facilities would have to be provided. The lack of moisture in the tailings and native earth would require the use of dust preventive methods in the excavation and loading process.

9.5.3 Backfill

Any backfill material that might be used should be of local pit-run material which is available from around the site. No special treatment of the final surface is considered in this assessment.

9.5.4 Transportation of the Material

There are structure rubble, tailings, and contaminated soil to be removed. There are no rail facilities. A slurry pipeline was considered; while water for this method of transport is available from the San Juan River, demands for water in the area for other purposes precluded its diversion for tailings transport purposes.

Truck transportation is the most logical and economical means to haul the material because most of the haul distances involved are relatively short. Trucks could move the tailings, debris, and other material from the site at the rate of about 4,800 tons/day. The material could be loaded by earth excavating equipment directly into the trucks. At the rate of 4,800 tons/day, on a 5-days-a-week 11-months-a-year basis, all the materials could be removed in approximately 1.8 yr. This estimate assumes that conventional truck-trailer dump trucks would be used. Dust control measures, such as water trucks for the roads and covers and washdown facilities for the trucks, and costs for repair of public roads are included in the trucking costs.

9.5.5 Disposal and Storage at Alternative Sites

A general description and list of the proposed storage sites are given in Chapter 8.

The deposit procedure would involve removing topsoil from the site, constructing containment dike(s), depositing the tailings and covering the tailings with the removed topsoil to a depth of at least 2 ft in most cases. The relocated and stabilized tailings would be gently sloped and contour-graded to minimize water erosion. Figure 9-2 illustrates in a schematic representation how these long-term storage sites would be developed.

Of the alternative sites evaluated, those in the following tabulation were selected as most suitable when compared with criteria for long-term storage:

<u>Option</u>	<u>Site</u>	<u>Site No.</u>
V	Many Devils	2
VI	Shiprock Campground	1
VII	Rattlesnake	5
VIII	Salt Creek	8
IX	Oil Field	6
X	Hogback	4
XI	Open-Pit Coal Mine	7

9.5.5.1 Option V - Many Devils (Site No. 2)

This alternative site is the closest one to the existing Shiprock site, 4 mi by existing roads but 2 mi straight line distance. It is about 0.25 mi north of the gravel road which runs east off U.S. Highway 666 to an oil field near the town of Shiprock. The site is within an area used for very limited winter grazing.

For site preparation, the top 2.5 ft of soil from over an area of approximately 40 acres of a natural geological surface depression would be removed and stockpiled. A containment dike would be constructed at one end as shown in Figure 9-2. The tailings then would be deposited up to 25 ft thick and the overburden used to stabilize the top of the pile. The site would be fenced with a 6-ft chainlink fence.

The advantages of the site are the short haulage distance, the availability of stabilization material, the natural drainage characteristics with which diking would allow for virtual self-containment and the separation of the pile from downstream drainage, and the impermeable Mancos Shale bedrock beneath the site.

The principal disadvantage is the potential growth of the town of Shiprock in this direction, negating the isolation features desired in a long-term storage site.

As shown in Table 9-1, the estimated total cost is \$5,800,000. The major cost components are as follows:

(a) Engineering (7% of item b)	\$ 295,000
--------------------------------	------------

(b) Remedial Action	\$4,235,000
(c) Environmental Assessment and EIS preparation	385,000
(d) Contingency (15% of items a, b, and c)	740,000
(e) Sinking Fund	<u>145,000</u>
Total Cost	\$5,800,000

This cost includes all of the work of Option I, the cost of tailings area contaminated material removal to this storage site, fencing, and inspection and maintenance. A sinking fund for the inspection and physical maintenance of the fencing and stabilized pile is included in an amount which will provide \$10,000 annually for the projected work.

9.5.5.2 Option VI - Shiprock Campground (Site No. 1)

The Navajo Tribal Park Authority has established a small campground facility near the intersection of the newly paved Redrock Valley road and U.S. Highway 666, approximately 6 mi south of the town of Shiprock, New Mexico. Approximately 9.75 mi northwest of the campground is a site suitable for development into a long-term storage site for the tailings. The disposal site is not visible from the campground. The site also is hidden from the highway by bluffs.

If this site were selected, the top 2 ft of the existing soil material over an area of approximately 50 acres of a naturally depressed area would be removed and stockpiled. A containment dike would be constructed, the tailings would be deposited and the overburden then used to stabilize the top of the pile. The limited watershed area south of the site away from the pile would be graded to divert surface water.

The advantages of this site are its easy accessibility by means of a good highway to the campground area and a 0.75-mi-long haul road from the campground to the site, its natural drainage characteristics, the impermeability of the Mancos Shale bedrock, and the availability of stabilization material.

A disadvantage is the ease of trespass onto the site because of its nearness to the main highway.

As shown in Table 9-1, the estimated total cost is \$6,100,000. The major cost components are as follows:

(a) Engineering (7% of item b)	\$ 315,000
(b) Remedial Action	4,480,000
(c) Environmental Assessment and EIS preparation	385,000

(d) Contingency (15% of items a, b, and c)	\$ 775,000
(e) Sinking Fund	<u>145,000</u>
Total Cost	\$6,100,000

9.5.5.3 Option VII - Rattlesnake (Site No. 5)

This option site is located approximately 8 mi west of Shiprock. The tailings would be deposited against a 30-ft-high bluff in an area on a gradual plain leading to the Shiprock Mountain.

Forty acres along the bluff would be covered to a depth of approximately 25 ft with tailings and other contaminated material and 2 ft of earth cover. The covered pile would be contour-graded to minimize water erosion.

The advantages of the site are the limited acreage that would be disturbed and have to be maintained, and the relatively short haul road distance and easy hauling conditions.

The site's disadvantages include the sandstone bedrock which may act as a ground water recharge area and the limited amount of available stabilization cover material.

As shown in Table 9-1, the estimated total cost is \$6,900,000. The major cost components are as follows:

(a) Engineering (6% of item b)	\$ 310,000
(b) Remedial Action	5,180,000
(c) Environmental Assessment and EIS preparation	385,000
(d) Contingency (15% of items a, b, and c)	880,000
(e) Sinking Fund	<u>145,000</u>
Total Cost	\$6,900,000

The sinking fund at 7% would provide \$10,000 annually for the expected maintenance.

9.5.5.4 Option VIII - Salt Creek Area (Site No. 8)

This site area is located 8.5 mi northeast of Shiprock, along the high side of a gentle ridge sloping into the Salt Creek Wash. In several locations in this area there are naturally formed three-sided basinlike areas, any one of which could be used as a long-term repository for the tailings.

The tailings would be placed in an excavated area where enough of the natural earth and rocks would be removed to form

a dike and to provide 2 ft of surface cover. The tailings would cover approximately 50 acres to a contoured-level depth of approximately 20 ft.

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

A disadvantage is the requirement that the tailings would have to be hauled through the town of Shiprock, including a left turn through a traffic signal and up a 6% grade for 0.5 mi, and the construction of 2.25 mi of haul road.

As shown in Table 9-1, the estimated total cost is \$7,000,000. The major cost components are as follows:

(a) Engineering (6% of item b)	\$ 315,000
(b) Remedial Action	5,260,000
(c) Environmental Assessment and EIS preparation	385,000
(d) Contingency (15% of items a, b, and c)	895,000
(e) Sinking Fund	<u>145,000</u>
Total Cost	\$7,000,000

9.5.5.5 Option IX - Oil Field (Site No. 6)

This site area is located about 10 mi southeast of Shiprock, and about 2 mi east of the new Shiprock airport. There are producing oil wells in the area. There are several locations in this area with similar drainage conditions. With some excavation, these areas can be formed into almost natural basins.

The tailings would be placed on Mancos Shale bedrock from which 2 ft of surface material would be removed for later stabilization of the pile. The tailings pile would cover approximately 50 acres to a depth of about 20 ft. A dike would be formed to contain the tailings, and natural drainage channels would be rerouted to bypass the tailings.

The advantages of the sites in this area are their natural drainage configurations of limited watershed potential, their ability to be separated from other drainage systems, their access to highways, their nearness to stabilization material, and the underlying impermeable bedrock.

As shown in Table 9-1, the estimated total cost is \$7,200,000. The major cost components are as follows:

(a) Engineering (6% of item b)	\$ 325,000
(b) Remedial Action	5,425,000
(c) Environmental Assessment and EIS preparation	385,000
(d) Contingency (15% of items a, b, and c)	920,000
(e) Sinking Fund	<u>145,000</u>
Total Cost	\$7,200,000

9.5.5.6 Option X - Hogback (Site No. 4)

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

The tailings would be placed on the eastern slope of the drainage swale in an area eroded out of the bedrock. Approximately 80 acres would be covered by about 15 ft of tailings, which then would be stabilized with a minimum of 2 ft of cover material. The tailings would be isolated further by construction of dikes.

The site's advantages are its isolation from population centers, its isolated drainage system, its lack of serious water erosion features, and its lack of potential for future development.

The disadvantages of the site include the sandstone bedrock which may act as a recharge medium, the limited availability of stabilizing material, the long distance from a paved road, and the possible adverse effects on the relatively good grazing land.

As shown in Table 9-1, the estimated total cost is \$12,000,000. The major cost components are as follows:

(a) Engineering (6% of item b)	\$ 560,000
(b) Remedial Action	9,315,000
(c) Environmental Assessment and EIS preparation	385,000
(d) Contingency (15% of items a, b, and c)	1,540,000
(e) Sinking Fund	<u>200,000</u>
Total Cost	\$12,000,000

The maintenance sinking fund is larger in this option than for all the other storage sites because of its remoteness. Travel time for personnel, equipment and materials would require an additional \$4,000/yr for these efforts.

9.5.5.7 Option XI - Within an Operating Open-Pit Coal Mine (Site No. 7)

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

The advantages of the site are that the tailings would be permanently buried under at least 50-100 ft of overburden, radon emissions would be contained, the tailings would not interfere with future land uses, and fencing and maintenance would be unnecessary although an appropriate identification monument would be placed at the site.

Disadvantages are the necessity of obtaining approvals, the potential problems of interference with coal mining operations, and the haulage cost over heavily traveled public roads. In addition, some Mesa Verde coal-bearing strata have recharge potential to aquifers underlying Farmington; therefore, the mine site would have to be studied to anticipate such a problem.

As shown in Table 9-1, the estimated total cost is \$12,500,000. The major cost components are as follows:

(a) Engineering (4% of item b)	\$ 410,000
(b) Remedial Action	10,230,000
(c) Environmental Assessment and EIS preparation	230,000
(d) Contingency (15% of items a, b, and c)	1,630,000
(e) Sinking Fund	<u>0</u>
Total Cost	\$12,500,000

Due to the deep burial, no maintenance is required.

9.6 ANALYSES OF COSTS AND BENEFITS

As summarized in Table 9-1, the total estimated costs for the 11 remedial options vary from a low of \$540,000 to a high of \$12,500,000. The purpose of this section is to compare the cost of the various alternatives with the corresponding anticipated benefits.

9.6.1 Health Benefits

Each of the remedial action alternatives considered in this chapter has an associated number of health effects that would be avoided as a result of the action. These avoided health effects are referred to as health benefits. In Chapter 3 the estimated number of health effects was determined for the Shiprock tailings piles in their present condition. In order to estimate the number of health benefits attributable to a particular remedial action, the effect of that remedial action on radon exhalation from the piles must be determined, because the health effects calculated in Chapter 3 were associated with radon and its daughters. While there are some benefits associated with actions such as fencing, these have not been quantified in this assessment of health benefits because under present conditions the associated benefits are small compared with those resulting from the reduction of radon exhalation.

In this evaluation, the health benefit of each option is calculated from the reduction in radon exhalation that is expected for that option. For example, if the radon exhalation and, hence, the number of health effects, is reduced by 60% for a particular remedial action, there will be a corresponding health benefit. This health benefit is equal to 60% of the number of health effects that would be expected had the remedial action not been implemented. The radon exhalation is reduced by cover material or by physical removal of the tailings to an isolated location. In the case of cover material of thickness t , the reduction in radon exhalation is given in Figure 6-1, Chapter 6, as a function of $[1 - \exp(-0.2t)]$. Physical removal of the tailings results in a 100% reduction in exposure to the population.

The results of the determination of potential cancer cases avoided (health benefits) for each option are given as a function of time in part A of Table 9-2. While there is a small health benefit predictable from the off-site action, it has not been included in these analyses. Therefore, Option I is shown to have only a minor health benefit from the minimal radon flux reduction. However, Options II through IV have increasing health benefits depending upon the corresponding reduction in radon exhalation, and Options V through IX result in the avoidance of all pile radon-induced potential health effects. The cost per potential cancer case avoided for each option is included as part B in Table 9-2.

As an alternative to the presentation in Table 9-2 the number of potential cancer cases avoided per million dollars expended were calculated and plotted in Figure 9-3. Option III yields the maximum health benefit per unit cost. In contrast, Option IX yields the minimum benefit per unit cost.

The curve shown in Figure 9-3 for Option III was computed for 4 ft of cover material. This thickness was obtained by optimizing the health benefit/cost ratio. Since the radon exhalation, and hence potential health effects, is reduced by cover material by the factor $[1 - \exp(-0.2t)]$, the number of health benefits is $B_0 [1 - \exp(-0.2t)]$, where B_0 is the maximum number of health benefits. If the cost of each option is expressed as a function of cover thickness, such as $(A + bt)$, the benefit-to-cost ratio becomes:

$$\frac{B}{C} = \frac{B_0 [1 - \exp(-0.2t)]}{(A + bt)}$$

where

$\frac{B}{C}$ = Health benefit-to-option-cost ratio in terms of the number of health effects avoided per option cost (in units of $\$10^6$)

t = Cover thickness (ft)

A = Option cost with no cover material

b = Additional cost per foot of cover material

$(A + bt)$ = Option cost for thickness t ($\$10^6$)

B_0 = Maximum number of health effect avoidances

$B_0 [1 - \exp(-0.2t)]$ = Health benefits for thickness t

The above B/C expression was differentiated, set to zero, and solved for t to obtain the thickness which maximized B/C . The expression solved is as follows:

$$t = 5 (\exp 0.2t - 1) - A/b$$

Less cover does not attenuate the radon gas sufficiently, and more cover increases the cost with very little additional decrease in radon emission. The optimized thickness provides the best balance between cost and health benefit. For Option III, a radon exhalation reduction of about 60% is achieved with 30% of the cover material thickness (4 ft) that would be required for 95% reduction (13 ft). (See Figure 6-1, Chapter 6.)

9.6.2 Land Value Benefits

Because all Reservation land is owned commonly by the Navajo Tribe, there is no conventional valuation for Navajo properties. There are ways, however, that dollar values of land on the Navajo Reservation can be approximated. (This was discussed in Chapter 4.) It is estimated that the value of land in the Shiprock area used for grazing purposes, with the presence of an occasional residence, corral, or shed is no more than \$50/acre. The value of the site as it now exists would be approximately \$200/acre. If the tailings were to be removed, the site would be worth approximately \$3,500/acre as industrial land. The site contains 230 acres. Under Option II (2-ft stabilization cover) the value of the land would remain about the same as a result of restricted use. Under Option IV (13-ft cover) the value of the land, except for the portions occupied by the pile, could increase to as much as \$1,000/acre; hence, the total net land value of the available 158 acres could be as much as \$158,000. Under Options V through XI, where the tailings would be relocated and the site decontaminated, the net increase in property value could be as much as \$759,000.

FIGURE 9-1. RADIUM ACTIVITY CONCENTRATION IN CONTAMINATED SUBSOIL

130-01

FIGURE 9- 2 SCHEMATIC OF TYPICAL LONG-TERM TAILINGS STORAGE SITE

130-01

FIGURE 9-3. POTENTIAL CANCER CASES AVOIDED
PER MILLION DOLLARS EXPENDED

130-01

Table 9-1
COST ESTIMATE SUMMARY

COST OPTION NUMBER	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
Description	Tailings Remain at Shiprock				Tailings Removed From Shiprock Site For Storage And Stabilization At:						
	Minimal remedial action	Stabilization at the site	Stabilization at the Site Pile Consolidation	Stabilization at the site Pile Consolidation	Many Devils area	Shiprock Campground area	Rattlesnake Site	Salt Creek site	Oilfield site	Hogback site	An Operating Open-Pit Coal Mine
		2 ft cover	4 ft cover	13 ft cover	2 ft cover						
Storage Site Identification Number					Site No. 2	Site No. 1	Site No. 5	Site No. 8	Site No. 6	Site No. 4	Site No. 7
REMOVAL COST											
Minimum Cost (used in cost-benefits analysis). For Options V through XI this cost includes removal from Shiprock of all tailings and rubble and removal of 2 ft of material below the tailings interface with the natural soil.	540	1,100	1,600	3,400	5,800	6,100	6,900	7,000	7,200	12,000	12,500
Minimum cost plus cost to remove 3 ft of subsoil beneath tailings interface					6,090	6,400	7,220	7,320	7,510	12,623	13,210
Minimum cost plus cost to remove 4 ft of subsoil beneath tailings interface					6,380	6,720	7,530	7,630	7,830	13,250	13,930
REMOVAL PLUS BACKFILL COST											
Minimum cost plus backfill of site to surrounding property surface					6,270	6,570	7,370	7,470	7,670	12,465	12,970
Minimum cost plus cost to remove 3 ft of subsoil beneath tailings interface and backfill to surrounding property surface					6,720	7,040	7,840	7,940	8,140	13,240	13,830
Minimum cost plus costs to remove 4 ft of subsoil beneath tailings interface and backfill to surrounding property surface					7,160	7,500	8,300	8,400	8,600	14,020	14,700

Notes: 1. All costs are total costs (in thousands of dollars) and are presented in 1976 dollars.

TABLE 9-2

POTENTIAL CANCER CASES AVOIDED AND COST
PER POTENTIAL CANCER CASE AVOIDED

A. NUMBER OF POTENTIAL CANCER CASES AVOIDED											
Options:	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
Option Costs in Million \$	0.54	1.10	1.60	3.40	5.80	6.10	6.90	7.00	7.20	12.00	12.50
Years After Remedial Action											
25	0	1	3	5	5	5	5	5	5	5	5
50	1	5	11	17	18	18	18	18	18	18	18
75	3	12	25	39	41	41	41	41	41	41	41
100	8	30	59	94	99	99	99	99	99	99	99
Potential Cancer Cases After 100 yr	91	69	40	5	0	0	0	0	0	0	0
B. COST PER POTENTIAL CANCER CASE AVOIDED (Million \$)											
Options:	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
Option Costs in Million \$	0.54	1.10	1.60	3.40	5.80	6.10	6.90	7.00	7.20	12.00	12.50
Years After Remedial Action											
25	1.35	0.76	0.55	0.75	1.19	1.25	1.42	1.44	1.48	2.46	2.58
50	0.39	0.21	0.15	0.21	0.33	0.35	0.39	0.40	0.41	0.68	0.71
75	0.16	0.09	0.07	0.09	0.14	0.15	0.17	0.17	0.17	0.29	0.30
100	0.07	0.04	0.03	0.04	0.06	0.06	0.07	0.07	0.07	0.12	0.13

APPENDIX A
REMEDIAL ACTION CRITERIA

- A.1 Surgeon General's Guidelines
- A.2 Radiological Criteria for Decontamination of Inactive Uranium Mill Sites
- A.3 Grand Junction Remedial Action Criteria (10CFR12)

APPENDIX A

REMEDIAL ACTION CRITERIA

The remedial action criteria used for the Phase II assessment of the cleanup of mill tailings are presented in the following documents:

A.1 SURGEON GENERAL'S GUIDELINES

DEPARTMENT OF HEALTH, EDUCATION AND WELFARE,
PUBLIC HEALTH SERVICE,
Washington, D. C., July 1970.

DR. R. L. CLEERE,
Executive Director, Colorado State Department of Health, 4210
E. 11th Avenue, Denver, Colorado

DEAR DR. CLEERE: I am pleased to respond to your letter of January 29 in which you asked Dr. M. W. Carter, Director of our Southwestern Radiological Health Laboratory, for Public Health Service and/or U. S. Atomic Energy Commission assistance in providing exposure guidelines applicable to homes with high concentrations of radon progeny.

The enclosed graded recommendations for action have been developed within the framework of existing Federal Radiation Council guidance for occupational exposure to airborne concentrations of radon and its daughters (progeny). Also, graded action levels applicable to external gamma radiation are included.

You will note in the accompanying Explanatory Notes that these recommendations apply specifically to dwellings constructed with or on uranium mill tailings. Further qualifications in the Explanatory Notes should be consulted before these recommendations are applied.

The specific information which your Department is developing on the variability of radon daughter concentrations in dwellings and on optimum control measures will be essential towards making those decisions necessary in applying the recommendations.

These recommendations have been directed to the Atomic Energy Commission for comment. Because of the urgency attached to your receiving the recommendations as soon as possible, they have been forwarded to you in advance of receiving AEC views and comments. We will advise you of the AEC response when received.

Sincerely yours,

PAUL J. PETERSON,
Acting Surgeon General

Enclosure:

RECOMMENDATIONS OF ACTION FOR RADIATION EXPOSURE LEVELS IN DWELLINGS
CONSTRUCTED ON OR WITH URANIUM MILL TAILINGS

External gamma radiation:

Level:	Recommendations
Greater than 0.1 mR/hr . . .	Remedial action indicated.
From 0.05 to 0.1 mR/hr . . .	Remedial action may be suggested.
Less than 0.05 mR/hr . . .	No action indicated.

Level:	Recommendations
Greater than 0.05 WL	Remedial action indicated.
From 0.01 to 0.05 WL	Remedial action may be suggested.
Less than 0.01 WL	No action indicated.

EXPLANATORY NOTES

1. These recommendations are written specifically for dwellings constructed on or with uranium mill tailings. This situation may involve continuous exposure of members of the public to radon daughter product activities and whole-body gamma irradiation levels in excess of the background radiation levels found within dwellings in the area not constructed with or on uranium mill tailings.

2. Although the initial concern was the presence of radon daughter product activities within these dwellings, preliminary surveys have indicated that in some instances, the gamma radiation levels were of prime importance. Thus, recommendations are made concerning both types of radiation. The recommendations applicable to a particular dwelling will be determined by whichever type of radiation has the high level.

3. Three levels for action are recommended for both external gamma and radon daughter product exposures. This graded system of actions is proposed to allow latitude in the middle ranges for the judgment of the on-site investigators.

4. The external gamma and radon daughter product levels proposed constitute exposures which are in addition to the natural background levels found within dwellings in the area not constructed on or with uranium mill tailings. In the Grand Junction, Colorado, area these levels are approximately 0.01 mR/hr (approximately 90 mrem/yr) and 0.004 Working Levels (WL) (approximately 0.2 CWLM/yr) respectively (1).

5. The expected health effects of concern will be different for the two types of radiation; i.e., leukemia for whole-body gamma radiation exposure and lung cancer for exposure to inhaled radon daughter products. This expectation is based, in part, on findings derived from population studies such as the Japanese atomic bomb

survivors and uranium miners. These specific health effects are considered to be mutually exclusive. The basis for this assumption is that the expected radiation contribution to whole-body exposure from inhaled radon and daughter products would be considerably less than the direct exposure from external gamma radiation at the levels encountered in the dwellings. Conversely, the external gamma radiation contribution to the lung dose is considered to comprise a negligible additional risk of lung cancer.

6. (a) A Working Level (WL) is the term used to describe radon daughter product activities in air. This term is defined as any combination of short-lived radon daughter products in 1 liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy (2). The numerical value of the WL is derived from the alpha energy released by the total decay through Ra C' of the short-lived radon daughter products, Ra A, Ra B and Ra C, at radioactive equilibrium with 100 pCi of ^{222}Rn per liter of air (3).

6. (b) A Working Level Month (WLM) is the term used to express the occupational exposure incurred in one working month of 170 hours by a uranium miner laboring in an atmosphere containing radon daughter products; i.e., one working month in a mine atmosphere containing 1 WL of radon daughter products equals 1 WLM.

6. (c) Cumulative Working Level Months (CWLM) is the term used to express the total accumulated occupational exposure to radon daughter products in air; i.e., an air concentration of radon daughter products of 1 WL would, in one working month, equal 1 WLM, and in 1 year or 12 months would equal 12 CWLM.

6. (d) Since occupational exposures are based upon 170 hours per month and continuous exposure involves approximately 170 hours per week, then an occupational exposure to an air concentration of 1 WL is equivalent to continuous exposure to 0.025 WL.

7. These recommendations are based on the assumption of a linear, non-threshold dose-effect relationship. The lack of definitive information precludes allowances for possible differences in radio-sensitivity due to age, sex, or other biological characteristics.

8. No action is indicated when the external gamma exposure rate is less than 0.05 mR/hr and the radon daughter product activity is less than 0.01 WL since under conditions of continuous exposure these levels would result in maximum annual exposures of approximately 400 mrem and 0.5 CWLM, respectively. The maximum annual value of 400 mrem is less than the dose limits recommended for an individual body exposure to external gamma irradiation.

The ICRP (5) recommends that the annual dose limit for members of the public shall be 1/10 of the corresponding annual occupational maximum permissible dose. The maximum annual value of 0.5 CWLM of radon daughter product exposure is approximately 1/10 of the 4 CWLM annual occupational exposure limit recommended by the FRC (6) for implementation on 1 January 1971, and less than 1/20 of the

annual occupational exposure limit of 12 CWLM recommended for uranium miners in the present FRC regulations (4).

9. Remedial action may be suggested in the case of external gamma exposure rates of 0.05-0.10 mR/hr or radon daughter product activities of 0.01-0.05 WL since under conditions of continuous exposure these levels would result in maximum annual exposures of approximately 400-900 mrem and 0.5-2.5 CWLM. The upper limit of these ranges exceeds the strictly applied recommendations of the FRC and ICRP for exposures of an individual member of the public. However, this extension seems justified in situations in which unforeseen exposures have occurred, since as stated by ICRP (5) "in general it will be appropriate to institute countermeasures only when their social cost and risk will be less than those resulting from the exposure." It is further stated by the ICRP (5) that very low levels of risk are implied in the dose limits for members of the public and that it is likely to be of minor consequence to their health if the dose limits are marginally or even substantially exceeded.

10. Remedial action is indicated at gamma exposures greater than 0.1 mR/hr or at radon daughter product activities greater than 0.05 WL. Under conditions of continuous exposure, these levels would result in minimum annual exposures of 900 mrem and 2.5 CWLM. All values above these would indicate the necessity for remedial action, since at these levels the maximum annual exposures recommended by the FRC and ICRP for an individual member of the public is exceeded.

11. With respect to the external gamma irradiation, from the estimates published by ICRP (7), it can be interpolated that the annual risk of leukemia under conditions of continuous exposure to 500 mrem per year is an increased incidence of about 10 cases per year per million persons exposed. The natural annual incidence of leukemia for all ages is given by ICRP (8) as 10-100 cases per million persons. With respect to radon daughter product exposures, it has been estimated by Archer and Lundin (9) that an exposure of 120 CWLM to a group of white adult males in the United States appears to approximately double the normal lung cancer incidence which for this population is about 2-3 cases per year per 10,000 persons. At an annual exposure of 2.5 CWLM, 48 years would be required to reach 120 CWLM.

12. It is considered that implementation of these recommendations for the various exposure ranges would make it highly unlikely that any serious health effects would result from exposure to radon daughter products or external gamma irradiation in this particular situation.

13. It is suggested that remedial action be taken only after an adequate number of measurements taken under a diversity of temporal and climatic conditions have clearly established that the average exposure is in excess of 0.1 mR/hr or 0.05 WL exist and in instituting corrective measures. However, it is considered that the additional health risks from continued exposure over this time period are of lesser consequence than the economic and social discomfitures of precipitous action.

Approved.

/s/ PAUL J. PETERSON,
for Jesse L. Steinfeld, M.D.,
Surgeon General, Public Health Service

July 27, 1970

REFERENCES

1. Personal communication, Mr. Robert D. Siek, Colorado State Department of Health.
2. U.S. Public Health Service Publication No. 494, Control of Radon and Daughters in Uranium Mines and Calculations on Biological Effects, 1957.
3. Federal Radiation Council Report No. 8 Revised, Guidance for the Control of Radiation Hazards in Uranium Mining, 1967.
4. Federal Radiation Council Report No. 1. Background Material for the Development of Radiation Protection Standards, 1960.
5. Recommendations of the International Commission on Radiological Protection, ICRP Publication 9, 1966.
6. Federal Register, Vol. 34, No. 10, pp 576-577, 1969.
7. The Evaluation of Risks from Radiation, ICRP Publication 8, 1966.
8. Radiosensitivity and Spatial Distribution of Dose, ICRP Publication 14, 1969.
9. V.E. Archer and F. E. Lundin, Jr., Radiogenic Lung Cancer in Man: Exposure-Effect Relationship, Environmental Research 1, pp 370-383, 1967.

A.2 RADIOLOGICAL CRITERIA FOR DECONTAMINATION OF INACTIVE URANIUM MILL SITES*

1. General

Radiological criteria for an engineering assessment of possible remedial actions applicable to uranium mill tailings piles and for the decontamination of inactive uranium mill sites are provided herein. These criteria are applicable to the sites, to their surrounding areas which have been contaminated by radioactive materials from the sites, and to buildings in which the materials have been used.

Critical radiation exposure pathways from inactive uranium mill sites to members of the general population are:

- (a) Radon escaping from the tailings pile carried by the wind into habitable structures where the holdup time is long enough, resulting in buildup of radon daughters to levels greater than the ambient air.
- (b) Tailings material used for construction of habitable structures can result in a buildup of radon daughters and increased gamma levels.
- (c) Gamma rays from tailings material cause whole body radiation exposure. This includes not only the "gamma shine" from the tailings pile that exposes people living nearby, but also the radiation exposure from tailings material that has been eroded off the pile onto surrounding land. The mill sites always show elevated gamma exposure levels because of contamination by ore, tailings solids, and process solutions.
- (d) ^{226}Ra , Th, and other radionuclides from tailings piles can be leached into ground water and thereafter into public and irrigation water supplies.
- (e) Windblown particulate material (Ra and Th) from the tailings pile can be inhaled causing a radiation dose to the lung.

Remedial actions may be required on inactive uranium mill tailings piles to reduce or prevent excess radiation exposure from radon progeny, gamma radiation, ^{226}Ra , and radioactive particulate material. If tailing material has been used as a building material, remedial actions may be required to reduce radon concentrations and/or gamma activity levels. Remedial actions performed on tailings piles

*Provided by U S Environmental Protection Agency, as attachment to letter dated Dec 1974.

and decontamination of mill sites and surrounding contaminated areas should result in residual exposures that are as low as practicable. There is no single permissible exposure level applicable to all such cases. An evaluation should be made on a case-by-case basis of the risk involved, balanced against (1) the cost of reducing the residual contamination, and (2) the economic effect on alternatives such as restricting the use of the land. The result of such an analysis can be used by all concerned to define the "as low as practicable" residual level of contamination that will be acceptable and determine whether restrictions will be required on the use of any contaminated land.

2. Tailings Pile or Pond

The operation of uranium mills results in the generation of waste material which is disposed of in tailings piles and ponds. Environmental contamination has occurred at those sites where measures were not taken to control the movement of the radioactive material. In order to restore the environmental quality and provide for protection of the public, such sites should be decontaminated and result in residual gamma radiation levels which are as low as practicable. For most situations this would require decontamination of the area by (1) removal of radioactive material to a location where the material would be isolated from the biosphere, or (2) providing sufficient cover such that the resultant gamma radiation levels are as low as practicable, preferably at background. However, under certain topographical conditions and economic considerations wherein complete removal is not practicable, the residual levels should not exceed 40 μ R/hr above background. This value is arbitrarily chosen for the purpose of providing an engineering estimate on cleanup of contaminated areas. It is considered to be sufficiently low that the expected exposures occurring after any remedial action at this level would not constitute a public concern. However, this should not be considered as the final criterion.* The gamma radiation level is the net, corrected measurement at 3 ft above the ground.

For each site a determination should be made of the radium concentration in the soil. Cleanup should reduce the soil concentration to less than two times the radium background specific for the area.

If the radioactive material remains in place and stabilized, the area should be designated as a controlled area. Due to the difficulty of controlling radon diffusion and the existing state-of-the-art of stabilization, the land should be restricted as to human occupancy and be properly fenced to limit access.

*When all phase II information is complete and the health impact of remedial actions identified an overall determination of as low as practicable protection levels can be assessed appropriately. Therefore, the above numbers are subject to change.

The ^{226}Ra activity contribution from the site in ground or surface water should meet applicable state or federal standards.

3. Open Land Areas

This area refers to all land beyond the fence of the sites where tailings are located. As with the tailings areas, decontamination of the uranium mill site and other areas contaminated by wind- or water-eroded tailings should result in residual gamma levels which are as low as practicable. Cleanup of the area would require returning of the windblown tailings material to the site and establishing a controlled area, or moving all the material to a location that will isolate the material from the biosphere.

If the residual gamma levels are less than $10\mu\text{R/hr}$ above background, the land may be released for unrestricted use. If residual levels are equal to or greater than $10\mu\text{R/hr}$ above background at a given site a determination should be made of the radium concentration in the soil. Cleanup should reduce the soil concentration to no more than two times the radium background specific for the area. Under certain topographical conditions wherein complete removal of tailings is not possible or practicable, the residual levels should be as low as practicable but should not exceed $40\mu\text{R/hr}$ above background and access should be controlled. This value is arbitrarily chosen for the purpose of providing an engineering estimate on cleanup of contaminated areas. The gamma radiation level is the net, corrected measurement at 3 ft above the ground.

4. Structures

It is possible that there will be several industrial and residential structures where tailings have been utilized for construction purposes. When it has been determined that tailings were used in the construction, the lower limits of the guidelines established by the Surgeon General for structures in Grand Junction, Colorado, will be used.

A.3 GRAND JUNCTION REMEDIAL ACTION CRITERIA (10CFR12)

Sec.	
12.1	Purpose.
12.2	Scope.
12.3	Definitions.
12.4	Interpretations.
12.5	Communications.
12.6	General radiation exposure level criteria for remedial action.
12.7	Criteria for determination of possible need for remedial action.
12.8	Determination of possible need for remedial action where criteria have not been met.
12.9	Factors to be considered in determination of order of priority for remedial action.
12.10	Selection of appropriate remedial action.

§ 12.1 Purpose.

(a) The regulations in this part establish the criteria for determination by the Commission of the need for, priority of and selection of appropriate remedial action to limit the exposure of individuals in the area of Grand Junction, Colo., to radiation emanating from uranium mill tailings which have been used as a construction-related material.

(b) The regulations in this part are issued pursuant to Public Law 92-314 (86 Stat. 222) of June 16, 1972.

§ 12.2 Scope.

The regulations in this part apply to all structures in the area of Grand Junction, Colo., under or adjacent to which uranium mill tailings have been used as a construction-related material between January 1, 1951, and June 16, 1972, inclusive.

§ 12.3 Definitions.

As used in this part:

(a) "Area of Grand Junction, Colo." means Mesa County, Colo.

(b) "Background" means radiation arising from cosmic rays and radioactive material other than uranium mill tailings.

(c) "Commission" means the U.S. Atomic Energy Commission or any duly authorized representative thereof.

(d) "Construction-related material" means any material used in the construction of a structure.

(e) "External gamma radiation level" means the average gamma radiation exposure rate for the habitable area of a structure as measured near floor level.

(f) "Indoor radon daughter concentration level" means that concentration of radon daughters determined by: (1) Averaging the results of 6 air samples each of at least 100 hours duration, and taken at a minimum of 4-week intervals throughout the year in a habitable area of a structure, or (2) utilizing some other procedure approved by the Commission.

(g) "Milliroentgen (mR)" means a unit equal to one-thousandth (1/1000) of a roentgen which roentgen is defined as an exposure dose of X or gamma radiation such that the associated corpuscular emission per 0.001293 grams of air produces, in air, ions carrying one electrostatic unit of quantity of electricity of either sign.

(h) "Radiation" means the electromagnetic energy (gamma) and the particulate radiation (alpha and beta) which emanate from the radioactive decay of radium and its daughter products.

(i) "Radon daughters" means the consecutive decay products of radon-222. Generally, these include Radium A (polonium-218), Radium B (lead-218), Radium C (bismuth-214), and Radium C' (polonium-214).

(j) "Remedial action" means any action taken with a reasonable expectation of reducing the radiation exposure resulting from uranium mill tailings which have been used as construction-related material in and around structures in the area of Grand Junction, Colo.

(k) "Surgeon General's guidelines" means radiation guidelines related to uranium mill tailings prepared and released by the Office of the U.S. Surgeon General, Department of Health, Education and Welfare on July 27, 1970.

(l) "Uranium mill tailings" means tailings from a uranium milling operation involved in the Federal uranium procurement program.

(m) "Working Level" (WL) means any combination of short-lived radon daughter products in 1 liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy.

§ 12.4 Interpretations.

Except as specifically authorized by the Commission in writing, no interpretation of the meaning of the regulations in this part by an officer or employee of the Commission other than a written interpretation by the General Counsel will be recognized to be binding upon the Commission.

§ 12.5 Communications.

Except where otherwise specified in this part, all communications concerning the regulations in this part should be addressed to the Director, Division of Operational Safety, U.S. Atomic Energy Commission, Washington, D.C., 20545.

§ 12.6 General radiation exposure level criteria for remedial action.

The basis for undertaking remedial action shall be the applicable guidelines published by the Surgeon General of the United States. These guidelines recommend the following graded action levels for remedial action in terms of external gamma radiation level (EGR) and indoor radon daughter concentration level (RDC) above background found within dwellings constructed on or with uranium mill tailings:

EGR	RDC	Recommendation
Greater than 0.1 mR/hr.	Greater than 0.05 WL.	Remedial action indicated.
From 0.05 to 0.1 mR/hr.	From 0.01 to 0.05 WL.	Remedial action may be suggested.
Less than 0.05 mR/hr.	Less than 0.01 WL.	No remedial action indicated.

§ 12.7 Criteria for determination of possible need for remedial action.

Once it is determined that a possible need for remedial action exists the record owner of a structure shall be notified of that structure's eligibility for an engineering assessment to confirm the need for remedial action and to ascertain the most appropriate remedial measure, if any. A determination of possible need will be made if as a result of the presence of uranium mill tailings under or adjacent to the structure, one of the following criteria is met:

(a) Where Commission approved data on indoor radon daughter concentration levels are available:

PART 12 - GRAND JUNCTION REMEDIAL ACTION CRITERIA

(1) For dwellings and schoolrooms: An indoor radon daughter concentration level of 0.01 WL or greater above background.

(2) For other structures: An indoor radon daughter concentration level of 0.03 WL or greater above background.

(b) Where Commission approved data on indoor radon daughter concentration levels are not available:

(1) For dwellings and schoolrooms:

(i) An external gamma radiation level of 0.05 mR/hr. or greater above background.

(ii) An indoor radon daughter concentration level of 0.01 WL or greater above background (presumed).

(a) It may be presumed that if the external gamma radiation level is equal to or exceeds 0.02 mR/hr. above background, the indoor radon daughter concentration level equals or exceeds 0.01 WL above background.

(b) It should be presumed that if the external gamma radiation level is less than 0.001 mR/hr. above background, the indoor radon daughter concentration level is less than 0.01 WL above background, and no possible need for remedial action exists.

(c) If the external gamma radiation level is equal to or greater than 0.001 mR/hr. above background but is less than 0.02 mR/hr. above background, measurements will be required to ascertain the indoor radon daughter concentration level.

(2) For other structures:

(i) An external gamma radiation level of 0.15 mR/hr. above background averaged on a room-by-room basis.

(ii) No presumptions shall be made on the external gamma radiation level/indoor radon daughter concentration level relationship. Decisions will be made in individual cases based upon the results of actual measurements.

§ 12.9 Factors to be considered in determination of order of priority for remedial action.

In determining the order of priority for execution of remedial action, consideration shall be given, but not necessarily limited to, the following factors:

(a) *Classification of structure.* Dwellings and schools shall be considered first.

(b) *Availability of data.* Those structures for which data on indoor radon daughter concentration levels and/or external gamma radiation levels are available when the program starts and which meet the criteria in § 12.7 will be considered first.

(c) *Order of application.* Insofar as feasible remedial action will be taken in the order in which the application is received.

(d) *Magnitude of radiation level.* In general, those structures with the highest radiation levels will be given primary consideration.

(e) *Geographical location of structures.* A group of structures located in the same immediate geographical vicinity may be given priority consideration particularly where they involve similar remedial efforts.

(f) *Availability of structures.* An attempt will be made to schedule remedial action during those periods when remedial action can be taken with minimum interference.

(g) *Climatic conditions.* Climatic conditions or other seasonal considerations may affect the scheduling of certain remedial measures.

§ 12.10 Selection of appropriate remedial action.

(a) Tailings will be removed from those structures where the appropriately averaged external gamma radiation level is equal to or greater than 0.05 mR/hr. above background in the case of dwellings and schools and 0.15 mR/hr. above background in the case of other structures.

(b) Where the criterion in paragraph (a) of this section is not met, other remedial action techniques, including but not limited to sealants, ventilation, and shielding may be considered in addition to that of tailings removal. The Commission shall select the remedial action technique, or combination of techniques, which it determines to be the most appropriate under the circumstances.

§ 12.8 Determination of possible need for remedial action where criteria have not been met.

The possible need for remedial action may be determined where the criteria in § 12.7 have not been met if various other factors are present. Such factors include, but are not necessarily limited to, size of the affected area, distribution of radiation levels in the affected area, amount of tailings, age of individuals occupying affected area, occupancy time, and use of the affected area.

*Corrected
37 FR 26734

December 31, 1972

610

APPENDIX B

SHIPROCK EPA DECONTAMINATION RECOMMENDATIONS

- B.1 Recommendations for the Decontamination of Uranium Mill Sites on the Navajo Reservation; October 1974
- B.2 EPA Status Report on Evaluation of Inactive Uranium Mill Sites; March, April, and May 1976

ENVIRONMENTAL PROTECTION AGENCY
Office of Radiation Programs
National Environmental Research Center
Las Vegas, Nevada 89114

B.1 RECOMMENDATIONS FOR THE DECONTAMINATION OF URANIUM MILL SITES ON THE NAVAJO RESERVATION

Introduction

A number of uranium mill sites in the United States are inactive or have been abandoned. All of these sites contain radioactive tailings piles which are fully, partially, or not stabilized against wind and water erosion. In addition, some sites contain structures, equipment, and buildings which may be or are being utilized for other activities.

Four of these sites are located on Navajo lands at Tuba City and Monument Valley, Arizona; Mexican Hat, Utah; and Shiprock, New Mexico. Some activities are in progress at the sites and future activities are being considered. Training activities are being conducted at the Shiprock and Mexican Hat sites. Both the Tuba City and Mexican Hat sites are being considered for light industry. Due to its remoteness and lack of structures and buildings, no utilization of the Monument Valley site is presently anticipated.

Radiation from the tailings piles, from scattered tailings, and from uranium ore poses potential radiological health problems to present and future occupants of the sites and surrounding areas. The tailings from uranium milling operations contain essentially all of the natural radioactivity associated with the ore except for the majority of the uranium which is recovered as a product. The principal environmental radiological implications and associated health hazards appear to be related to radionuclides of the uranium-238 decay chain, primarily thorium-230, radium-226, radon-222 (a noble gas), and radon-222 progeny. Although these radionuclides occur in nature, their concentrations in tailings material are several orders of magnitude greater than their average terrestrial concentrations. Thus, the mining and milling processes have made the material more available to cause exposure to man since large quantities of the material have been assembled at the mill site locations in a relatively mobile physical form.

The major potential routes of exposure to man are:

1. Inhalation of wind-blown tailings. The primary hazard relates to thorium-230 and radium-226, each of which cause exposure to both the bone and the lung.
2. Inhalation of the progeny of radon-222, a noble gas, which diffuses from the pile. This exposure is to the lung.
3. External whole body gamma exposure from the radionuclides in the tailings pile (primarily radon-222 and its progeny) and in surface contamination from tailings spread around the pile.
4. Hydrological:

a. Ingestion by man of ground or surface water contamination resulting from either radioactivity (primarily radium-226) leached from the tailings material or from radioactivity wind-blown into surface water.

b. Erosion and removal of tailings material from the pile by flood waters. This, in turn, can create additional contaminated locations with the same problems as the original tailings pile.

These potential problems have been recognized by the U.S. Public Health Service's Indian Health Service (IHS) and the Navajo Nation as well as the U.S. Environmental Protection Agency (EPA) and involved State agencies. In order to minimize or alleviate these problems, the IHS and the Navajo Nation wish to seek funding to decontaminate the sites and stabilize the tailings piles. The amount of funds needed is based on the size of the areas requiring decontamination, reshaping, and the amount of material necessary to cover the piles, along with other factors.

The Environmental Protection Agency was requested by the Navajo Tribal Council Chairman to participate in activities to obtain the cost estimates. This participation, determined at an interagency meeting, consisted primarily of delineating the spread and depth of contamination around the mill site. Other supportive radiological information would be gathered during the delineation activities.

Procedures

All of the mill sites and their local environs are contaminated with mill tailings to some degree from wind and water erosion and from mill site activities. In addition, uranium ore lost through handling and storage operations is also present. The spread of mill tailings and ore was delineated by locating iso-exposure rate contour lines around the mill site. Each line corresponds to an above-ground exposure rate due only to scattered tailings and ore. They were constructed from a series of points located with radiation survey instruments modified to detect radiation from scattered tailings and ore on the ground in the presence of direct radiation from the tailings pile. Each point was located from instrument readings taken at increasing distances from the site until a predetermined value was observed. This point was then staked and located by an IHS surveying crew.

Generally, two and sometimes three iso-exposure rate contour lines were located around each site and were designated as 40 μ R/hr, 10 μ R/hr and background lines. If scattered tailings and ore were removed from the inside of the lines, the remaining radioactive materials on the outside of the line would produce an above-ground exposure rate approximately equal to that of the line designation.

The depth of below-grade ore and tailings was determined by bore hole logging. Holes were drilled in the mill site areas

at predetermined locations and a radiation measuring device was lowered into the holes to establish a depth versus instrument reading or gamma log. Interpretation of the logs indicated the depth to which contaminated earth cover should be removed to achieve near background radiation levels. In some areas, inaccessible to drilling equipment, trenches were hand dug to depth where background measurements could be attained. Various types of samples and radiation measurements were made depending on the location and utilization of the sites.

Results and Recommendations

Scattered tailings and ore were observed and measured around all four sites and ranged in distance from several thousands of feet to several hundreds of feet from the piles and mill sites. Mexican Hat and Tuba City appeared to have the most extensive scattering, while Shiprock and Monument Valley were less extensive, respectively. It appears that Shiprock scattering would have been more extensive had the tailings not been wind lifted off the river bluff (about 100 ft high) permitting greater dispersion.

Depths of tailings and ore below-grade generally ranged from 2 to 12 inches. This is exclusive of washes draining the sites, close vicinity of the piles, areas where the ground was disturbed, and where off-site dumping has occurred. Wind-eroded tailings were found to be located within the top two inches of soil except for some "piling" around flora and lee sides of small depressions. Impaction was noted on the sides of abrupt land rises and hills. Water eroded tailings near dikes around the piles were several feet deep while tailings in the washes varied from the surface to several feet in depth. Generally, the washes draining the pile area had tailings down to bedrock in the vicinity of the piles and were contaminated until they entered nearby streams or rivers. Tailings and ore depths in the mill area were found to be highly variable, with an approximate average depth of six inches.

Some recommendations pertaining to decontamination common to all four sites are presented.

Stabilization

Long-term stabilization of the piles is necessary to prevent wind and water erosion and to substantially reduce radon emanation and gamma radiation. In addition, it must be durable and last for many years with minimal maintenance. Some work directed at long-term stabilization is in progress or planned by the Atomic Energy Commission, but results may not be available for near-term application.

Two additional types of stabilization can be employed. One (short-term) can be used during the decontamination activities and the other (interim) to contain the piles until long-term recommendations become available.

Recommendations:

1. In order to prevent recontamination of clean areas during the decontamination activities, short-term stabilization should be applied. This can be accomplished with dust-control chemicals or water.

2. After decontamination has been completed, interim stabilization can be accomplished by chemical stabilization or a six-inch cover of clean fill.

General Decontamination Guidance

Decontamination

In order to complete an effective decontamination effort, radiological recommendations will have to be coordinated with and incorporated {via a meeting(s)} into regular civil engineering aspects of earth moving. The primary purpose of the recommendations are to minimize on-site and off-site airborne radioactive materials and to prevent contamination and recontamination of clean areas.

1. Any required modification of the pile shape should be accomplished first using water or chemicals for dust control, followed by short-term stabilization.

2. High activity areas, exclusive of the pile, should be decontaminated early when practical.

3. Decontamination should begin in upwind areas, where feasible, with water used for dust control.

4. Areas decontaminated should be "secured" and access controlled to prevent recontamination by vehicle and personnel traffic.

5. Earth-moving equipment and operating procedures should be selected on the basis of minimizing the mixing or transfer of contamination to underlying clean earth during stripping of the overlying contaminated earth.

Supportive Radiological Surveys

Decontamination activities should be monitored to assure that the contaminants have been removed from the designated areas and that contamination control procedures are initiated and effective.

Recommendations:

1. Monitor areas as soon as possible during the decontamination effort to locate missed contaminants and to locate isolated spot anomalies.

2. Monitor dust control visually and augment with on- and off-site air sampling.

3. Monitor and decontaminate excavation vehicles entering clean areas and leaving the site.

Radiological Safety

Personnel used for decontamination of the sites are subject to internal and external radiation exposures. External exposure results primarily from gamma radiation emitted from tailings and ore, while internal exposure can result from inhalation and ingestion. Inhalation exposures result from airborne radon daughters and suspended tailings and ore particulates. Ingestion results from material removed from the trachial-bronchial tree and mechanical transfer from contaminated objects such as clothing and equipment.

Recommendations:

1. Approved respirators should be worn by personnel working with tailings and during dusty decontamination operations.

2. Clothing (outer garments and shoes) should be provided for the decontamination personnel and be retained on site.

3. A clothing change and shower area should be provided to minimize personnel contamination and to reduce off-site contamination.

4. Personnel monitoring for internal and external radiation exposure should be provided, if practical, to check personnel protection practices and to provide documentation for legal purposes.

Shiprock

This mill site is located on relatively level ground bounded on the north by a river bluff. It contains one stabilized pile and another pile not stabilized which has been redistributed by recent site activities. The stabilized pile has been breeched in some areas by site activities and erosion.

With reference to the enclosed map (Figure B-1), two lines were established around the mill site. The blue line (background line) indicates the distance from the site that scattered tailings and ore deposited on the ground would produce above ground exposures near background levels provided that the ground inside the blue line is decontaminated. The red line (not shown in Figure B-1) is similar to the blue line except that the approximate above ground exposure rate would be 10 μ R/hr from contamination remaining outside the red line.

Since the red line (10 μ R/hr) and blue line (background) are reasonably close, it is recommended that decontamination of the site occur within the boundary of the blue line.

With regard to topography, past and present site utilization, radiological considerations, and decontamination procedures, the site has been divided into specific areas labeled A through F. Decontamination of each area will be discussed separately.

Area A:

This area (shaded orange) is located at the southeast section of the enclosed map and is bounded by the blue line, river bluff, and a line extending along the southeast boundary of the lagoons.

Recommendations:

1. Remove two inches of topsoil between the red and blue lines.
2. Grade on a taper beginning at two inches deep at the red line to 12 inches deep at the pile edge.

Area B:

This area (shaded green) is located on the southwest section of the site adjacent to Area A bounded by the blue line, the southwest side of the lagoons, and an extension of the line through the points (X0, Y0; X0, Y4).

Recommendations:

1. Remove two inches of topsoil between the blue and red lines.
2. Grade on a taper beginning two inches deep at the red line to 12 inches deep at the pile edge.

Area C:

This area (shaded red) is located in the northwest section of the site and is bounded by the blue line and the northwest site fence line.

The recommendation is to remove two inches of topsoil from this area excluding the main site access road.

Area D:

This area (shaded brown) encompasses the mill site and is bounded by the northwest fence line, the "scale house" road, the tailings pile, a line through points (X0, Y1; X4, Y2), and a line through the points (X4, Y-6; X0, Y-6).

Recommendations:

1. Grade on a taper beginning from the "scale house" road and fence line to the southwest line through the points (X4,Y1; X4,Y-6). The taper should begin at the fence line and road at a depth of two inches and end at 12 inches at the southwest line.

2. Grade 24 inches from the southwest line to the pile location.

Area E:

This area (shaded yellow) is located in the northwest section adjacent to Areas B, C, and D and the lagoon on the southeast side. Equipment and debris have been buried in this suspected lightly used pond.

Recommendations:

1. A sub-area outlined in green within Area E will need to be excavated to a minimum depth of approximately 10 feet based on pile contours and logging information.

2. Grade on a taper of two inches to 12 inches from the sides

Area F:

This area (shaded blue) is located in the northeast corner of the site adjacent to Areas C and D and is bounded by the blue line, the river bluff, and the tailings pile.

Recommendations:

1. Remove fill from this area except the area between the stabilized pile and the river bluff.

2. Remove two inches of topsoil between the red and blue lines.

3. Remove two inches of soil between the red line and the line between the line described by the coordinates (X6, Y-4; X-6 Y-12).

4. Remove six inches of topsoil from the remaining area in Area F. Additional removal of topsoil will be required in this area and will be determined by a radiological survey.

Other Areas:

Main roadway into the site:

Recommendation: Remove four inches of roadbed from the highway to the mill parking lot.

Area between the river bluff and the stabilized pile:

Recommendation: Cover this area, where practical, with six inches of clean fill.

Stabilized pile:

Some of the stabilizing cover for this pile has been eroded away or moved by recent site activities.

Recommendation: Cover the exposed areas with six inches of clean fill.

Site Buildings:

Corroded supporting framework appears to render the mill building structurally unsound and not useable without extensive repairs and renovation.

Recommendations:

1. Tear the building down for salvage provided that the salvageable material can be decontaminated at a reasonable cost. If decontamination costs are determined to be prohibitive, bury the structural material at a specified location in the tailings pile.
2. If no use is anticipated for the building foundation, remove and bury it in the tailings pile. If a use is anticipated, contamination-decontamination assessment will be necessary to determine if utilization is possible.

All other buildings are contaminated to some degree with windblown and tracked tailings and should be decontaminated after the possibility of re-contamination has been minimized.

Recommendations (Any combination of the following may be used where applicable):

1. Dry vacuuming
2. Wet scrubbing
3. Fire hosing

B.2 EPA STATUS REPORT ON EVALUATION OF INACTIVE
URANIUM MILL SITES; MARCH, APRIL, AND MAY 1976

Background

For background information and a description of the responsibilities of various agencies, see our previous reports.

Sites on Navajo Lands

Shiprock Progress Report - Decontamination activities at this site began indirectly with a letter dated November 9, 1973, from the Navajo Tribal Chairman to the EPA Administrator which requested EPA and other Federal agency participation concerning assistance relative to stabilizing the tailings piles at four inactive uranium mill sites of the Navajo Reservation. During April 1974, radiation surveys were conducted around the four sites to determine the extent of wind- and water-eroded mill tailings in order to provide a basis for deriving decontamination cost estimates. Radiological criteria were needed and developed concerning the decontamination of inactive uranium mill sites in order to interpret the results of the radiation surveys. The survey results, based on the radiological criteria, then became recommendations for decontaminating the sites and were forwarded to the Navajo Tribe in October 1974.

Both the Mexican Hat, Utah, and Shiprock, New Mexico, sites were being utilized at the time of the surveys. Construction industry crafts were being taught at the former while the latter was a base of operations for the Navajo Engineering and Construction Authority (NECA) which is a Tribal enterprise. On the Shiprock site NECA was also operating a heavy equipment training school which utilized, in part, the tailings ponds for practice areas. In order to discourage the use of the tailings ponds for practice and to attempt to reduce the radiological exposure to site workers, representatives of the Tribe, NECA, and Federal and State agencies decided that the site should be decontaminated. The decontamination activities would be conducted by the NECA training program which would be assisted by the involved organizations and agencies. These agencies were the Navajo Environmental Protection Commission (NEPC); NECA; the Public Health Service, Indian Health Service (IHS); the Environmental Protection Agency (Region VI office and the Office of Radiation Programs--Las Vegas Facility (ORP--LVF)); and the New Mexico Environmental Improvement Agency (NMEIA). This decontamination effort was officially launched by the Tribal Vice Chairman on January 8, 1975.

An informal agreement was prepared by the ORP--LVF participating staff member outlining the responsibilities of the participating agencies' support concerning the decontamination activities. The agreement was reviewed and approved by members of these agencies and put into effect immediately. A technician provided by the NEPC was assigned to the Shiprock site to con-

duct surveys, operate sampling equipment, maintain day-to-day coordination with the participants concerning radiation matters, and to assist NECA training concerning the enforcement of radiation protection measures. A draft "Work Plan for the Decontamination of the Shiprock Uranium Mill Site" was prepared by the ORP--LVF staff member and forwarded to IHS for distribution among the participating agencies for comments. After the comments were received, the plan was finalized and became the basis for conducting the decontamination activities (Figure B-2). The major decontamination tasks are outlined in blocks 1 through 10. The dependent sub-tasks are connected by dashed lines to the major tasks at an approximate time which they should occur. They also identify the agency which is to participate in the sub-tasks. The time base for the tasks could not be set up in time intervals because of the uncertainty of the efficiency of the trainees and funding. Major tasks 1 through 5 constitute approximately 85% of the earth-moving activities required to decontaminate the site. Areas depicted by the work plan tasks are identified in Figure B-1. Major tasks (numbers 4 and 9) will not be completed until a decision from the Phase II surveys has been reached concerning the disposition of the tailings piles. This is because, if the piles are to be moved off site, the clean fill cover will also have to be moved which will result in an unnecessary expense.

Task 1 (Adjust Unstabilized Pile Boundary) has been completed and involved moving the unstabilized pile away from the mill buildings for a distance of 300 feet. Approximately 120,000 yards of tailings were moved to rough shape and adjust the pile boundary. Although not indicated on the work plan, a sprinkling system was installed on the unstabilized pile to control wind erosion. This involved cutting a roadway down to the river on the east side of the site to gain access to water. Approximately 5,000 yards of earth was removed for the roadway, and 7,500 yards of tailings were adjusted on the pile to provide elevated ramps for the sprinkler laterals.

Sub-task 1c (Obtain Permission to Decontaminate Site Environs) has not been completed; however, some progress has been made in this area. Some of the land, contaminated with windblown tailings, is not located on the mill site property. Permission must be obtained from the land user to strip the affected areas and will probably involve monetary remuneration because of a temporary loss of a grazing area.

Task 2 has been completed. This work was directed at removing a tailings pond adjacent to the millyard buildings on the southwest corner of the site. Approximately 100,000 cubic yards of tailings and contaminated earth were removed from the area to a depth of 18 feet below grade in some sections. The excavation activities were complicated because of trash buried in this area which caused some delays and damage to the excavation equipment. The trash included barrels, rebar, concrete, stationary engines, vehicles and tanks. Clean fill for this area is being hauled in from a location southeast of the site over a new haul road constructed from clean fill.

The fill is loaded into off-highway dump trucks with a conveyor belt and front loader and hauled approximately 1/2 mile to the tailings pond. Refill of the pond is now approximately 90% complete.

The residual net gamma ray exposure rates in the excavated pond area, measured at 3 feet above the ground, were less than 10 μ R/hr. This is probably the first tailings pond that has been excavated and decontaminated to a degree to allow unrestricted use of the area.

All of the sub-tasks for Task 2 have been completed except 2f and 2h. These involve the disposition of the former mill buildings. Because of the poor physical condition of the buildings, the members of the participating agencies recommended that they be torn down and buried between the tailings piles or decontaminated and sold for scrap. The present status of sub-task 2f is that a bid for the removal and salvage of the buildings has been forwarded to the Navajo Tribe and is awaiting action. Late removal of the buildings will complicate the decontamination activities in the mill yard.

Task 3 (Decontaminate Ore Storage Area Yard) is approximately 60% completed. The decontamination of this huge area is complicated because some fill was added over the contaminated ground by the prior site operator and training activities conducted before cognizance of the problem. Fill covering portions of the yard must be removed to gain access to the underlying contaminated earth and trash that was also buried by the prior site occupant.

A new shop building for NECA equipment maintenance has been erected in this area. The land underneath the shop and the adjacent area was decontaminated to background levels before construction began. This required an excavation to 3-4 feet below grade of a square area approximately 200 feet on each side. Clean fill was obtained from the borrow area and compacted for the building foundation. The transfer of maintenance activities from the old shop building to the new shop will relieve the problem of trying to accommodate the maintenance activities while decontaminating the mill yard.

Task 4 (Cover Stabilized Pile and Bank Area) has been significantly reduced in order to minimize the amount of material to be hauled away in the event that the tailings piles are re-located. Some clean fill, however, has been added to cover small areas where raw tailings are exposed. The dike on the river bluff has been completely rebuilt with contaminated fill from the ore-storage yard and is substantial enough to support heavy equipment. A steep wash, that could weaken the dike, was partially filled and reinforced to prevent a breakthrough of impounded water. Drainage surveys need to be conducted in order that the placement of the remainder of the dike will be adequate to handle a projected runoff.

Sub-tasks 4a and 4d have been completed, and 4b is partially complete and will continue after the drainage survey is completed. Sub-task 4c will be completed in the near future, while 4e will be deferred until the decontamination of the ore-storage yard has been completed.

No direct work has been done on Task 5 (Decontaminate Mill Site). However, some or parts of the sub-tasks have been completed. Tailings used for bedding the gas service line have been removed from along the side of the occupied buildings out to the gas main (5a). Tailings, also used for bedding the water line running from the artesian well head located in the fair grounds to the storage tank in the ore storage yard, have been excavated on site. Permission will be required from the land user to remove the tailings between the site boundary and the fair grounds, and will require approximately 800 feet of excavation. The tailings used for bedding the water line has a cross section of approximately 1 ft. by 2 ft.

An alternate parking lot (5d) has been constructed near the NECA office in area C. This will limit vehicle traffic in the mill yard and minimize "tracking" of contaminants into cleaned areas.

Task 6 (Decontaminate Area C) has been completed except for the decontamination of the mill site access road and parking lot in front of the office building. This task was completed ahead of the scheduled time because of the decision to locate the alternative parking lot (sd) in that area. No work has been completed on any of the Tasks 7, 8, 9, and 10, their sub-tasks, or the Task 6 sub-tasks. Tasks 7 and 8 can be completed quickly when they become due on the work plan. Tasks 9 and 10 will have to await the results and decisions concerning the site disposition derived from the Phase II study.

Radiation protection measures being taken by students and cadre are the wearing of respirators and coveralls with a mandatory shower before leaving the site. Coveralls are laundered on site and not worn off site. Airborne dust is being minimized by limiting access to certain areas, placing clean fill cover on some haul roads and by a judicious use of mobile watering systems.

Several radiation "yardsticks" are being employed to determine the effectiveness of the decontamination efforts. These are:

1. Four continuously operated off-site airborne particulate samplers are located around the site in order to measure wind-eroded tailings and relate their concentrations to site activities.
2. A meteorological station (temperature and wind speed and direction @ 1 meter and 10 meters) has been established as an aid to interpreting the airborne particulate sample data.

3. Indoor radon progeny samplers are located in the on-site occupied buildings to establish working levels and relate the working levels to decontamination activities.

4. Gamma surveys are conducted periodically around and in the occupied buildings to establish radiation exposure rates and relate changes in the rates to the decontamination activities.

5. Thermoluminescent dosimeter stations are located in the occupied buildings to measure the cumulative exposures and to relate these to decontamination activities.

6. Thermoluminescent dosimeters are worn by selected personnel to establish cumulative exposures and relate them to decontamination activities.

7. An on-site air particulate sampler has been established to measure radionuclide concentrations in air and to relate changes in these concentrations to decontamination activities.

8. Gamma radiation measurements were made on the intersections of a land survey grid (200 ft. centers) which was established over the site and adjacent contaminated areas. These measurements will be compared with others made at the same locations in order to assess the general overall effectiveness of the decontamination activities.

An updated estimate of the expected yardage that has been or will be moved to decontaminate the site through Task 8 is:

<u>Cubic Yards</u>	<u>Purpose</u>
140,000	Decontaminate the site environs to near background levels
100,000	Removal of former tailings pond
5,000	Sprinkling system roadway
100,000	Fill for former tailings pond
7,500	Piling tailings to elevate sprinkling system laterals
20,000	Diking around piles
45,000	Site leveling
120,000	Moving tailings back 300 ft. from buildings and pile shaping
25,000	Dike repair and fill for wash.

In general, it is estimated that the decontamination work is 70% complete and that Tasks 1 through 8 should be completed in September 1976. The original objectives of the decontamination efforts were to clean up the local environs around the site to a degree that it could be used in an unrestricted manner; to provide interim stabilization of the tailings piles in order to prevent or minimize further wind and water erosion into the local environment until permanent stabilization could be defined and applied; to provide a technical information base which could be applied to the decontamination of other inactive mill sites; and to investigate parameters which contribute to on- and off-site exposures. If, after the completion of Task 8, a decision resulting from the Phase II study indicates that the tailings piles will remain in place, Tasks 9 and 10 can be completed with some modifications and separate funding. If a Phase II recommendation is acted upon whereby the tailings piles will be relocated, then a substantial portion of that work will have been completed without the addition of any significant unnecessary materials to the tailings volume.

Mexican Hat - The site occupant is still using the site for training purposes. Some earth-moving was reported to have been done on the east side of the site, adjacent to the tailings pile, and in the ore-storage yard. The executive director of the Navajo Environmental Protection Commission has taken action to discourage any further earth-moving activities on site. On- and off-site sampling is continuing at this location.

Tuba City - Track Etch monitoring is continuing in the mill housing area.

Monument Valley - Track Etch monitoring is continuing for dwellings in the local area.

Other

Utah - Particulate air sampling has been terminated near the Vitro site.

FIGURE B-1. PLOT PLAN FOR EPA MINIMUM REMEDIAL ACTION PLAN

130-01

WORK PLAN FOR DECONTAMINATION OF THE SHIPROCK URANIUM MILL SITE

FIGURE B-2 WORK PLAN FOR EPA MINIMUM REMEDIAL ACTION