**A SUMMARY OF THE PHASE II - TITLE I ENGINEERING
ASSESSMENT OF INACTIVE URANIUM MILL TAILINGS
MAYBELL SITE, MAYBELL, COLORADO**

OCTOBER 1977

PREPARED FOR

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

BY

Ford, Bacon & Davis Utah Inc.

MASTER

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By

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

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 is a summary of a parent report (issued under separate cover) entitled, "Phase II - Title I Engineering Assessment of Inactive Uranium Mill Tailings, Maybell Site, Maybell, Colorado". Both reports are authorized under the U.S. Energy Research and Development Administration (ERDA) Contract No. E(05-1)-1658. These reports are part of a series of reports on inactive uranium millsites that address 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, to identify reasonable remedial action options for each site, and to estimate the remedial action costs. If additional data that may alter or have an impact on a final remedial action decision for any site are required, they can be obtained during the Title II Engineering Effort.

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) The State of Colorado: Department of Health, Mr. A. J. Hazle, and Mr. G. A. Franz
- (3) Union Carbide Corporation, Mr. R. G. Beverly, Grand Junction Office, Mr. G. Bitler, and other Maybell personnel
- (4) EG&G, Las Vegas, Nevada, Mr. Jack Doyle; for aerial photography
- (5) 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 Maybell, Colorado. The Phase II - Title I services include the preparation of topographic maps, the performance of core drillings sufficient to determine areas and volumes of tailings and radiometric measurements to determine radium-contaminated materials, the evaluation of resulting radiation exposures of individuals and nearby populations, the investigation of site hydrology and meteorology and the evaluation and costing of alternative corrective actions.

Radon gas release from the 2.6 million tons of tailings at the Maybell site constitutes the most significant environmental impact, although windblown tailings and external gamma radiation are also factors. The three alternative actions presented range from fencing and maintenance (Option I), to placing the tailings in an open-pit mine and adding 2 ft of stabilization cover material (Option III). Cost estimates for the three options range from \$250,000 to \$4,520,000.

Reprocessing the tailings for uranium does not appear to be economically attractive at present.

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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

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

CHAPTER 1

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

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 Myabell 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 three alternatives:

- (a) Minimum remedial action, which amounts to improving the fencing around the site
- (b) Stabilization with 2 ft of cover material for long-term storage at the present site
- (c) Removal of the tailings to a nearby open-pit mine and stabilization with 2 ft of cover material

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

1.1.1 Background

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

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

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

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

The Phase I assessment began in May 1974, with teams consisting of representatives of the AEC, the EPA, and the states involved visiting 21 of the inactive sites. The Phase I report was presented to the JCAE in October 1974. Table 1-1 summarized the conditions at the time of the Phase I visits.⁽¹⁾ Based on the findings presented in the report, the decision was made to proceed with Phase II.

On May 5, 1975, ERDA, the successor to AEC, announced that Ford, Bacon & Davis Utah Inc. of Salt Lake City had been selected to provide the architect-engineering (A-E) services for Phase II. ERDA's Grand Junction, Colorado, office (GJO) was authorized to negotiate and administer the terms of a contract with FB&DU. The contract was effective on June 23, 1975. The Salt Lake City Vitro site was assigned as the initial task, and work began immediately. Field work at Maybell was performed from May 21 through May 23, 1976. Radon and radon flux measurements were made from Oct 18 through Oct 21, 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 Maybell 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 clean-up or decontamination.
- (f) Determination of the adequacy and the environmental suitability of sites to which mill tailings containing radium can be moved for long-term (>50 years) storage; and once such sites are identified, perform evaluation and estimate the costs involved.
- (g) Performance of engineering assessments of structures where uranium mill tailings have been used in off-site construction to arrive at recommendations and estimated costs of performing remedial action.
- (h) Evaluation of various methods, techniques and materials for stabilizing uranium mill tailings to prevent wind and water erosion, to inhibit or eliminate radon exhalation, and to minimize maintenance and control costs.
- (i) Evaluation of availability of suitable fill and stabilization cover materials that could be used.
- (j) Evaluation of radiation exposures of individuals and nearby populations resulting from the inactive uranium millsite, with specific attention to:

- (1) Gamma
- (2) Radon
- (3) Radon daughter concentrations
- (4) Radium and other naturally occurring radio-isotopes 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 Maybell millsite and tailings pile are located 5 mi north of the Yampa River, approximately 25 mi west of Craig, in Moffat County, in northwestern Colorado. The site is at an elevation of 6,220 ft above sea level in a rolling, sagebrush-covered area. The site and its relationship to the surrounding area are shown in the aerial photo of Figure 2-1, Chapter 2.*

1.2.2 Ownership and History of Milling Operations and Processing

Union Carbide Corporation has been the owner and operator of the site since its inception in 1957. The plant became operational in 1957, processed 2.6 million tons of ore, and shut down in the fall of 1964. The ore had a grade of 0.098% U_3O_8 and all the concentrate produced was sold to the AEC. The ore came from nearby open-pit mines. An upgrader circuit at the processing plant was used to treat low-grade ore before leaching.

*All figures and tables referenced in this summary are from the parent report and are included in the Addendum.

1.2.3 Present Condition of the Site

Figure 2-3 is a descriptive map of a portion of the site as it now exists. The site area is characterized by deep open pits from which the ore was extracted, piles of removed overburden, and the relatively flat yet sloping surface of the 80-acre tailings pile. Although the tailings pile was stabilized by the addition of 6 in. of earth cover and vegetation, erosion has exposed about 20% of the pile's surface and only about 40% of the surface is covered with vegetation. Off-pile ditches and a dike on the east side of the pile divert upslope water away from the tailings. Most of the water that collects on the tailings drains off the pile through a drainage system on the tailings, and the water is channeled into nearby Johnson Wash. The tailings are enclosed with a barbed-wire fence. Figures 2-4A and 2-4B are typical cross-sections through the pile.

On another portion of the site, heap leaching operations utilizing low-grade ore are being conducted by Union Carbide Corporation.

1.2.4 Tailings and Soil Characteristics

The tailings are generally of finely ground sands with some slime and a slight clay content. Bulk densities run between 83.6 and 96.6 lb/ft³. There are approximately 2.6 million tons of tailings on the site. The weight and volume of the tailings and cover material are given in Table 2-1, Chapter 2.

The soil beneath the tailings consists of dark brown, clayey and silty fine sands of medium density.

1.2.5 Geology, Hydrology and Meteorology

The Maybell tailings pile is located on a gentle southwestern slope near the head of a small drainage system. The Browns Park Formation underlies the site and in turn is underlain by the Mancos Shale. The Browns Park Formation primarily is composed of sandstone units, and some shale layers within the formation act as barriers to the downward and upward migration of ground waters. A simplified stratigraphic column is shown in Figure 2-5, Chapter 2.

The Yampa River, 5 mi to the south, is the closest perennial stream flowing through the area downdrainage from the site. Drainage at the site consists of diversion ditches around the pile and drainage channels into Johnson Wash, a dry tributary of Lay Creek. Lay Creek enters the Yampa River approximately 2.5 mi downstream from Johnson Wash. Other surface waters near the site consist of standing water in the inactive Rob Pit. Contamination from the pile into the area's surface waters is limited because the pile is not subject to flooding, a diversion system protects most of the pile from off-site overland flow, and the dishlike configuration of the pile collects the precipitation which falls on the pile. However, a dike failure during mill operations left about 200 tons of tailings in the wash leading to Johnson Wash. Also,

there is evidence of both water and wind erosion from the steep eastern slope of the pile.

The unconfined ground waters of the area are within the Browns Park Formation and in unconsolidated valley deposits. The water table at the site is 150 ft below the tailings-subsoil interface and the flow gradient is to the west-southwest. The confined ground waters are contained within the lower sections of the Browns Park Formation by shale layers, or are very deep aquifers confined by the thick sequence of Mancos Shale. Increased concentrations of radionuclides are unlikely because percolation through the tailings is limited almost entirely to the precipitation which falls on the site. Another source of radionuclides to the ground water system is the percolation of waters through the ore-bearing strata; this source makes any potential contamination from the tailings insignificant.

Strong winds are common in the area and tend to flow from the west-southwest. Tailings and cover material have eroded from the eastern edge of the pile, which would be difficult to revegetate in its present condition. The average annual rainfall at Craig is 14 in. High-intensity rainfall such as thunderstorms are infrequent but can occur in the Maybell area during May through October. Such storms could result in further erosion of the eastern margin of the pile and in the transport of contaminated streambed material further downstream.

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 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 piles.
- (c) Inhalation and ingestion of windblown tailings. The primary health effect relates to the alpha emitters ^{230}Th and ^{226}Ra , each of which causes exposure to the bones and lungs.
- (d) Ingestion of ground and surface water contaminated with radioactive elements (primarily ^{226}Ra) and other toxic materials.
- (e) Contamination of food through uptake and concentration of radioactive elements by plants and animals is another pathway 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 ERDA-supplied continuous radon monitors at four locations in the vicinity of the Maybell tailings pile. The locations and values of the 24-hr radon concentrations, including background, are shown in Figure 3-3, Chapter 3. The highest outdoor radon concentration (15 pCi/l) was measured on the pile. Background measurements of atmospheric radon at 2 locations, 2.5 to 3.5 mi from the site, averaged 3.0 pCi/l. Radon above the average background level was detected at 0.5 mi from the site.

1.3.1.2 Direct Gamma Radiation

The lowest value of gross gamma radiation in the area (4,000 ft northwest of the tailings) was 11 $\mu\text{R/hr}$ as measured 3 ft above ground with an energy-compensated Geiger Mueller detector.⁽²⁾ Above the surface of the tailings pile, gamma radiation rates ranged to a maximum of 340 $\mu\text{R/hr}$. In the area surrounding the tailings the gamma radiation rates were higher than twice background due largely to windblown tailings and stockpiles of low-grade ore nearby.

1.3.1.3 Windblown Contaminants

Prevailing winds in the area are from west-southwest. Surface soil samples indicate windblown contamination to the east of the pile. At 375 yd east of the pile, a surface soil sample contained 10 times the average ^{226}Ra background concentration of 1.5 pCi/g. Windblown contamination 500 yd toward the east is also shown by the iso-exposure lines illustrated in Figure 3-10, Chapter 3. These lines were plotted based on EPA gamma radiation measurements.

1.3.1.4 Ground and Surface Water Contamination

Three water samples taken from upstream and downstream in Lay Creek and at the confluence of Lay Creek with Johnson Wash, contained 0.18, 0.19, and 0.16 pCi/l, respectively, of ^{226}Ra ; (2) these concentrations are well below the Interim Drinking Water Standard of 5 pCi/l of combined ^{226}Ra and ^{228}Ra .

A water sample from the wash just off the tailings contained 12.8 pCi/l of ^{226}Ra and a sample from Johnson Wash, 0.5 mi downstream from the pile, had a ^{226}Ra concentration of 0.02 pCi/l.

A well water sample from a cased 150-ft monitoring well west of the tailings contained 10.4 pCi/l of ^{226}Ra . This 150-ft well was drilled into the Browns Park Formation, the host rock for the uranium deposits in this vicinity; and contamination in the water in this formation cannot be attributed to the tailings pile.

The quality of the Yampa River was monitored from 1961 to 1970 and the ^{226}Ra concentration downstream from the site averaged 0.08 pCi/l. (1)

Considering the existing data and the distance between Maybell and the tailings, the tailings have not increased the ^{226}Ra content of the water at Maybell.

1.3.1.5 Soil Contamination

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

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^a</u>	<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 six 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 μ 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 μ R/hr above background is used in such circumstances. Average background in the Maybell area was determined in this study to be 11 μ R/hr. As a guideline for the land beyond the site, if residual gamma levels are less than 10 μ R/hr above background, the land may be released for unrestricted use. Where cleanup is necessary the radium content of the soil should be reduced to no more than twice the radium background in the area. If the radioactive tailings material is stabilized in place, the same criteria apply but control of gamma radiation would be by an earth covering. However, the area should be designated a controlled area, be fenced to limit access, and be restricted as to human occupancy. The numerical guidelines provide a basis for the engineering assessment, but are subject to review based on the overall findings of Phase II.

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

1.3.3 Potential Health Impact

Radon gas exhalation from the pile and the subsequent inhalation of radon daughters account for most of the potential total dose to the population from the Maybell site under present conditions. The gamma radiation exposure from the pile is virtually zero since there are very few persons who live or work within

0.4 mi of the pile where gamma radiation is above background.

Gamma radiation can be reduced effectively by shielding with any dense material. However, experience has shown that it is very difficult to control the movement of radon gas through porous 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 pile. 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⁽³⁾ indicate that 13 ft of earth cover theoretically would be required to reduce the radon diffusion from the Maybell 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. Since the end results of long-term exposure to low-level radiation may be diseases such as lung cancer or leukemia, which also are attributable to many other causes, the determination of specific cause in any given case becomes very difficult. Therefore, the usual approach to evaluation of the health impact of low-level radiation exposures is to make projections from observed effects of high exposures on the premise that the effects are linear. A considerable amount of information has been accumulated on the high incidence of lung cancer in uranium miners exposed to radon and its daughters in mine air. 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).⁽⁴⁾ 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 equili-

brium 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. (5)

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

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

For continuous exposure:

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

On the basis of measurements of radon concentrations in excess of background values, it is calculated that the average pile radon-induced lung cancer risk due to the pile in the area within 4 mi from the Maybell site is 1.8×10^{-6} per person per year, or 1% of the average cancer risk due to all causes for Colorado residents (1.8×10^{-4}). (6)

The 25-yr health effects were calculated for a static population of 433 in the 0- to 4-mi area. The cumulative health effects for 25 yr for pile-induced Rn and background Rn are 0.02 and 1.7, respectively.

Pile-induced radon daughter health effects are approximately 1% of the background radon daughter health effects for the 0- to 4-mi area. The exposure and consequent risk from the Maybell tailings pile is minimal, especially comparing pile radon health effects with background radon health effects.

1.3.4 Nonradioactive Pollutants

There are other potentially toxic materials in the tailings. Chemical analyses of tailings samples from auger holes in the Maybell pile showed barium, chromium, and lead in concentrations between 5 and 30 ppm. The highest selenium concentration was 24 ppm and arsenic concentration was 3 ppm. Vanadium was present at about 40 ppm.

Water from a well west of the tailings that taps the Browns Park Formation had concentrations of iron, arsenic, lead, and selenium above the acceptable EPA Interim Drinking Water Standards. The Browns Park Formation is the host rock for the uranium in this area and is not used as a potable water supply.

A surface water sample taken from a wash near the pile contained above-acceptable levels of iron, lead, and selenium. This

water is runoff from the pile that traverses areas of bare tailings where erosion has occurred.

1.4 SOCIOECONOMIC AND LAND USE IMPACTS

Except for the mineral-related activity near the pile, virtually all the land near the tailings site is used for grazing. There are two small population centers in the vicinity, 20 dwellings and commercial buildings at Maybell, and 4 trailers and 1 house east of Maybell near the Yampa River bridge.

The Federal Government administers several sections of land near the site. Most of the remaining area is held by eight private or corporate groups. All the land surrounding the Maybell site was assessed in 1972, and is listed at a 30% value of \$2.05/acre throughout the survey area.

The presence of the tailings restricts the use of the site itself; e.g. it cannot now be used for grazing. This loss is minimal, however, compared with the much larger loss caused by areas disrupted by open-pit mines, overburden, and ore stockpiles. If the tailings were not present there would be virtually no change in land uses and values in the surrounding areas.

1.5 RECOVERY OF RESIDUAL VALUES

Estimates of the uranium content of the Maybell tailings by the AEC indicate an average U_3O_8 concentration of 0.015% for the tailings. This concentration is in a range where reprocessing is questionable.

There are five factors that should be employed to evaluate whether reprocessing the Maybell 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 Maybell tailings is not a practical economic consideration at this time and would not be until the market value of U_3O_8 reaches \$70/lb.

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.

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 existing 6-in. cover on the Maybell tailings pile has been eroded by wind and rainfall. This cover provides partial control over gamma radiation, but little control over radon exhalation. Repair of the existing cover or an increase in the depth of cover are proposed as remedial actions in Options II and III.

1.7 OFF-SITE REMEDIAL ACTION

In the Maybell vicinity there have been no off-site structures identified which require remedial action. Furthermore, since contamination from overburden piles and from low-grade ore stockpiles is so extensive, no cleanup of windblown mill tailings contamination has been proposed. As a result of dike failure during mill operations, tailings were carried from the pile into a small wash that leads into Johnson Wash. The cost for cleanup of tailings contamination in this wash are included in Options II and III. The locations at which tailings are on vacant lands or are farther than 10 ft from the structures were not subject to the criteria used in Phase II, but could constitute a problem in the future.

1.8 LONG-TERM STORAGE SITE SELECTION

No alternative disposal site has been considered for the Maybell tailings. With implementation of Option III the tailings would be isolated hydrologically and stabilized at the present site to meet the criteria for long-term storage.

1.9 REMEDIAL ACTIONS AND COST-BENEFIT ANALYSES

1.9.1 Remedial Action Options

The three remedial actions selected are summarized in Table 1-2. Option I serves as the base case from which the comparative costs and effectiveness of the other remedial actions are judged. Option I proposes no actions upon the tailings, but does provide for security fencing around them and for annual monitoring and maintenance. The cost of this option is \$250,000.

Option II, at a cost of \$940,000, includes the tasks of Option I plus the following work:

- (a) Addition of 1.5 ft of cover material to the existing pile stabilization

(b) Removal of eroded tailings from the wash leading into Johnson Wash

Option III provides for removal of the tailings to a nearby open-pit mine, for covering of the tailings with 2 ft of stabilization material, and for removal of tailings from Johnson Wash. The cost of this option is \$4,520,000.

1.9.2 Cost-Benefit Analyses

The principal objectives of the remedial options presented are to reduce further deterioration of site conditions through control of erosion, and to limit access so that tailings may not be removed from the site. Since population and off-pile radiation levels are so small, the health benefits associated with the remedial actions are negligible and no cost benefit analysis was performed.

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

SUMMARY OF REMEDIAL ACTION OPTIONS AND EFFECTS

<u>Option Number</u>	<u>Cost¹ (\$000)</u>	<u>Description of Remedial Action</u>	<u>Benefits</u>	<u>Adverse Effects</u>
I	250	New fencing, monitoring, and maintenance	A,B	V,W,X,Y,Z
II	940	2-ft stabilization cover, removal of tailings from wash, monitoring, maintenance, and fencing	A,C,D,E, F	V
III	4,520	Removal of the tailings to a nearby open-pit mine, 2-ft stabilization cover, fencing, and construction of drainage ditches around the pit	A,C,D,E, F,G	none

Notes

¹Costs are in 1977-value dollars

Definition of Benefits

- A. Better security
- B. Wind and water erosion partly controlled
- C. Wind and water erosion controlled by means of 2-ft stabilization
- D. Gamma radiation reduced to near-background levels
- E. Radon exhalation reduced by 25%
- F. Minimum maintenance required
- G. Tailings site available for unrestricted use

Definition of Adverse Effects

- V. Tailings site unavailable for use
- W. No decrease in erosion
- X. No decrease in gamma radiation
- Y. No decrease in radon exhalation
- Z. More maintenance required than benefit F

CHAPTER 1 REFERENCES

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3. H. W. Kraner, G. L. Schroeder, and R. D. Evans; "Measurements of the Effect of Atmospheric Variables on Radon-222 Flux and Soil-Gas Concentrations"; The Natural Radiation Environment; J. A. S. Adams and W. M. Lowder, eds; University of Chicago Press; 1964.
4. "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation"; Report of Advisory Committee on Biological Effects of Ionizing Radiation; NAS, National Research Council; Nov 1972.
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6. Vital Statistics of the U.S.; Vol II - Mortality; National Center for Health Statistics; HEW; 1968.

ADDENDUM

FIGURES AND TABLES

(The figures and tables contained on the following pages have been extracted from chapters of the parent report.)

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FIGURE 2-1. AERIAL PHOTOGRAPH OF SITE

FIGURE 2-3. DESCRIPTIVE MAP

PLAN

FIGURE 2-4A. CROSS-SECTION AT STATION 13+70

FIGURE 2-4B. CROSS-SECTION AT STATION 26+6753

FIGURE 2-5. SIMPLIFIED STRATIGRAPHIC COLUMN

130-11

TABLE 2-1
TAILINGS MATERIALS

	<u>Volume (yd³)</u>	<u>Weight* (tons)</u>
Uranium Tailings	1,900,000	2,600,000
Stabilization Cover	70,000	100,000
Total	1,970,000	2,700,000

* Weight based on average existing field densities which include moisture

FIGURE 3-3. RADON CONCENTRATION IN VICINITY OF PILE

NOTE
REFERENCE TECHNICAL NOTE
ORP/LV-75-5, GAMMA RADIATION
SURVEYS AT INACTIVE URANIUM
MILLSITES, USEPA, LAS VEGAS,
NEVADA, AUGUST 1975, FIGURE
11, PAGE 57

FIGURE 3-10. EPA GAMMA SURVEY SURROUNDING MILLSITE

R 94 W 6 th P M OF COLORADO