MASTER

PHASE II - TITLE I ENGINEERING ASSESSMENT
OF INACTIVE URANIUM MILL TAILINGS
LAKEVIEW SITE, LAKEVIEW, OREGON

DECEMBER 1977

PREPARED FOR

UNITED STATES DEPARTMENT OF ENERGY
GRAND JUNCTION, COLORADO, CONTRACT NO. E(05-1)-1658

BY

Ford, Bacon & Davis Utah Inc.

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NOTICE

This Phase II - Title I Engineering Assessment has been performed under ERDA Contract No. E(05-1)-1658 executed on June 23, 1975 between the U.S. Energy Research and Development Administration and Ford, Bacon & Davis Utah Inc. On October 1, 1977, ERDA was incorporated into the U.S. Department of Energy; hence, this engineering assessment is issued for the DOE, the present responsible agency.

FOREWORD

This report entitled, "Phase II - Title I Engineering Assessment of Inactive Uranium Mill Tailings, Lakeview Site, Lakeview, Oregon", 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, and addresses the radiological problems and estimated costs of remedial measures that would reduce exposure of the general public. Title I is not a scientific study but an engineering assessment to determine the relative magnitude of the hazards associated with each site, and to estimate the remedial action costs. If additional information that may alter or have an impact on a final remedial action decision for any site is required, it can be obtained during the Title II Engineering Effort. Chapter 1 of this report is a summary and is published under separate cover for those not requiring all of the details of this report.

Ford, Bacon & 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 radiometric analyses of samples. The preparation of this report could not have been accomplished without the cooperation and assistance 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) Atlantic Richfield Company; Mr. L. R. Selkirk, Mr. H. S. McAlister, and other company personnel
- (3) Mr. G. L. Toombs, Supervisor, Environmental Radiation Surveillance Program, Radiation Control Section, Oregon State Department of Human Resources
- (4) Mr. Allison E. Smith; Lakeview, Oregon; for assistance with site inspection
- (5) EG&G; Las Vegas, Nevada; Mr. Jack Doyle; for aerial photography
- (6) Center for Health and Environmental Studies, Brigham Young University, Provo, Utah; for socioeconomic studies

ABSTRACT

Ford, Bacon & Davis Utah Inc. has performed an engineering assessment of the problems resulting from the existence of radioactive uranium mill tailings at the Lakeview, Oregon site. The Phase II - Title I services include: performance of core drillings; analyses of soil, water, and other samples; radiometric measurements to determine areas with radium-contaminated materials; evaluation of resulting radiation exposures of individuals and nearby populations; investigation of site geology, hydrology, and meteorology; and evaluation and costing of alternative corrective actions.

Radon gas release from the 130,000 tons of tailings at the Lakeview site constitutes the main environmental impact, which is minimal. The two alternative actions presented are maintenance of the site now that the ARCO reclamation program has been completed (Option I); and addition of stabilization cover to a minimum depth of 2 ft, improved fencing, and removal of a few isolated spots of contamination (Option II). The cost estimates for these options are \$40,000 and \$290,000, respectively.

CONTENTS

<u>Chapter</u>	<u>Title</u>	<u>Page</u>
	Foreword	ii
	Abstract	iii
	List of Figures	viii
	List of Tables	x
	Glossary	xi
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	1-6
1.2.5	Geology, Hydrology, and Meteorology	1-6
1.3	Radioactivity and Pollutant Impacts on the Environment	1-7
1.3.1	Radiation Exposure Pathways, Contamination Mechanisms, and Background Levels . . .	1-7
1.3.1.1	Radon Gas Diffusion and Transport . . .	1-8
1.3.1.2	Direct Gamma Radiation	1-8
1.3.1.3	Windblown Contaminants . . .	1-8
1.3.1.4	Ground and Surface Water Contamination	1-8
1.3.1.5	Soil Contamination	1-8
1.3.2	Remedial Action Criteria . .	1-9
1.3.3	Potential Health Impact . .	1-10
1.3.4	Nonradioactive Pollutants .	1-12

CONTENTS (Cont)

<u>Chapter</u>	<u>Title</u>	<u>Page</u>
	1.4 Socioeconomic and Land Use Impacts	1-12
	1.5 Recovery of Residual Values	1-12
	1.6 Mill Tailings Stabilization	1-13
	1.7 Remedial Actions and Benefits	1-13
	1.7.1 Remedial Options	1-14
	1.7.2 Cost-Benefit Analyses	1-14
	Chapter 1 References	1-18
2	SITE DESCRIPTION	
	2.1 Location	2-1
	2.2 Topography	2-1
	2.3 Ownership	2-1
	2.4 History of Milling Operations and Processing	2-2
	2.5 Present Condition of the Site	2-2
	2.6 Tailings and Soil Characteristics	2-2
	2.7 Geology, Hydrology, and Meteorology	2-3
	2.7.1 Geology	2-3
	2.7.2 Surface Water Hydrology	2-3
	2.7.3 Ground Water Hydrology	2-3
	2.7.4 Meteorology	2-4
	Chapter 2 References	2-10
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	3-6
	3.4.5 Soil Contamination	3-6
	3.4.6 Off-Site Tailings Use	3-6

CONTENTS (Cont)

<u>Chapter</u>	<u>Title</u>	<u>Page</u>
	3.5 Remedial Action Criteria	3-7
	3.6 Potential Health Impact	3-8
	3.6.1 Assumptions and Uncertainties in Estimating Health Effects	3-9
	3.6.2 Health Effects	3-11
	3.7 Nonradioactive Pollutants	3-12
	Chapter 3 References	3-26
4	SOCIOECONOMIC AND LAND USE IMPACTS	
	4.1 Socioeconomic Background	4-1
	4.2 Population Estimates	4-2
	4.3 Land Use	4-2
	4.4 Impact of the Tailings on Land Values	4-3
	Chapter 4 References	4-7
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 Lakeview Recovery Economics	5-2
	5.2.1 Recovery	5-2
	5.2.2 Reprocessing Costs	5-3
	5.3 Assessment of Lakeview Mineral Recovery Potential	5-3
	Chapter 5 References	5-11
6	MILL TAILINGS STABILIZATION	
	6.1 Prevention of Wind and Water Erosion	6-1
	6.1.1 Chemical Stabilization of the Surface	6-1

CONTENTS (Cont)

<u>Chapter</u>	<u>Title</u>	<u>Page</u>
	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	REMEDIAL ACTIONS AND BENEFITS	
	7.1 Minimal Remedial Action Maintenance (Option I)	7-1
	7.1.1 Costs	7-1
	7.2 Additional Decontamination and Stabilization, Drainage Corrections and Security (Option II)	7-2
	7.2.1 Security and Maintenance	7-2
	7.2.2 Resulting Impacts	7-2
	7.2.3 Costs	7-3
	7.3 Impacts of the Options	7-3
	7.3.1 Health Benefits	7-3
	7.3.2 Land Value Benefits	7-3
<u>Appendix</u>		
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
	A.3 Grand Junction Remedial Action Criteria (10CFR12)	A-9
B	STATE OF OREGON REGULATIONS FOR CONTROL OF RADIATION	B-1

LIST OF FIGURES

<u>Number</u>	<u>Title</u>	<u>Page</u>
2-1	Aerial Photograph of Site	2-5
2-2	Descriptive Map	2-6
2-3	Simplified Stratigraphic Column	2-7
2-4	Surface Drainage	2-8
3-1	Radioactive Decay Chain of Uranium 238 .	3-13
3-2	Locations for ^{226}Ra Background Samples .	3-14
3-3	Radon Concentration in Vicinity of Pile	3-15
3-4	^{222}Rn and Atmospheric Transients at Mill Building on September 16, 1976 . .	3-16
3-5	^{222}Rn and Atmospheric Transients 0.2 Mi N of Pile on September 17, 1976	3-17
3-6	Reduction of Outdoor ^{222}Rn Concentra- tion with Distance from the Tailings Pile	3-18
3-7	Gamma Levels in the Site Vicinity . . .	3-19
3-8	Surface and Subsurface Radium Concentra- tions	3-20
3-9	Lung Cancer Risk from Continuous Exposure to Radon Diffusion	3-21
4-1	Map of Lake County Boundaries.	4-4
4-2	Population Projections	4-5
4-3	Vicinity Land Use	4-6
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 Ranging from 20 to 35% (Cost Adjusted to January 1977)	5-6

LIST OF FIGURES

<u>Number</u>	<u>Title</u>	<u>Page</u>
5-3	Operating Costs of Conventional Milling W/O Crushing and Grinding Facilities to Reprocess Tailings Containing 0.01 to 0.05% U ₃ O ₈ with Uranium Recovery Ranging from 35 to 60% (Cost Adjusted to January 1977)	5-7
5-4	Construction Costs of Heap Leaching Plant to Reprocess Uranium Mill Tailings Containing 0.01 to 0.05% U ₃ O ₈ with Uranium Recovery 20 to 35% (Cost Adjusted to January 1977)	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 ₃ O ₈ with Uranium Recovery Ranging from 35 to 60% (Cost Adjusted to January 1977)	5-9
6-1	Reduction of Radon Exhalation Flux with Depth of Cover	6-6
6-2	Reduction of Gamma Exposure Rate Resulting from Packed Earth Shielding	6-7

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	1-15
1-2	Cost Estimate Summary	1-17
2-1	Wind Information for Lakeview, Oregon . . .	2-9
3-1	Notations and Abbreviations Used in Chapter 3	3-22
3-2	Background Radiation Sources in Soil from Southern Oregon and Northern California . .	3-23
3-3	Radon Exhalation Flux from the Lakeview Tailings	3-24
3-4	Chemical Analyses of Lakeview Water Samples (mg/l)	3-25
5-1	Assay Results of Lakeview Tailings and Background Samples	5-10
7-1	Cost Estimate Summary	7-4

GLOSSARY

Abbreviations/Terms

Definitions

absorbed dose	Radiation energy absorbed per unit mass.
A-E	Architect-Engineer.
AEC	Atomic Energy Commission.
alpha particle (α)	A positively charged particle emitted from certain radioactive 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 detected by the mobile gamma survey where the recorded counts per second (c/s) from a large gamma-ray detector exceed the determined background for that area by 50 or more c/s.
aquifer	A water-bearing formation below the surface of the earth; the source of wells. A confined aquifer is overlain by relatively impermeable rock. An unconfined aquifer is one associated with the water table.
atmospheric pressure	Pressure exerted on the earth by the mass of the atmosphere surrounding the earth; expressed in inches of mercury (at sea level and 0°C, standard pressure is 29.921 in. Hg).
background radiation	Naturally occurring low-level radiation to which all life is exposed. Background radiation levels vary from place to place on the earth.
beta particle (β)	A particle emitted from some atoms undergoing radioactive decay. A negatively charged beta particle

	is identical to an electron. A positively charged beta particle is called a positron. Beta radiation can cause skin burns and beta-emitters are harmful if they enter the body.
BEIR	Biological Effects of Ionizing Radiation.
BOM (USBOM)	Bureau of Mines.
CHES	Center for Health and Environmental Studies, Brigham Young University, Provo, Utah.
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 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 (1 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 of different elements and having high penetrating power.
GJO	Grand Junction Office.
ground water	Subsurface water in the zone of full saturation which supplies wells and springs.
health effect	Adverse physiological response from tailings (in this report, one health effect is defined as one case of cancer from exposure to radioactivity).
heap leaching	A process for removing uranium from ore, tailings, or other material wherein the material is placed on an impermeable pad and wetted with appropriate reagents. The uranium solution is collected for further processing.
HEW (USHEW)	Department of Health, Education, and Welfare.

insult	Negative impact on the environment or the health of individuals.
Interim 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 on 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.
NIOSH	National Institute for Occupational Safety and Health.
noble gas	One of the gases, such as helium, neon, radon, etc., with completely filled electron shells which is therefore chemically inert.
NRC	Nuclear Regulatory Commission.

nuclide	A general term applicable to all atomic forms of the elements; nuclides comprise all the isotopic forms of all the elements. Nuclides are distinguished by their atomic number, atomic mass, and energy state.
ORNL	Oak Ridge National Laboratory.
ORP-LVF (EPA)	Office of Radiation Programs, Las Vegas Facility (Environmental Protection Agency).
pCi/l	Picocurie per liter.
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 1 rad means the absorption of 100 ergs of radiation energy per gram of absorbing material.
radioactivity	The spontaneous decay or disintegration of an unstable atomic nucleus, usually accompanied by the emission of ionizing radiation.
radioactive decay chain	A succession of nuclides each of which transforms by radioactive disintegration into the next until a stable nuclide results. The first member is called the parent, the intermediate members are called daughters, and the final stable member is called the end product.

radium	A radioactive element, chemically similar to barium, formed as a daughter product of uranium (^{238}U). The most common isotope of radium, ^{226}Ra , has a half-life of 1,620 yr. Radium is present in all uranium-bearing ores. Trace quantities of both uranium and radium are found in all areas, contributing to the 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 radium in the soil.
radon concentration	The amount of radon per unit volume. In this assessment, the average value for a 24-hr period of atmospheric radon concentrations, determined by collecting data for each 30 min period of a 24-hr day and averaging these values.
radon daughter	One of several short-lived radioactive daughter products of radon (several of the daughters emit alpha particles).
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 from a surface 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	(Acronym 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 minerals in tailings material.
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 ore processing in uranium mills (see tailings). These sands normally contain less radioactive material than the slimes.
scintillometer	A gamma-ray detection instrument normally utilizing a NaI crystal.
slimes	Extremely fine-grained materials, mixed with small amounts of water, produced along with the sands as waste products of ore processing in uranium mills (see tailings). 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 the 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 limited. 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 Lakeview 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 two potential practical options:

- (a) Maintenance of the site after the decontamination and stabilization program of ARCO.
- (b) Stabilization with additional cover, upgrading the fencing and removal of small areas of contaminated soil.

The estimated costs of carrying out the remedial action options 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.

Dr. James L. Liverman, testifying for the AEC, proposed that a comprehensive study should be made of all such piles, rather than treating the potential problem on a piecemeal basis. He proposed that the study be a cooperative two-phase undertaking by the states concerned and the appropriate federal agencies, such as the

*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.

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 summarizes 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. Field work on the Lakeview site was performed from September 15 through September 19, 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. 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 and gamma surveys. The EPA staff provided the results of radiation surveys they previously had made at the Lakeview site.

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

following:

- (a) Preparation of an engineering assessment report for each site, and preparation of a comprehensive report suitable for submission to the Congress on reasonable remedial action alternatives and their estimated 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 yr) 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.

Not all of these items received attention at this site.

1.2 SITE DESCRIPTION

1.2.1 Location and Topography

The Lakeview millsite and tailings pile are located approximately 16 mi north of the Oregon-California border in south-central Oregon. It is 96 mi east of Klamath Falls, Oregon in Goose Lake Valley at an elevation of 4,750 ft above sea level. Mountains surround the site on the east and west and reach elevations of 8,000 ft. The site and its relationship to the surrounding area are shown in the aerial photo in Figure 2-1, Chapter 2.

1.2.2 Ownership and History of Milling Operations and Processing

The mill was built and operated by the Lakeview Mining Company in 1958. The same people owned the Gunnison Mining Company at Gunnison, Colorado. Between 1960 and 1968, the property had five different owners. Atlantic Richfield acquired the site in 1968, and is the current owner. The plant processed a total of 130,000 tons of ore with a grade of 0.15% U_3O_8 , and a total of 171 tons of the uranium oxide was sold to the AEC. The ore was obtained from mines in southern Lake County. An acid leach process was utilized to process the ore.

1.2.3 Present Condition of the Site

Figure 2-2, Chapter 2, is a descriptive map of a portion of the site as it now exists. With the exception of the old mill building and the office building, the structures and machinery are being or have been removed. The old mill building and the site are being decontaminated by the owner. The tailings pile, which occupies some 30 acres of the 258-acre site, has been stabilized with earth cover varying in thickness from 18 to 24 in. A dense growth of grasses covers the pile which is surrounded by a hog-style fence.

A seasonal stream which drains a canyon east of the site passes through the site north of the tailings, then between the tailings and the evaporation ponds on the west. The six evaporation ponds occupy 64 acres and are still in their original shapes and are sustaining a healthy weed growth. The entire site is fenced with barbed-wire fencing. Atlantic Richfield has completed its reclamation program and the mill building and other structures have been decontaminated and the machinery and other salvageable items have been removed.

1.2.4 Tailings and Soil Characteristics

The uranium tailings are a fine sand, brown in color resting on a compacted clay liner which overlies a rich dark brown-to-black loam.

1.2.5 Geology, Hydrology, and Meteorology

The Lakeview site is located in an unconsolidated valley fill consisting of clays, sands and gravels which overlie sedimentary rocks of lacustrine and fluvial origin. The site is at the eastern boundary of the Goose Lake Graben, which is block-faulted by northerly and northeasterly normal faults. A simplified stratigraphic column is shown in Figure 2-3, Chapter 2.

The surface waters near the site consist of drainage ditches, ponded water after rains, and an unnamed stream from Hammersley Canyon which is routed between the tailings pile and the adjacent evaporation ponds. There is no evidence that the stream flow has eroded the tailings pile or the embankments surrounding the evaporation ponds.

Ground water occurs under confined and unconfined conditions. There is a strong upward flow gradient from leaky artesian aquifers in the thin unconsolidated lacustrine sediments. Contamination of the ground water is unlikely. A known geothermal area is located adjacent to Warner Mountain and surface water temperature at Hunters Hot Springs 1 mi northwest of the site is 212°F.

The mean annual precipitation of 16 in. occurs fairly uniformly throughout 9 mo of the yr. The other 3 mo, July through September, receive less than 6% of the total precipitation. The average

annual evaporation rate is 45 in.

Prevailing winds blow from the south with windspeeds less than 15 mph about 85% of the time.

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 , and ^{222}Rn daughters contained in the uranium tailings. Although these radionuclides occur in nature, their concentrations in the 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 and Rn daughters. This exposure affects the lungs. For this assessment, no criteria have been established for radon concentrations in air. However, the pathway for radon and radon daughters accounts for the major portion of the exposure to the population.
- (b) External whole-body gamma exposure directly from radionuclides in the pile.
- (c) Inhalation and ingestion of windblown tailings. The primary health effect relates to the alpha emitters ^{230}Th and ^{226}Ra , each of which causes exposure to the bones and lungs.
- (d) Ingestion of ground and surface water contaminated with radioactive elements (primarily ^{226}Ra) and other toxic materials.
- (e) Contamination of food through uptake and concentration of radioactive elements by plants and animals is another pathway 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 eight locations in the vicinity of the Lakeview tailings pile. The locations and values of the radon measurements, including background, are shown in Figure 3-3, Chapter 3. No correlation was found between radon concentration and distance from the pile. The lowest concentration off the pile was 0.6 pCi/l at a distance of 0.3 mi, while the highest concentration was 0.8 pCi/l measured at 3 different locations.

Eight 24-hr measurements of atmospheric radon indicated an average background concentration of 0.7 pCi/l for the Lakeview area.

1.3.1.2 Direct Gamma Radiation

The range of natural background values in the Lakeview area was between 5 and 10 $\mu\text{R/hr}$, averaging 8 $\mu\text{R/hr}$ as measured with an energy-compensated Geiger Mueller detector.⁽²⁾ Above the surface of the tailings pile, gamma radiation rates were measured as high as 53 $\mu\text{R/hr}$. At the former ore stockpile area, gamma radiation reached a maximum of 340 $\mu\text{R/hr}$; however, since the field survey this situation has been remedied as part of the ARCO reclamation program.

1.3.1.3 Windblown Contaminants

Background gamma radiation rates were reached within 0.05 mi from the tailings pile.

Surface soil samples obtained around the site contained only background levels of ^{226}Ra , except for one sample taken from the evaporation pond north of the tailings pile. This sample did not appear to be due to windblown contamination.

1.3.1.4 Ground and Surface Water Contamination

The East Fork of Thomas Creek flows within 0.25 mi from the Lakeview tailings pile. The stream from Hammersley Canyon flows along the edge of the tailings pile. An analysis of all water samples downstream from the tailings pile showed ^{226}Ra concentrations to be significantly less than the EPA Interim Drinking Water Standards.

1.3.1.5 Soil Contamination

The amount of ^{226}Ra leaching from the tailings into the soil was determined by drilling auger holes around the tailings pile. The radioactivity profile was measured in these holes with a Geiger probe in a lead shield that collimates the radiation. These auger holes were drilled 2 to 2.5 ft deep and no radioactive contamination was observed. Analyses of soil samples⁽³⁾ obtained

previously from a trench dug through the pile indicated ^{226}Ra was being trapped in the clay liner under the tailings.

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> ^a	<u>Recommendations</u>
Greater than 0.1 mR/hr ^b	Greater than 0.05 WL ^c	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

^aBased upon yearly average values from 6 air samples of at least 100-hr duration taken at a minimum of 4-wk intervals throughout the year.

^bmR/hr = milliroentgen per hour, a measure of gamma radiation;
1 mR/hr = 1,000 $\mu\text{R/hr}$.

^cWL = working level, a measure of alpha radiation from short-lived radon daughter elements.

The criteria for land decontamination have the objective of 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 $\mu\text{R/hr}$ above background is used in such circumstances. Average background in the Lakeview area was determined in this

study to be 8 $\mu\text{R/hr}$. As a guideline for the land beyond the site, if residual gamma levels are less than 10 $\mu\text{R/hr}$ 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.

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

1.3.3 Potential Health Impact

Radon gas exhalation from the pile and the subsequent inhalation of radon daughters account for most of the total dose to the population from the Lakeview site under present conditions. The gamma radiation exposure from the pile is essentially zero since the gamma radiation levels are in the background range within 0.05 mi from the pile.

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⁽⁴⁾ indicate that 13 ft of earth cover theoretically would be required to reduce the radon diffusion from the Lakeview tailings by 95%.

The health significance to man of long-term exposure to radiation is a subject that has been studied extensively for many years. The end result of long-term exposure to low-level radiation is increased susceptibility to diseases such as lung cancer or leukemia, which also are attributable to many other causes. Thus, 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. This provides a basis for calculating the probable health effects of low-level

exposure to large populations. (The term "health effect" refers to an incidence of disease; for radon daughter exposure, 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).⁽⁵⁾ 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 one working level of radon daughter products in air for 170 hr, which is a work-month. A working level (WL) is a unit of measure of radon daughter products which recognizes that the several daughter elements are frequently not in equilibrium with each other 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 (6 cancer cases per year per 10^6 person-WLM) is considered to have an uncertainty factor of about 3. The relative risk estimator can be several factors larger than the absolute risk estimator.⁽⁶⁾

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 estimated that the average pile radon-induced lung cancer risk to individuals within 5 mi from the tailings site is 1.9×10^{-6} per person per year. The health effect rate for background radon is approximately 17 times that attributable to pile radon. The average lung cancer risk due to all causes for Oregon residents is 3.4×10^{-4} per person per year.⁽⁷⁾ At 0.2 mi from the edge of the tailings pile, which is the distance to the nearest occupied dwellings, the lung cancer risk due to pile radon is about 6% of the average risk to residents of Oregon from all causes.

As a result of the low population density, the low radiation levels of the tailings at the Lakeview site, and the relatively high background radon levels, the potential health impact of the pile is minimal. The cumulative number of health effects after 100 yr is estimated to be 0.82 using a 4.3% declining growth rate. In 100 yr the background radon is calculated to cause 14 health effects for the same population growth.

1.3.4 Nonradioactive Pollutants

Six water samples were taken from the vicinity of the Lakeview site and chemically analyzed. Two of these samples were taken from a pond northwest of the pile. The third sample was taken from a stream under a road 900 yd north of the pile. The remaining three water samples were taken south of the pile: one sample from the Hammersley Canyon stream, one from a ditch, and one from a well. The three samples obtained north of the tailings contained arsenic and selenium above the EPA Interim Drinking Water Standards. However, these samples are upstream from the tailings pile and the evaporation ponds. It is not likely that the tailings contributed to their contamination. In addition, the Hammersley Canyon stream that flows along the edge of the tailings pile was sampled south of the pile (downstream) and no significant contamination was found.

1.4 SOCIOECONOMIC AND LAND USE IMPACTS

The mill and tailings site are located about 2 mi northeast from Lakeview, a city with about 2,900 inhabitants. Farmers and farm laborers are the largest employment sector; however, Lakeview enjoys a healthy, stable economy with a diversified base of agriculture, forestry, local recreation, manufacturing, retailing, and government employment.

The land usage near the site is diverse and consists of numerous small and large holdings, a lumber mill is on the south of the site, and additional commercial development could occur along U.S. Highway 395 which is adjacent to the millsite. There is interest in using the millsite for other industrial activities; however, there are no strong pressures to use the tailings area for other purposes. Market value of land in the area varies from \$1,000/acre to \$2,500/acre.

1.5 RECOVERY OF RESIDUAL VALUES

Estimates of the uranium content of the Lakeview tailings by the AEC indicate an average U_3O_8 concentration of 0.018%.

There are five factors that should be employed to evaluate whether reprocessing the Lakeview tailings to extract residual uranium and other mineral values would be practicable:

- (a) The amount of tailings present

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

Based on the aforementioned criteria, reprocessing of the Lakeview tailings is not a practical economic consideration at this time and would not be practical until the market value of U_3O_8 reaches \$300/lb in present dollars.

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.

The tailings pile is presently covered with a nominal 2 ft of earth. This cover greatly reduces the wind and water erosion. Gamma radiation generally has been reduced to twice background levels but radon exhalation has been reduced by an estimated 30% due to this thickness of cover material.

1.7 REMEDIAL ACTIONS AND BENEFITS

The remedial actions take into consideration the decontamination and stabilization efforts of the owner and of the remoteness of the site from areas of large population.

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

No alternative disposal site has been considered for the Lakeview tailings. In their present condition, or with the implementation of either of the two remedial action options, the tailings meet the criteria for long-term storage.

1.7.1 Remedial Options

Option I includes provisions for a continuing maintenance program. No additional decontamination or stabilization work is proposed for the site except the completion of the ARCO program. The cost for this option is \$40,000 and would provide approximately \$2,800/yr for monitoring and physical maintenance.

In addition to the action of Option I, Option II provides for: decontaminating of additional on-site, but off-pile areas; straightening portions of the stream as it passes through the site in order to reduce the residence time of surface water on the site; improving security in the form of a 6-ft-high chainlink fence; and adding sufficient material to the pile to have a minimum cover of 2 ft. The cost of this option is \$290,000. If additional cover is desired it would add approximately \$193,600/ft of cover to the option cost.

1.7.2 Cost-Benefit Analyses

The principal reasons for the remedial options are to provide maintenance or better site decontamination and security. Population and off-pile radiation levels are so small that health benefits associated with the remedial actions are negligible. The costs for Options I and II are summarized in Table 1-2.

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

	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.

^aThis table does not necessarily represent conditions at the present time.

TABLE 1-2
COST ESTIMATE SUMMARY

<u>Option No.</u>	<u>Description</u>	<u>Estimated Cost(\$)*</u>
I	Maintenance and monitoring	40,000
II	Additional site decontamination and stabilization, drainage improvements, security, monitoring, and maintenance	290,000

*Costs are in thousands of dollars, based on 1977 value

CHAPTER 1 REFERENCES

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CHAPTER 2
SITE DESCRIPTION

CHAPTER 2

SITE DESCRIPTION

The purpose of this chapter is to describe the site at Lakeview, Oregon, and the characteristics of the tailings materials present on the site.

2.1 LOCATION

The Lakeview millsite is approximately 2 mi northwest of Lakeview, Lake County, Oregon and is adjacent to U.S. Highway 395. The site, shown in Figure 2-1, is approximately 16 mi north of the California-Oregon border in South Central Oregon, and 96 mi east of Klamath Falls, Oregon. More specifically, the site is in portions of Sections 3,4,9, and 10, Township 39 South, Range 20 East, Washington Meridian, and at 42 deg 12 min 43 sec north latitude and 120 deg 22 min 09 sec west longitude.

2.2 TOPOGRAPHY

The tailings site is located in Goose Lake Valley, a large flat mountain valley at an elevation of 4,750 ft above sea level. Mountain peaks in surrounding ranges to the east and west are in the Fremont National Forest and reach elevations of over 8,000 ft. The general area contains many lakes, the largest of which is Goose Lake, located about 10 mi south of the site. The drainage in the site area is to the south by means of nearby Thomas Creek. Surface water collected in Hammersley Canyon, west of the site, passes through the site in an east-to-west direction and flows near the north and west sides of the tailings pile. The higher mountain areas are pine covered, with sage and scrub brush on the foothills. The valleys are grassy meadows, primarily ranchland. The area immediately surrounding most of the site is well-vegetated ranchland with occasional ranch homes and barns. A lumber mill is to the southeast. The mill area is about 0.3 mi east of the tailings pond and occupies approximately 12 acres.

2.3 OWNERSHIP

The mill was built and operated by the Lakeview Mining Company in 1958. The personnel of this firm were also the owners of the Gunnison Mining Company, which operated the mill at Gunnison, Colorado. Both companies were acquired in 1961 by Kerr-McGee Oil Industries through its subsidiary, Kermac Fuels Corporation. Between 1960 and 1968 the property had five owners. In 1968, the property was obtained by Atlantic Richfield Company, the current owners.

2.4 HISTORY OF MILLING OPERATIONS AND PROCESSING⁽¹⁾

During the 1958-1961 period of operations, 130,000 tons of ore averaging 0.15% U_3O_8 were treated; 171 tons of uranium oxide were sold to the AEC. The mill treated ores from the White King and Lucky Lass mines of southern Lake County, Oregon. Ore was from silicified volcanic rocks in the White King orebody in which uranium mineral was found as the arsenate, novacekite. In the Lucky Lass ore, the uranium occurred as autunite. The mill operated with a rated capacity of 210 tons of ore per day.

Ground ore at a minus 65-mesh size was leached using sodium chlorate and sulfuric acid. After leaching, the pregnant solution and solids were separated by a four-stage countercurrent classifier and thickener circuit, with the washed solids from the final units being sent to tailings. Pregnant solutions were treated by solvent extraction to recover and concentrate the uranium.⁽²⁾

2.5 PRESENT CONDITION OF THE SITE

Figure 2-2 contains a descriptive map of the 258-acre site as it now exists. The tailings occupy 30 acres, and the evaporation ponds approximately 64 acres. The tailings have been stabilized with an earth cover from 18 to 24 in. thick. The pile is almost square with a very flat surface, although the stabilization cover has ridges which contain moisture. This cover is supporting a vigorous growth of vegetation. The average depth of the tailings, including cover, is 3.7 ft. An earth dike was formed around the tailings before they were emplaced. The tailings have been fenced with a hog-wire-type fence, and radiation signs are posted. There is also a barbed-wire fence around the site proper.

Atlantic Richfield has completed its reclamation program; the mill building and other structures have been decontaminated, and the machinery and other salvagable items have been removed and decontaminated by the owners.

2.6 TAILINGS AND SOIL CHARACTERISTICS

Mill records indicate that there are approximately 130,000 tons of tailings on the site in the tailings pile area. The uranium tailings are mostly fine sand, brown in color. The soil beneath the tailings is a rich dark-brown loam. A previous report⁽³⁾ indicated that a clay liner was placed at the bottom of the tailings pond during construction. Assay results of composite tailings samples are shown in Table 5-1, Chapter 5.

(1) See end of chapter for references.

2.7 GEOLOGY, HYDROLOGY, AND METEOROLOGY

2.7.1 Geology

The Lakeview site is located on unconsolidated valley fill consisting of clays, sands, and gravels, which overlie sedimentary rocks of lacustrine and fluvial origin.⁽⁴⁾ The unconsolidated materials are approximately 650 ft thick under the site. The site is located at the eastern boundary of the Goose Lake Graben, which is block-faulted by northerly and northeasterly normal faults which result in the present topography of parallel ridges and valleys. East of Lakeview the upthrown block forming the Warner Mountains rises a distance of 1,600 ft within 1.5 mi. The rock units in the Warner Mountains consist of interstratified andesitic flows, tuffs, lacustrine sediments and basalt flows. Sediments eroded from the Warner Mountains have become the thick sequence of unconsolidated material of the valley floor. A simplified stratigraphic column is shown in Figure 2-3.

2.7.2 Surface Water Hydrology

The surface waters near the site consist of drainage ditches, ponded water from rainfall on the site, and an unnamed stream, from Hammersley Canyon, which runs between the tailings pile and the adjacent evaporation ponds. Within the canyon section, the stream is intermittent and is recharged during the wet season by ground water. From the mouth of the canyon, 0.6 mi east of the tailings to its junction with East Fork of Thomas Creek 0.25 mi southwest of the tailings, the stream flows only during or immediately after periods of precipitation or snowmelt. The stream loses most of its flow to infiltration before reaching the tailings pile. There is no evidence that the stream flow has eroded the tailings pile or the embankments surrounding the evaporation ponds.

The evaporation ponds are dry except after a heavy rainfall. Water from the irrigation ditches near the site cannot affect the site nor is there a potential for physical erosion of tailings. Overland flow onto the pile is limited to the precipitation that actually falls on the pile. The location of surface waters is given in Figure 2-4.

2.7.3 Ground Water Hydrology

In the vicinity of the tailings pile, ground water occurs under confined and unconfined conditions. Drilling logs from 54 wells within 2 mi of the property indicate a strong upward flow gradient from leaky artesian aquifers in the thin unconsolidated lacustrine sediments.

A known geothermal area is located parallel to the fault zone adjacent to Warner Mountain both north and south of Lakeview. The water temperature at Hunters Hot Springs 1 mi northwest of the site is 212° F. The Lakeview Mining Company drilled two wells

in 1958, both of which were artesian with water temperatures of 98° F. The wells were completed at depths of 509 and 800 ft.

Unconfined ground water wells are generally completed in aquifers at depths less than 100 ft. These water table aquifers appear to be lenticular and are located at varying depths. It is difficult to separate artesian and composite artesian wells unless the chemical constituents are known. The comparison of water table levels with piezometric surfaces has little meaning.

Downward percolation of precipitation into the tailings pile occurs primarily during the winter months. Contamination of ground water is unlikely. A cemented gravel hardpan underlies the tailings pile protecting lower aquifers. Shallow ground waters move laterally through the tailings toward the surface drainage to the west. There is no evidence of springs at the base of the tailings pile. The Oregon Departments of Health and Water Resources periodically have monitored the ground water for evidence of pollution from the pile.⁽⁵⁾

2.7.4 Meteorology

The mean annual precipitation of 16 in. is spread fairly evenly throughout 9 mo of the year, with slightly more falling in the winter. The other 3 mo, July, August, and September, together receive less than 6% of the total precipitation. The average annual evaporation loss at Lakeview is estimated to be 45 in. Evaporation exceeds precipitation except during the months of February, March, and April.

Prevailing winds blow from the south with a secondary maximum from the north. The mountains block winds from the east. Wind speeds measured at the Lakeview airport are quite light: 85% of the observations are less than 15 mph. The windiest seasons are spring and fall. Wind information for the Lakeview area is presented in Table 2-1.

FIGURE 2-1. AERIAL PHOTOGRAPH OF SITE

FIGURE 2-2. DESCRIPTIVE MAP

SYSTEM	ROCK CHARACTERISTICS	POSITION OF THE TAILINGS
QUATERNARY	UNCONSOLIDATED DEPOSITS; CLAYS, SILTS, SANDS, EVAPORITES, GRAVELS, ALLUVIUM LANDSLIDE DEBRIS; SOME DEPOSITS ARE AQUIFERS, OTHERS ACT AS CONFINING LAYERS
	BASALTIC AND ANDESITIC FLOWS, INTERBEDDED CLASTIC SEQUENCES; SOME STRATA ARE POTENTIAL AQUIFERS	
	BASALTIC FLOWS; CAN YIELD WATER IN JOINTED AND FRACTURED AREAS	
TERTIARY	TUFFS AND FLOWS; LIMITED POTENTIAL AQUIFER	

FIGURE 2-3. SIMPLIFIED STRATIGRAPHIC COLUMN

FIGURE 2-4. SURFACE DRAINAGE

TABLE 2-1
WIND INFORMATION FOR LAKEVIEW, OREGON

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep	Oct.	Nov.	Dec.	Annual
Most Frequent Direction of Winds Greater Than 4 mph	S	S	S	S	S	N	N	N	N	N	S	N	S
Frequency (%)	14	21	26	18	17	14	12	7	19	20	20	16	15
Secondary Direction of Winds Greater Than 4 mph	N	N	N	W	N	S	S	S	S	S	N	S	N
Frequency (%)	8	9	5	7	9	6	10	7	9	16	14	12	11
Speed (All Directions)													
Average (mph)	6.0	8.8	9.3	8.7	8.8	7.1	6.7	6.3	8.8	10.2	8.3	7.0	8.1
15 mph (%)	93	82	82	83	83	91	92	92	82	75	82	87	85
16-31 mph (%)	7	17	18	16	17	9	8	8	18	25	17	13	15
32 mph (%)	<0.5	1	<0.5	1	<0.5	0	<0.5	0	<0.5	<0.5	1	0	<0.5

Note: These are cumulative data from January 1959 to May 1962.

CHAPTER 2 REFERENCES

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CHAPTER 3

RADIOACTIVITY AND POLLUTANT IMPACT ON THE ENVIRONMENT

CHAPTER 3

RADIOACTIVITY AND POLLUTANT IMPACT ON THE ENVIRONMENT

The principal objective of the assessment in this chapter is to determine the magnitude and characteristics of the radiation emitted from the Lakeview uranium tailings pile and the resulting potential exposure to the population residing and working in the vicinity of Lakeview, Oregon. 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 compo-

nents of the decay chain shown in Figure 3-1 all reach the same level of activity, matching that of the longest-lived initiating isotope. This condition is known as secular equilibrium. When the uranium is removed in the milling process, ^{230}Th , which is not removed, becomes the controlling isotope. After processing the ore for uranium, the thorium, radium, and other members of the decay chain remain in the spent ore solids in the form of a waste slurry. The slurry is pumped to tailings ponds. The sands and slimes that remain constitute the tailings piles. Generally, as at Lakeview, the slimes constitute only 20% of solid waste material, but they may contain 80% of the radioactive elements of major concern: radium, and its daughters.

3.2 RADIATION EFFECTS

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

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

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

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

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 0.8 pCi/g.⁽¹⁾ The sample locations taken within a 100-mi radius of Lakeview and the corresponding ^{226}Ra concentrations are shown in Figure 3-2. No previous measurements are available for the area. Another natural source of radiation in the environment arises from the decay of ^{232}Th , the predominant thorium isotope. The half-life of ^{232}Th is 1.4×10^{10} yr. It is also the parent of a decay chain containing isotopes of radium and radon. The average background value in the same off-site samples for each member of the thorium decay chain, assuming equilibrium, is about 0.7 pCi/g of soil. Table 3-2 lists the major background radioactive sources. The background values of the radium and thorium chains vary with locations by factors of 9 and 4, respectively. Previous measurements⁽²⁾ of background ^{226}Ra and ^{232}Th yielded values of 0.8 and 0.4 pCi/g, respectively.

Background values of radon concentrations were measured at eight locations using continuous radon monitors supplied by ERDA.⁽³⁾ An average outdoor value of 0.7 pCi/l was obtained from the 24-hr samples for the Lakeview area. However, the range of the measurements extends from 0.6 to 0.8 pCi/l.

Background gamma ray levels, as measured 3 ft above the ground, also were determined at several locations within 0.5 mi from the site by using a calibrated and energy-compensated Geiger Mueller detector. A value of 8 $\mu\text{R/hr}$ was established as the average background level, but the values ranged from 5 to 10 $\mu\text{R/hr}$.⁽¹⁾ Previous measurements of background gamma rates⁽⁴⁾ were reported as between 8 and 10 $\mu\text{R/hr}$. Cosmic rays are part of the measured background radiation levels. The contribution from cosmic rays is generally dependent upon the altitude and is approximately 6 $\mu\text{R/hr}$ in the Lakeview area,⁽⁵⁾ or approximately 75% of the measured average background value.

3.4 RADIATION EXPOSURE PATHWAYS AND CONTAMINATION MECHANISMS

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

(1) See end of chapter for references.

to man are:

- (a) Inhalation of the ^{222}Rn daughters, from decay of ^{222}Rn escaping from the pile; the principal exposure hazard is to the lungs.
- (b) External whole-body gamma exposure directly from the radionuclides in the tailings pile (primarily from ^{214}Bi) and in surface contamination from tailings spread in the general vicinity of the pile.
- (c) Inhalation of windblown tailings; the primary hazard relates to the alpha emitters ^{230}Th and ^{226}Ra , each of which causes exposure to the bones and the lungs.
- (d) Ingestion by man of ground or surface water contaminated from either radioactivity (primarily from ^{226}Ra) leached from the tailings pile or from solids physically transported into surface water.
- (e) Erosion and removal of tailings material from the pile by flood waters or heavy rainfall; this can create additional contaminated locations with the same problems as the original tailings pile.
- (f) Physical removal from the tailings pile also provides a mechanism for contamination of other locations.
- (g) Contamination of food through uptake and concentration of radioactive elements by plants and animals is another pathway which can occur; however, this pathway was not considered in this assessment.

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

3.4.1 Radon Gas Diffusion and Transport

Field measurements of the radon exhalation flux from the tailings using the charcoal canister technique⁽⁶⁾ are listed in Table 3-3. The current values range from 610 to 710 pCi/m²-s on the tailings pile. The weather was dry during the measurement period but the soil was moist. Radon flux depends principally on radium content of tailings. In general, reported values of radon flux vary considerably from time to time at a single sampling location due in part to differing moisture, soil, and climatological factors, to major changes in pile configuration between different locations, and to the difficulty of performing such measurements.

Radon gas above background, considered to be from the pile, was detected at distances up to 0.2 mi from the site. The locations and corresponding 24-hr average radon concentrations, includ-

ing background, measured during this program with the continuous radon monitors are shown in Figure 3-3. The average background radon concentration was 0.7 pCi/l and the highest value measured was 0.8 pCi/l.

Variation of radon concentration at two locations during the measurement period and the available weather data are shown in Figures 3-4 and 3-5. The sample location for Figure 3-4 is in the mill building, 0.5 mi east of the tailings pile. Figure 3-5 illustrates the measurements 0.2 mi north of the tailings pile. A diurnal variation of ^{222}Rn concentration is present in Figure 3-5. Radon concentration measurements made near the pile during this program generally indicated increased concentrations during the night, with reduced values during the day. The increase in concentration is probably the result of an inversion condition and reduced wind velocities. High winds tend to disperse the radon and generally do not result in significantly higher measurements of radon concentration downwind from the tailings pile. Data were not recorded during high winds or rainstorms.

The radon concentration measurements are plotted in Figure 3-6 as a function of distance from the edge of the tailings pile. Model calculations were also performed with annual meteorology data to provide an additional estimate of the radon concentration in the vicinity of the pile. The FB&DU model first determines radon flux and the total radon releases from the pile with diffusion theory using radium soil concentrations, and pile configuration deduced from the drilling and survey data. Then the radon transport off-pile is calculated by Gaussian diffusion⁽⁷⁾ plus wind drift conditions. Meteorology for the town of Lakeview during a 4-yr period (1959-1962) was used. The measured values are somewhat lower than the model results.

The model curve of radon concentration-versus-distance was used to calculate potential health effects resulting from radon diffusing from the Lakeview tailings. Radon daughter measurements were performed at two locations about 0.8 mi downwind (north) of the tailings pile.⁽²⁾ These measurements both yielded 0.001 WL for the 45-hr sampling period in October 1973.

3.4.2 Direct Gamma Radiation

The external gamma radiation (EGR) levels measured on the site are shown in Figure 3-7. These measurements included background and were taken with calibrated, energy-compensated Geiger Mueller detectors. The highest gamma radiation rate on the tailings pile (53 $\mu\text{R/hr}$) was made near the center of the eastern tailings dike. Gamma measurements on the pile ranged between 1 and 7 times background. In the former mill and ore storage areas, gamma radiation rates were measured from background to as high as 340 $\mu\text{R/hr}$ north of the mill in the ore storage area; however, the elevated levels occurred only in isolated spots and the ARCO decontamination program had not been completed at the time of the measurements.

The only other elevated gamma readings off-pile were measured in the evaporation pond area. These levels ranged from background to about twice background.

3.4.3 Windblown Contaminants

Another pathway is the result of windblown tailings. Prevailing winds are from the south. However, at Lakeview this pathway was not a significant factor in spreading radioactive contamination off the site.

Surface soil samples were taken in the area surrounding the tailings.⁽¹⁾ The sample locations and ^{226}Ra concentrations are shown in Figure 3-8. Only one soil or sediment sample was found that contained ^{226}Ra above twice background; however, this sample, which contained 4.0 pCi/g, did not appear to be due to windblown contamination. It was taken from the evaporation pond north of the tailings pile.

No air particulate measurements were performed at the Lakeview site.

3.4.4 Ground and Surface Water Contamination

Seven water samples were taken from the vicinity of the Lakeview tailings pile and analyzed for ^{226}Ra as shown in Figure 3-8.⁽¹⁾ Two samples taken from a stream north of the tailings piles each contained 0.03 pCi/l. Two samples were taken from a pond north of the tailings pile and contained 0.006 and 0.07 pCi/l, respectively. Three samples were obtained south of the tailings pile: from a stream, a ditch, and a well. These samples contained 0.004, 0.54, and 0.03 pCi/l, respectively. All the water samples were considerably below the EPA Interim Drinking Water Regulations for radium contamination; therefore, this pathway does not presently represent a significant health hazard from ^{226}Ra .

3.4.5 Soil Contamination

The amount of ^{226}Ra leaching from the tailings into the soil was determined in hand-auger holes around the tailings pile. The radioactivity profile was measured in these holes with a Geiger tube probe in a lead shield that collimates the radiation. The locations of the holes are shown in Figure 2-2, Chapter 2. These auger holes were drilled 2 to 2.5 ft deep and no radioactive contamination was observed from the gamma probe measurements.

Soil samples obtained previously⁽⁴⁾ from drilling through the tailings pile indicated ^{226}Ra concentrations of 37 pCi/g at the top surface of the tailings, 44 pCi/g at a depth of 24 in. beneath the tailings surface, 64 pCi/g at 43 in. and 22 pCi/g at 60 in. The latter two samples were obtained in the clay lining under the tailings.

3.4.6 Off-Site Tailings Use

A mobile gamma survey located sites where the gamma radiation rate was above the background level. A follow-up survey was performed at these locations to determine the source of the radiation. None of the elevated gamma locations contained tailings.

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,⁽⁸⁾ and criteria pertaining to the mill tailings site and open land.⁽⁹⁾ 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 (10CFR712). Appendix B contains the pertinent State of Oregon Regulations for Radiation Control.

The criteria which apply to the structures are the guidelines published by the Surgeon General of the United States.⁽⁸⁾ 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 from 6 air samples of at least 100-hr duration taken at a minimum of 4-wk intervals throughout the year.

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) For the tailings pile:

- (1) Tailings should be covered so that residual gamma ray levels do not exceed 0.040 mR/hr above back-

ground. The area also should be designated a control area with restricted access.

- (2) Where the site is not considered suitable for long-term stabilization, remove so that residual radium concentration in the soil does not exceed twice background values.
- (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 pile. 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 pathway and results in the largest estimated population dose. (1,10) In order to estimate the health effects from the pile radon, the model values were used which indicated elevation radon levels to 0.3 mi from the site.
- (b) External Gamma Radiation - gamma radiation above background is measurable to distances up to 0.05 mi from the pile, an area with no inhabitants. People on site will receive some gamma exposure until all contaminated material is removed or covered to reduce the gamma radiation. Exposure to the local population within 0.5 mi from the pile has been evaluated and yields a negligible health impact compared with exposure from radon daughters.
- (c) Airborne Activity - the lack of significant quantities of windblown tailings, toward inhabited areas indicates that direct 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. (11,12) Complete stabilization of the Lakeview tailings against wind erosion will eliminate any gradual accumulation of tailings off the site.

- (d) Water Contamination - the low ^{226}Ra activity in nearby off-site surface and ground water indicates little, if any, contamination from the tailings pile.
- (e) Subsoil Contamination - no leaching of radioactive materials into the ground around the pile was found in this study. Data were not obtained for the soil beneath the clay liner of the pond.
- (f) Physical Removal - no tailings have been identified under or near structures off site.

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

It is extremely difficult to predict with any assurance that a specific health effect will be observed within a given time after chronic exposure to low doses of toxic material. Therefore, the usual approach to evaluation of the health impact of low-level radiation exposures is to make projections from observed effects of high exposures on the basis that the effects are linear, using the conservative assumption of no threshold for the effects. The resulting risk estimators also have associated uncertainties due to biological variability among individuals and to unknown contributions from other biological insults which may be present simultaneously with the insult of interest. No synergistic effects are considered explicitly in this analysis. For the purpose of this engineering study, lung cancer is the potential health effect considered for RDC. The health effects were estimated using 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).⁽¹³⁾ 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, 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. (14)

The commitment, then, of 6 cancers per year has a statistical basis and relates to 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. (15) 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 for 30×10^6 person-WLM
total cumulative 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. (14,16,17) These investigations yielded risk estimator values consistent with the risk estimator used in the present assessment. The relative risk estimator can be several factors larger than the absolute risk estimator. (18)

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 (equivalent to 1 pCi/l Rn 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⁽¹³⁾ used for continual exposure to gamma radiation is:

100 effects per year for 10^6 person-rem
continuous exposure to gamma radiation

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

The model curve of radon concentration-versus-distance (Figure 3-6) was used to determine the health effects due to radon from the Lakeview pile. First, an indoor radon daughter concentration is deduced from the outdoor radon concentration curve using the conversion factor 1 pCi/l of ^{222}Rn outside equals 0.25 WLM/yr inside, then, the resulting RDC distribution is multiplied by the risk estimators given previously to yield the health effect risk per person as a function of distance from the pile. The estimated annual radiation-induced lung cancer risk as a function of distance from the edge of the pile is given in Figure 3-9 for prolonged continuous exposure. The curve shown in the figure represents the sum of the estimated annual radiation-induced risk from the tailings plus the average lung cancer risk per year from all causes for residents of the State of Oregon.⁽¹⁹⁾ The risk for developing lung cancer from pile radon at the edge of the pile is small compared with the natural occurrence risk of 3.4×10^{-4} per person per year. Health effects from total population RDC exposures for the area within 5 mi from the tailings pile perimeter were calculated. The average risk to an individual within this area is 1.9×10^{-6} per year. The population within 1 mi of the site is very low, and the contribution of pile radon to the total radon concentration at distances more than 0.3 mi away is very small. Health effect values were calculated by converting the appropriate radon concentrations in the Lakeview area to equivalent WLM/yr and multiplying by the absolute risk estimator. The nearest residents to the tailings pile are approximately 0.2 mi away where the health effect rate is 9.5×10^{-6} per person per year. Using a representative population distribution, the health effect rate for the present population of 2,880 is 5.4×10^{-3} health effects per year. The cumulative number of health effects after 100 yr is estimated to be 0.82 using a 4.3% declining growth rate discussed in Chapter 4.

No health effects were attributed to gamma radiation from the pile, because the gamma population exposure is zero within 0.05 mi surrounding the pile where the gamma radiation from the pile is greater than the background range.

Also estimated are health effects from background radon concentrations. The pile-induced radon daughter health effects from the tailings are approximately 6% of the background value. In 100 yr, the background radon is calculated to cause 14 health effects for the 4.3% declining population rate of Chapter 4.

If the relative risk estimator is used, the health effects estimates are correspondingly larger. The uncertainty in the health effects estimation is about a factor of 4.

Since the health effects from the Lakeview tailings are minimal, a more detailed health effects analysis is not presented.

3.7 NONRADIOACTIVE POLLUTANTS

Six water samples were taken from the vicinity of the Lakeview site and chemically analyzed. The locations of these samples are shown in Figure 3-8 and the analyses are listed in Table 3-4. Two of these samples were taken from a pond northwest of the pile. The third sample was taken from a stream under a road 900 yd north of the pile. Three water samples were taken south of the pile: one sample from a stream, one sample from a ditch, and the final sample from a well. The three samples obtained north of the tailings contained arsenic and selenium above the EPA Interim Drinking Water Standards; however, the samples north of the pile are upstream from the tailings pile and the stream sample is upstream from the evaporation ponds. It is not likely that the tailings contributed to this contamination. In addition, the Hammersley Canyon stream that flows along the edge of the tailings pile was sampled downstream from the pile and no significant contamination was found.

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

130-18

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

130-18

FIGURE 3-3. RADON CONCENTRATION IN VICINITY OF PILE

LEGEND

..... U.S. WEATHER STATION DATA

***** AC GENERATOR STOPPED

← WIND DIRECTION (UP = NORTH, DOWN = SOUTH)

FIGURE 3-4. ^{222}Rn AND ATMOSPHERIC TRANSIENTS AT MILL BUILDING ON SEPTEMBER 16, 1976

130-18

LEGEND

..... U.S. WEATHER STATION DATA

← WIND DIRECTION (UP = NORTH, DOWN = SOUTH)

FIGURE 3-5. ^{222}Rn AND ATMOSPHERIC TRANSIENTS 0.2 MI N OF PILE ON SEPTEMBER 17, 1976

130-18

FIGURE 3-6. REDUCTION OF OUTDOOR 222Rn CONCENTRATION WITH DISTANCE FROM THE TAILINGS PILE

130-18

FIGURE 3-7. GAMMA LEVELS IN THE SITE VICINITY

FIGURE 3-8. SURFACE AND SUBSURFACE RADIUM CONCENTRATIONS

130-18

FIGURE 3-9. LUNG CANCER RISK FROM CONTINUOUS EXPOSURE TO RADON DIFFUSION

130-18

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 FROM
SOUTHERN OREGON AND NORTHERN CALIFORNIA⁽¹⁾

Isotope (Decay Chain)	Average Value (pCi/g)	Range (pCi/g)
^{226}Ra (^{238}U)	0.81 ± 0.57	0.24-2.05
^{232}Th (^{232}Th)	0.67 ± 0.32	0.43-1.48
^{40}K	16.00 ± 2.8	10.5 -19.9

TABLE 3-3

RADON EXHALATION FLUX FROM THE LAKEVIEW TAILINGS

<u>Sample</u>	<u>Radon Flux (pCi/m²-s)</u>
1 (LVO-C1) ^a	190
2 (LVO-C2) ^a	220
3 (LVO-C3) ^b	710
4 (LVO-C4) ^b	610

^aPlaced in evaporation pond area
^bPlaced on tailings pile

TABLE 3-4

CHEMICAL ANALYSES OF LAKEVIEW WATER SAMPLES (mg/l)
(Samples Taken September 1976)

<u>Sample^a</u>	<u>As</u>	<u>Ba</u>	<u>Cd</u>	<u>Cr</u>	<u>V</u>	<u>Fe</u>	<u>Pb</u>	<u>Se</u>
A - Stream at road 900 yds N of pile	0.080	0.21	<0.001	0.020	0.070	0.634	0.010	0.055
B - Pool N end of pile	0.069	0.26	<0.001	0.024	<0.001	1.816	0.008	0.061
C - Runoff from pool NW of pile	0.074	0.18	<0.001	0.025	0.040	0.512	0.004	0.058
D - Stream by roads S of pile	0.024	0.25	<0.001	0.023	0.120	1.049	0.002	0.005
E - Ditch S of pile	0.020	0.22	<0.001	<0.001	<0.001	2.050	0.011	0.007
F - Well at house S of pile	0.011	0.17	<0.001	<0.001	0.060	0.160	0.002	0.005
EPA Interim Drinking Water Standards ^b	0.05	1.0	0.01	0.05	--	0.3 ^c	0.05	0.01

^a See Figure 3-8 for locations

^b Federal Register, Dec. 24, 1975

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

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CHAPTER 4
SOCIOECONOMIC AND LAND USE IMPACTS

CHAPTER 4

SOCIOECONOMIC AND LAND USE IMPACTS

The Lakeview tailings and millsite are located in Lake County, Oregon near the intersection of the Oregon, California, and Nevada state lines.⁽¹⁾ Lakeview, the county seat, is located 2 mi south-east of the site. Klamath Falls, Oregon, the area's largest city is located 96 mi to the west. State Highway 140 and U. S. Highway 395 service the area. The boundaries of Lake County are shown in Figure 4-1.

4.1 SOCIOECONOMIC BACKGROUND

Lakeview, Oregon is similar to many small towns in the rural areas of the Western United States. Although it is neither a major tourist destination nor on a principal route to major tourist attractions, the lake and countryside provide recreation areas and stimulate some associated economic activity. The principal economic activities are lumber, farming, ranching, and government. The U. S. Bureau of Land Management, the U. S. Forest Service, some state agencies, and nearly all county bureaus have offices in Lakeview.

The future demographic and economic conditions of Lakeview can be projected by extrapolating statistical data obtained for the four census records of 1940 to 1970 and a recent 1977 survey by Portland State College.⁽²⁾ Lakeview's and Lake County's populations generally have increased except during the 1960's. Since 1940 the population of the State of Oregon has more than doubled. During the depression years of the 1930's, Lake County's male population was 57.2%, far higher than the state's average of 51.6%. Since that time the percentage of males in the population of Lake County has decreased and is now equal to the state's average of 49%. The median age of the county inhabitants has increased from 28.9 in 1940 to 31.1 in 1970, while the median age of the state's population has decreased from 32.4 in 1940 to 29.0 in 1970. Ethnically, the population of Lake County is dominantly Caucasian. Educational attainment is high and median income is higher in Lakeview than in the county or state as a whole. Although farmers and farm laborers have decreased in numbers and in percentage of the work force, they remain the largest employment sector. Managers, professionals, service workers, clerks, and nonfarm laborers constitute over half the work force. Traditionally, Lake County has looked to agriculture, forestry, and fishing as the prime employer and manufacturing as the second largest employment sector. In recent years, there has been a gradual increase in government-related jobs and retail business. Mining has never been a major employment sector of the area's economy and even during the 1950's

(1) See end of chapter for references.

made up less than 5% of the work force.

Lakeview enjoys a healthy stable economy with a diversified base of agriculture, forestry, local recreation, manufacturing, retailing, and government employment.

4.2 POPULATION ESTIMATES

The recent population study by Portland State College indicates that in 1977 there were 2,880 people living in Lakeview. This value was used for the health effects calculations. Census figures indicate that in 1970 there were 2,705 people living in Lakeview.

Several factors must be considered in determining population projections and future growth patterns for Lakeview. First, tourism offers a potential for modest growth. Second, distance from major markets and isolation of the region discourage industrialization. Third, lumbering, ranching, and farming cannot be the basis for sustained population growth.

Considering these factors, three annual rates of growth are projected for Lakeview. The highest assumes that the 4.3% annual growth rate experienced in 1976-1977 will be sustained. The second rate is 1.8%, which is approximately the annual growth rate of the State of Oregon. The third rate, -1.7%, was the rate of decline for the city from 1960 to 1970. Population growth factors for constant growth rates are presented in Figure 4-2.

Assumptions of a steady rate of growth may be highly unrealistic. For the reasons given above, the rate of growth could decline and approach zero by some future date. Also presented in Figure 4-2 are the population projections for a steady growth rate for 10 yr, followed by a declining rate to zero growth at 25 yr. This is referred to as a "declining rate of growth."

The constant -1.7% rate indicates there will be 0.67 as many city inhabitants in the year 2000 and 0.43 times as many in 2025 as in 1977. If the most rapid constant growth rate (4.3%) is assumed, there will be 2.6 persons in the year 2000 and 7.5 people in 2025 in Lakeview for every person who lived there in 1977. Those constant rates would be tenable only for short periods of time.

Either the 1.8% declining rate of growth or the 4.3% declining rate of growth is more likely. The 1.8% declining rate of growth would result in 1.2 times as many people in the year 2000 in Lakeview than lived there in 1977, and the 4.3% declining rate of growth would yield a population in the year 2000 that would be 1.6 times larger than in 1977.

4.3 LAND USE

As might be expected in an area with a highly diversified economic base, the land usage near Lakeview is diverse and con-

sists of numerous small and large holdings. Much of the land at higher elevations is used for timber, and some acreages on the valley floor are used by lumber companies for storage, processing, and manufacturing. Other large tracts of land are used for ranching and farming. Commercial and housing developments are close to town. The area south and west of the tailings is used for ranching and grazing. Small "ranchettes" and homesites are located along roads near the site. Southeast of the site a lumber company runs a small operation, and just east of it is a cemetery. Commercial and industrial activities to the east of the pile include a drive-in theater, motel, service station, and greenhouse. North of the pile are some tourist-related facilities near the geothermal springs. A map depicting land usages is shown in Figure 4-3.

4.4 IMPACT OF THE TAILINGS ON LAND VALUES

Land values range from approximately \$130 to \$3,500/acre with values of improvements reflected in land use. Some recent sales have varied between \$1,000 and \$2,500/acre. Industrial land is the most expensive land. The vicinity near the tailings area is zoned for a number of land uses; however, few changes in land use are expected in the study area because there is little demand for additional land. Some commercial development can be anticipated along the highways, but housing developments will expand toward the lake.

The presence of the tailings restricts the use of the site itself. It is not available for ranchettes, grazing, or logging. However, the impact on surrounding land use has been minimal. There are no strong pressures to use the tailings area for other purposes, although the millsite probably will be used by industrial companies because of the buildings.

FIGURE 4-1. MAP OF LAKE COUNTY BOUNDARIES

130-18

FIGURE 4-2. POPULATION PROJECTIONS

FIGURE 4-3. VICINITY LAND USE

130-18

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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) Does the Lakeview tailings pile represent a future uranium resource?
- (b) Should the pile be reprocessed?
- (c) Is there any likelihood that once stabilized the pile 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 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 operations 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 60% 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 of the size considered -- 500 to 5,000 tons/day.

The heap leaching site must be an acceptable tailings disposal

(1) See end of chapter for references.

site that can be stabilized readily and maintained, or must be adjacent to the tailings disposal site. A heap leach site of about 3 acres of relatively flat ground would be required if the 130,000 tons of Lakeview tailings were to be leached and stabilized in place. The reprocessing site would also require water and power.

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 site. There is one existing uranium mill 577 mi from Lakeview. This mill has a capacity of 500 tons/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 have sufficient capacity to handle 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 mill-site 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 than a heap leach facility as seen in Figure 5-1. Some industry tests have shown heap leach recoveries on tailings to be higher than the values in Figure 5-1.

The major disadvantage of a new conventional uranium mill is the higher construction cost.

5.2 LAKEVIEW 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 Lakeview tailings pile consists of 130,000 tons of tailings containing 0.018% U_3O_8 as determined from AEC records.⁽²⁾ Using the AEC estimate, the Lakeview pile contains 46,800 lb of U_3O_8 . A chemical analysis⁽³⁾ of a composite tailings sample is

given in Table 5-1. Further sampling would be necessary to verify the estimate. Recovery of a sufficient fraction of radium to eliminate the potential health hazards is not technically feasible at this time.

5.2.2 Reprocessing Costs

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

Ranges 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 \$2.7 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 heap leach facility are obtained from the lower range of Figure 5-4.

5.3 ASSESSMENT OF LAKEVIEW MINERAL RECOVERY POTENTIAL

Using Figures 5-1 through 5-5, the breakdown cost of recovery for the Lakeview pile 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	10,300	0.5	2.7	3.2	311
Conven- tional	18,700	0.9	4.7*	5.6	299
Haulage to Exist- ing Mill	18,700	0.9	7.5**	8.4	449

* For a 500-ton/day facility

** Transportation cost for 577 mi at \$0.10/ton-mi

From the economic evaluation of the reprocessing of the Lakeview tailings it can be seen that none of the three proposed options are presently economically feasible. The lowest cost for reprocessing appears to be about \$300/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 affect significantly the conclusions based upon the experience in the uranium industry over the last 25 yr.

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

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

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)

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)

TABLE 5-1

ASSAY RESULTS OF LAKEVIEW TAILINGS AND BACKGROUND SAMPLES
(ppm)

<u>Element</u>	<u>Tailings Pile</u>	<u>AEC Estimate*</u>	<u>Background Composite</u>
Arsenic	2,030	--	2.2
Beryllium	0.14	--	0.3
Cadmium	0.53	--	0.5
Copper	10	--	21
Chromium	16	--	39
Lead	104	--	7.9
Molybdenum	260	--	2.1
Mercury	34	--	0.1
Selenium	40	--	3.9
Uranium (U ₃ O ₈)	22	180	1.1
Zinc	32	--	45

*Calculated tails assay based on plant operation⁽¹⁾

CHAPTER 5 REFERENCES

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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 prevents 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 Lakeview tailings pile.

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 7.

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 specific chemical makeup of the solidified slurry and would require research to

⁽¹⁾See end of chapter for references.

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
- (e) Proper selection of plants conducive to self-regeneration under conditions anticipated over a long time

Growth of vegetation at sites receiving less than 10 in. of annual precipitation and with high evapotranspiration rates requires irrigation and fertilization. At Lakeview, precipitation averages about 16 in. annually.

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 Lakeview tailings is likely to constitute a problem. The techniques which could be employed to control leaching from tailings piles include the following:

- (a) Employ chemical stabilization to prevent leaching into underground aquifers (This is the same stabilization system discussed in paragraph 6.1.2).
- (b) Physically compact the tailings to reduce the percolation of water through the materials.
- (c) 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.
- (d) For a new site, line the storage area with an impermeable membrane (bentonitic clays and various plastic materials commonly are used for this purpose).

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 still 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.^(4,5) 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. However, the tailings pile at Lakeview is presently covered with about 2 ft of earth which offers protection from wind and water erosion. This cover reduces gamma radiation to near background rates but reduces radon exhalation by only 30% compared to bare tailings.

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

130-18

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

130-18

CHAPTER 6 REFERENCES

1. "Methods and Costs for Stabilizing Fine Sized Mineral Wastes"; Bureau of Mines Report of Investigation; RI7896; 1974.
2. A. B. Tanner; "Radon Migration in the Ground: A Review"; The Natural Radiation Environment; J. A. S. Adams and W. M. Lowder, eds; University of Chicago Press; pp. 161-190; 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. S. Adams and W. M. Lowder, eds; University of Chicago Press; 1964.
4. K. J. Schiager; "Analysis of Radiation Exposure on or Near Uranium Mill Tailings Piles"; Radiation Data and Reports; Vol 15; Jul 1974.
5. "Evaluation of Various Methods, Techniques and Materials for Stabilizing Uranium Mill Tailings"; FB&DU report (in preparation).

CHAPTER 7
REMEDIAL ACTIONS AND BENEFITS

CHAPTER 7

REMEDIAL ACTIONS AND BENEFITS

The remedial actions for the Lakeview site take into consideration the decontamination and stabilization efforts by ARCO. It is assumed that the program there is completed, that the tailings are stabilized, and that the mill and millsite are decontaminated.

The two remedial action options include a continual maintenance program and additional site area decontamination, stabilization, drainage corrections, and security.

There are no off-site areas or locations where tailings need to be removed.

7.1 MINIMAL REMEDIAL ACTION, MAINTENANCE (Option I)

Long-term maintenance of the site following completion of the ARCO reclamation program is specified in this option. This involves periodic monitoring and repair of fences, signs, and stabilization cover. This option assumes that there is a nominal 2 ft of earth cover on the tailings as a result of the current actions.

Provision for the annual monitoring and maintenance costs for an extended period of time is included in the form of a perpetual care fund which at 7% annual interest would provide the money necessary for projected inspection and maintenance functions. The perpetual care fund is a mechanism to indicate the long-range control and financing needed to maintain the integrity of the stabilized tailings pile.

7.1.1 Costs

As shown in Table 7-1 the cost for this option is \$40,000. The major cost components are as follows:

(a) Engineering	\$ 0
(b) Remedial action (perpetual care fund)	40,000
(c) Environmental assessment	0
(d) Contingency	<u>0</u>
Total Cost	\$40,000

The perpetual care fund at 7% interest would provide approximately \$2,800/yr for monitoring and maintenance of the fencing and the tailings.

7.2 ADDITIONAL DECONTAMINATION AND STABILIZATION, DRAINAGE CORRECTIONS AND SECURITY (Option II)

The principal objectives of this option are to remove some minor amounts of contaminated material in the evaporation ponds and the millsite, to provide increased security, and to improve the surface hydrology of the stream which crosses the site.

Off-pile contaminated material in and near the evaporation ponds and in the ore storage area would be removed and placed on the surface of the pile. The total amount of material to be cleaned up approximates 4.5 acres to depths of 2 ft in a few isolated locations.

The seasonal stream which drains Hammersley Canyon, east of the site, runs along the north edge of the site and then turns southwest between the pile and the settling ponds. In the area north of the pile, the stream channel is well-defined and relatively straight; however, on the west side it meanders considerably, thus slowing the water flow. In this option, the channel would be straightened west of the pile, to the location where the stream crosses the county road southwest of the site.

Stabilization cover then would be added to a few locations on the existing pile, so that it would be completely covered with a minimum of 2 ft of earth. Gamma readings indicate that the south edge of the pile just beyond the dike also would need this cover. The pile then would be seeded with grasses appropriate to the area.

7.2.1 Security and Maintenance

In this option a 6-ft-high chainlink fence topped by three strands of barbed wire would be erected around the pile. Also, radiation warning signs would be displayed prominently on the fence, gates, and in other appropriate areas.

No irrigation would be needed but physical maintenance would be required as described in Option I.

7.2.2 Resulting Impacts

Under this option the full 2 ft of cover would offer greater resistance to wind and water erosion. Also, the cover would further reduce the gamma radiation, but would not greatly effect the exhalation of radon from the pile.

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

7.2.3 Costs

As shown in Table 7-1, the cost for this option is \$290,000. The major cost components are as follows:

(a) Engineering (12% of item b)	\$ 24,000
(b) Remedial action	186,000
(c) Environmental assessment	15,000
(d) Contingency (15% of items a, b, and c)	35,000
(e) Perpetual care fund	<u>30,000</u>
Total Cost	\$290,000

The perpetual care fund at 7% interest would provide approximately \$2,100/yr for monitoring and maintenance of the fencing and tailings. This is \$700/yr less than in Option I, primarily because of the more adequately stabilized pile and the more secure type of fencing.

7.3 IMPACTS OF THE OPTIONS

7.3.1 Health Benefits

The ARCO decontamination program and either of the options presented would leave some of the land areas around the pile in a condition suitable for restricted activities.

As discussed in Chapter 3, the health effects from the pile are negligible. In view of the small health effects, no cost-benefit analysis has been performed for this site.

7.3.2 Land Value Benefits

The property surrounding the Lakeview site is mostly under private ownership. The estimated market value of the land (excluding improvements or mineral values) varies from less than \$1,000/acre to almost \$2,500/acre; hence, after stabilization of the tailings and decontamination of the site, the average value of the approximately 228 acres of land not covered by tailings could increase from a current estimated \$800/acre to a possible \$1,000/acre for a net increase of \$45,600.

TABLE 7-1

COST ESTIMATE SUMMARY

<u>Option No.</u>	<u>Description</u>	<u>Estimated Cost (\$)*</u>
I	Maintenance	40,000
II	Additional site decontamination and stabilization, drainage improvements, security and maintenance	290,000

*Costs are in thousands of dollars, based on 1977 value

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 (10CFR712)

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 Biologic 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 $\mu\text{R/hr}$ 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.

**ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
RULES AND REGULATIONS**

56777

**PART 712—GRAND JUNCTION
REMEDIAL ACTION CRITERIA**

Sec.	
712.1	Purpose.
712.2	Scope.
712.3	Definitions.
712.4	Interpretations.
712.5	Communications.
712.6	General radiation exposure level criteria for remedial action.
712.7	Criteria for determination of possible need for remedial action.
712.8	Determination of possible need for remedial action where criteria have not been met.
712.9	Factors to be considered in determination of order of priority for remedial action.
712.10	Selection of appropriate remedial action.

AUTHORITY: Sec. 203, 86 Stat. 226.

§ 712.1 Purpose.

(a) The regulations in this part establish the criteria for determination by ERDA 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 tailing which have been used as a construction-related material.

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

§ 712.2 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.

§ 712.3 Definitions.

As used in this part:

(a) "Administrator" means the Administrator of Energy Research and Development or his duly authorized representative.

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

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

(d) "ERDA" means the U.S. Energy Research and Development Administration or any duly authorized representative thereof.

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

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

(g) "Indoor radon daughter concentration level" means that concentration of radon daughters determined by: (1) Averaging the results of 5 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.

(h) "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 gram of air produces, in air, ions carrying one electrostatic unit of quantity of electricity of either sign.

(i) "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.

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

(k) "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.

(l) "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.

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

(n) "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 1.3×10^4 MeV of potential alpha energy.

§ 712.4 Interpretations.

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

56778

(b) Where ERDA 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.

§ 712.3 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 § 712.7 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.

§ 712.5 Communications.

Except where otherwise specified in this part, all communications concerning the regulations in this part should be addressed to the Director, Division of Safety, Standards, and Compliance, U.S. Energy Research and Development Administration, Washington, D.C. 20545.

§ 712.6 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 0.25 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.

§ 712.7 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 ERDA approved data on indoor radon daughter concentration levels are available:

(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.

§ 712.9 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 § 712.7 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 or certain remedial measures.

§ 712.10 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. ERDA shall select the remedial action technique or combination of techniques, which it determines to be the most appropriate under the circumstances.

APPENDIX B

STATE OF OREGON REGULATIONS
FOR CONTROL OF RADIATION

APPENDIX B

STATE OF OREGON REGULATIONS
FOR CONTROL OF RADIATION

Sec. C. 105 Permissible Levels of Radiation from External Sources
in Unrestricted Areas. (1)

- (a) Except as authorized by the Radiation Control Agency pursuant to paragraph (b) of this Section, no licensee or registrant shall possess, use, or transfer sources of radiation in such a manner as to create in any unrestricted area from such sources of radiation in his possession.

(1) It is the intent of this Section to limit radiation levels so that it is unlikely that individuals in unrestricted areas would receive a dose to the whole body in excess of 0.5 rem in any one year. If in specific instances, it is determined by the Radiation Control Agency that this intent is not being met, the Radiation Control Agency may, pursuant to Section A.7, impose such additional requirements on the licensee or registrant as may be necessary to meet the intent.