DOE/UMT-0116
FBDU-360-11
UC 70A

ENGINEERING ASSESSMENT OF INACTIVE URANIUM MILL TAILINGS

MAYBELL SITE
MAYBELL, COLORADO

September 1981

DISCLAIMER

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

Prepared for

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

Contract No. DE-AC04-76GJ01658

By

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

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

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

DISCLAIMER

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

NOTICE

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

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

FOREWORD

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

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

Ford, Bacon & Davis Utah Inc. (FB&DU) has received excellent cooperation and assistance in obtaining new data to prepare this report. Special recognition is due Richard H. Campbell and Mark Matthews of DOE, as well as Jim Kirchner of the Union Carbide Corporation. Several local, county, and state agencies contributed information, as did many private individuals.

ABSTRACT

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

Radon gas released from the 2.6 million dry tons of tailings at the Maybell site constitutes the most significant environmental impact, although windblown tailings and external gamma radiation also are factors. The two alternative actions presented in this engineering assessment range from millsite decontamination with the addition of 3 m of stabilization cover material (Option I), to disposal of the tailings in a nearby open pit mine and decontamination of the tailings site (Option II). Cost estimates for the two options are about $11,700,000 for stabilization in-place and about $22,700,000 for disposal within a distance of 2 mi.

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

(a) Heap leaching

(b) Treatment at an existing mill

(c) Reprocessing at a new conventional mill constructed for tailings reprocessing

The cost of the uranium recovered would be about $125 and $165/lb of U_3O_8 by heap leach and conventional plant processes, respectively. The spot market price for uranium was $25/lb early in 1981. Therefore, reprocessing the tailings for uranium recovery is not economically attractive at present.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont)

TABLE OF CONTENTS (Cont)

TABLE OF CONTENTS (Cont)

TABLE OF CONTENTS (Cont)

LIST OF FIGURES

LIST OF FIGURES (Cont)

LIST OF FIGURES (Cont)

LIST OF TABLES

CHAPTER 1

SUMMARY

CHAPTER 1

SUMMARY

1.1 INTRODUCTION

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

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

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

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

(a) Exhalation of radon gas from the tailings

(b) On-site and off-site direct radiation

(c) Land contamination from windblown tailings

(d) Hydrology and contamination by water pathways

(e) Potential health impact

(f) Potential for extraction of additional minerals from the tailings

Investigation of these and other factors originally led to the evaluation of three potential practicable remedial action alternatives. Since that time, some alternatives have been judged unacceptable because of new criteria that have been proposed. In this report, the remedial action alternatives are the following:

(a) Option I - Stabilization of tailings on site with a 3-m cover

(b) Option II - Disposal of the tailings in an open pit mine about 2 mi from the pile

1.1.1 Background

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

---

*The proceedings of these hearings and the Summary Report on the Phase I Study were published by the JCAE as Appendix 3 to ERDA Authorizing Legislation for Fiscal Year 1976. Hearings before the Subcommittee on Legislation, JCAE, on Fusion Power, Biomedical and Environmental Research; Operational Safety; Waste Management and Transportation, Feb 18 and 27, 1975, Part 2. The Phase I report on the Maybell site appears as Appendix I to Reference 4.

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

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

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

On May 5, 1975, ERDA, the successor to AEC, announced that Ford, Bacon & Davis Utah Inc. of Salt Lake City, Utah, had been selected to provide the architect-engineering (A-E) 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. The original work at Maybell was performed in May and October 1976, and the original Phase II - Title I Engineering Assessment was published in October 1977.[2]

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

In 1979, DOE established the UMTRA Program Office in Albuquerque, New Mexico. Work on the program has since been directed by personnel in that office. The supplementary field work by FB&DU in support of this report was performed during the week of August 4, 1980.

1.1.2 Scope of Phase II Engineering Assessment

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

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

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

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

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

(b) Determination of property ownership in order to obtain release of Federal Government and A-E liability for performance of engineering assessment work at both inactive millsites and privately owned structures.

(c) Preparation of topographic maps of millsites and other sites to which tailings and other radioactive materials might be moved.

(d) Performance of core drillings and radiometric measurements ample to determine volumes of tailings and other radium-contaminated materials.

(e) Performance of radiometric surveys, as required, to determine areas and structures requiring cleanup or decontamination.

(f) Determination of the adequacy and the environmental suitability of sites at which mill tailings containing radium could be disposed; and once such sites are identified, perform evaluations and estimate the costs involved.

(g) Performance of engineering assessments of structures where uranium mill tailings have been used in off-site construction to arrive at recommendations and estimated costs of performing remedial action.

(h) Evaluation of various methods, techniques, and materials for stabilizing uranium mill tailings to prevent wind and water erosion, to inhibit or eliminate radon exhalation, and to minimize maintenance and control costs.

(i) Evaluation of availability of suitable fill and stabilization cover materials that could be used.

(j) Evaluation of radiation exposures of individuals and nearby populations resulting from the inactive uranium millsite, with specific attention to:

(1) Gamma radiation

(2) Radon

(3) Radon daughter concentrations

(4) Radium and other naturally occurring radioisotopes in the tailings

(k) Review of existing information about site hydrology and meteorology.

(l) Evaluation of recovering residual values, such as uranium and vanadium in the tailings and other residues on the sites.

(m) Performance of demographic and land use studies. Investigation of community and area planning, and industrial and growth projections.

(n) Evaluation of the alternative corrective actions for each site in order to arrive at recommendations, estimated costs, and 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 the Maybell site.

1.2 SITE DESCRIPTION

1.2.1 Location and Topography

The Maybell millsite and tailings pile are located approximately 25 mi west of the town of Craig, in Moffat County in northwestern Colorado. The site is 5 mi north of the Yampa River in a rolling, sagebrush-covered area. The elevation is 6,220 ft above sea level. The site and its relationship to the surrounding area are shown in the aerial photograph in Figure 2-1.

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 dry 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. Figure 2-3 shows the present ownership of the site.

1.2.3 Present Condition of the Site

Figure 2-4 is a descriptive map of a portion of the site as it now exists. The site vicinity is characterized by deep open pits from which the ore was extracted, piles of overburden, and the relatively flat yet sloping surface of the 80-acre tailings pile. Figures 2-5A and 2-5B show typical cross-sections of the pile. The tailings are enclosed with a barbed-wire fence.

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 through a drainage system on the pile, and the water is channeled into nearby Johnson Wash.

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 slight clay contents. Bulk densities run between 84 and 97 lb/ft^3. There are approximately 2.6 million dry tons of tailings on the site. The weights and volumes of the tailings, cover material, and contaminated materials are given in Table 2-1.

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

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 Formation. 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 2-6.

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 includes 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 of Johnson Wash. Other surface water near the site consists 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 that falls on the pile. However, a dike failure during mill operations left about 200 tons of tailings in the wash leading to Johnson Wash.

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-soil interface, and the flow gradient is to the west-southwest. The confined ground waters are contained in 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 that falls on the site. Another source of radionuclides to the ground water system is the percolation of waters through the ore-bearing strata; compared to this source, any potential contamination from the tailings is insignificant.

There is evidence of both water and wind erosion on the steep eastern slope of the pile. Tailings and cover material have eroded from the pile's eastern edge, and revegetation under present conditions would be difficult. Strong winds are common in the area and tend to blow from the west-southwest. The average annual rainfall at Craig is 14 in. High-intensity rainfall such as that from thunderstorms is infrequent but can occur in the Maybell area from 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 farther 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. The principal environmental radiological impact and associated health effects arise from the ^{230}Th, ^{226}Ra, ^{222}Rn, and ^{222}Rn daughters contained in the uranium tailings. Although these radionuclides occur in nature, their concentrations in tailings material are several orders of magnitude greater than their average concentrations in the earth's crust. Because of the chemical treatments these radionuclides have experienced, the ^{226}Ra appears to be more soluble and, therefore, more mobile.

1.3.1 Radiation Exposure Pathways, Contamination Mechanisms, and Background Levels

The major potential environmental routes of exposure to man are:

(a) Inhalation of ^{222}Rn and its daughter products, resulting from the continuous radioactive decay of ^{226}Ra in the tailings. Radon is a gas which diffuses from the pile. The principal exposure results from inhalation of ^{222}Rn daughters. This exposure affects the lungs. For this assessment, no criteria have been established for radon concentrations in air. However, the pathway for radon and radon daughters accounts for the major portion of the exposure to the population.

(b) External whole-body gamma exposure directly from radionuclides in the pile.

(c) Inhalation and ingestion of windblown tailings. The primary health effect relates to the alpha emitters ^{230}Th and ^{226}Ra, each of which causes exposure to the bones and lungs.

(d) Ingestion of ground and surface water contaminated with radioactive elements (primarily ^{226}Ra) and other toxic materials.

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

1.3.1.1 Radon Gas Diffusion and Transport

Measurements of the radon exhalation flux from the tailings made in 1976 using the charcoal canister technique(3) ranged from 75 to 99 pCi/m^2-s on the tailings pile. Measurements of the radon exhalation flux from the tailings made in 1980 ranged from about 70 to about 190 pCi/m^2-s, with a mean flux estimated to be about 125 pCi/m^2-s. Radon flux depends principally on radium content of tailings; however, it also varies considerably because of moisture, soil characteristics, and climatological conditions.

Short-term radon measurements were performed by FB&DU in 1976 with continuous radon monitors supplied by ERDA 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 3-5. The highest outdoor radon concentration (15 pCi/l) was measured on the pile. Background measurements of atmospheric radon at two locations about 2.5 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 μR/hr as measured 3 ft above ground with an energy-compensated Geiger Mueller detector.(4) Above the surface of the tailings pile, the gamma radiation rates ranged to a maximum of 340 μR/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 the 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 800 ft toward the east is shown by the 5-pCi/g line illustrated in Figure 3-13. The 5-pCi/g line includes about 50 acres of land outside the site boundaries that are considered to be contaminated by windblown tailings.

1.3.1.4 Ground and Surface Water Contamination

Three water samples, taken upstream and downstream in Lay Creek and at the confluence of Lay Creek and Johnson Wash, contained ^{226}Ra concentrations of 0.18, 0.19, and 0.16 pCi/l, respectively.(4) These concentrations are well below the limit for radionuclides in the EPA Interim Primary Drinking Water Regulations (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 of 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. Contamination of 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 of the site averaged 0.08 pCi/l.(1)

Considering the existing data and the distance between Maybell and the tailings site, the tailings do not appear to have 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 extends to a depth of 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.(4)

1.3.2 Remedial Action Criteria

For the purpose of conducting the original engineering assessment,(2) provisional criteria provided by the EPA were used. The criteria were in two categories, and applied either to structures with tailings present or to land areas to be decontaminated. For structures, the indoor radiation level below which no remedial action was indicated was considered to be an external gamma radiation level of less than 0.05 mR/hr above background and a radon daughter concentration of less than

0.01 WL above background. Land could be released for unrestricted use if the external gamma radiation levels were less than 10 μR/hr above background. When cleanup was necessary, residual radium content of the soil after remedial action should not exceed twice background in the area.

Since enactment of the Uranium Mill Tailings Radiation Control Act of 1978 (PL 95-604), which was effective November 8, 1978, the EPA has published interim (45 FR 27366) and proposed (45 FR 27370) standards for structures and open lands. These standards establish the indoor radon daughter concentration, including background, below which no remedial action is indicated at 0.015 WL. The indoor gamma radiation limit is 0.02 mR/hr above background.

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

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

(a) The average annual release of ^{222}Rn from the disposal site to the atmosphere by residual radioactive materials will not exceed 2 pCi/m^2-s.

(b) Substances released from residual radioactive materials after disposal will not cause:

  (1) the concentrations of those substances in any underground source of drinking water to exceed the level specified below,* or

  (2) an increase in the concentrations of those substances in any underground source of drinking water where the concentrations of those substances prior to remedial action exceed the levels specified below for causes other than residual radioactive materials.*

---

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

Substance	mg/l
Arsenic	0.05
Barium	1.0
Cadmium	0.01
Chromium	0.05
Lead	0.05
Mercury	0.002
Molybdenum	0.05
Nitrogen (in nitrate)	10.0
Selenium	0.01
Silver	0.05

	pCi/l
Combined ^{226}Ra and ^{228}Ra	5.0
Gross alpha particle activity (including ^{226}Ra but excluding radon and uranium)	15.0
Uranium	10.0

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

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

While these standards may undergo further revisions, the interim and proposed standards as indicated above form the basis for determining required remedial actions and their associated costs.

1.3.3 Potential Health Impact

Radon gas exhalation from the pile and the subsequent inhalation of radon daughters account for most of the total dose to the population from the Maybell site under present conditions. The gamma radiation exposure from the pile is virtually zero since there are very few people 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 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 time can be made long enough, then, theoretically, virtually all of the radon and its daughter products will have decayed before escaping to the atmosphere. Calculations using the theoretical techniques of Kraner, Schroeder, and Evans[5] earlier indicated that 13 ft of earth cover would be required to reduce the radon diffusion from the Maybell tailings by 95%. Later experimental work[6] has demonstrated that 2 to 3 ft of compacted clay may be sufficient to reduce radon flux to less than 2 pCi/m^2-s, assuming the continued integrity of the clay cover.

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

The risk estimators used in this report are given in the report of the National Academy of Sciences Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR-III report).[7] This report presents risk estimators for lung cancer derived from epidemiological studies of both uranium miners and fluorspar miners. The average of the age-dependent absolute risk estimator for these two groups as applied to the population at large is 150 cancers per year per 10^6 person-WLM of continuous exposure, assuming a lifetime plateau to age 75. The term WLM means working level months, or an exposure to a concentration of one working level of radon daughter products in air for 170 hr, which is a work-month. A working level (WL) is a unit of measure of radon daughter products which recognizes that the several daughter elements are frequently not in equilibrium with each other or with the parent radon. Because of the many factors that contribute to natural biological variability and of the many differences between exposure conditions in mines and residences, this estimator (150 cancer cases per year per 10^6 person-WLM of continuous exposure) is considered to have an uncertainty factor of about 3. Another means of expressing risk is the relative risk estimator, which yields risk as a percentage increase in health effects per 10^6 person-WLM of continuous exposure. However, this method has been shown to be invalid(8) and is not considered in this assessment.

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

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

For continuous exposure:

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

On the basis of predictions of radon concentrations in excess of the background value, it was calculated that the average lung cancer risk attributable to radon released from the tailings pile in the area within 5 mi of the Maybell site is 3.3×10^{-7} per person per year, or less than 1% of the average lung cancer risk due to all causes for Colorado residents (1.8×10^{-4}).(9) For those within 0.5 mi of the pile, the average lung cancer risk due to the pile is less than 10% of the cancer risk due to all causes.

The 25-yr health effects were calculated for three population projections using the present population of 100 people in the 0- to 5-mi area. The results for pile-induced radon and background radon for the area were as follows:

25-Year Cumulative Health Effects within 5 Miles of Edge of Pile

Projected Population Growth	Pile-Induced RDC	Background RDC
0.3% constant growth rate	0.0008	0.3
15% declining growth rate[a]	0.0033	1.2
20% composite growth rate[b]	0.0060	2.2

Pile-induced radon daughter health effects are less than 1% of the background radon daughter health effects for residents within 5 mi of the tailings site. The exposure and consequent risk will continue as long as the radiation source remains in its present location and condition.

1.3.4 Nonradioactive Pollutants

There are other potentially toxic materials in the tailings. Chemical analyses of tailings samples from drill holes on 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 limits of the EPA Interim Primary Drinking Water Regulations. 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, including about 20 dwellings and commercial buildings at Maybell, and four trailers and one house east of Maybell near the Yampa River bridge.

---

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

[b]Holds constant at 20% for 8 yr, then declines linearly over 5 yr from its initial value to zero and remains constant at zero thereafter.

The Federal Government administers several sections of land near the site. Most of the remaining area is held by 12 private or corporate groups. All the land surrounding the Maybell site was assessed in 1974 and is listed at a market value of $7/acre.

The presence of the tailings restricts the use of the site itself; i.e., it cannot now be used for grazing. This loss of usable land 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.

As part of a new program, the Federal Coal Leasing Program, several large tracts of land near Maybell would be leased to private individuals or groups for mining purposes. Also, a hydroelectric project known as the Juniper-Cross Mountain Dam is planned for the Yampa River near Maybell. This project would include construction of two separate electricity-generating dams.

1.5 RECOVERY OF RESIDUAL VALUES

Only a few samples of tailings were obtained during this study. Consequently, calculations based on these samples would not be statistically representative.

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

(a) The amount of tailings present

(b) Concentrations of residual values

(c) Projected recovery

(d) Current market price of recovered values

(e) Proximity to processing mills

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

(a) Heap leaching

(b) Treatment at an existing mill

(c) Reprocessing at a new conventional mill constructed for tailings reprocessing

The cost of the uranium recovered would be about \$125 and \$165/lb of U_3O_8 by heap leach and conventional plant processes, respectively. The spot market price for uranium was \$25/lb early in 1981. Therefore, reprocessing the Maybell tailings for uranium recovery is not economically attractive under present market conditions.

1.6 MILL TAILINGS STABILIZATION

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

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

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

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

1.7 OFF-SITE REMEDIAL ACTION

In the Maybell vicinity, no off-site structures that require remedial action have been identified. However, a mobile scanning unit operated by the AEC performed a gamma radiation survey of the Craig, Colorado, area in 1973. Eighty-six anomalies with levels above background criteria were discovered. Natural radioactive materials were found at 46 locations, radioactive materials in instruments or ore were found at seven locations, roof eave drip from fallout from the Chinese weapons tests was presumed to be the cause of five anomalies, and the source of 25 other anomalies could not be verified. The remaining three anomalies were caused by tailings use.

The results of a gamma survey showed that a total of about 50 acres of off-site property has been contaminated as a result of windblown tailings.

1.8 DISPOSAL SITE SELECTION

In this report, one of the alternative remedial action options includes moving the Maybell tailings to a disposal site. The disposal site was selected after consultation with local, State of Colorado, and federal agencies; concerned individuals; and personnel in industry. The site was evaluated to a limited extent on the bases of hydrology, meteorology, geology, ecology, economics, and proximity to population centers. Since the responsibility for disposal site selection lies primarily with the Federal Government, with input from the State, the disposal site evaluated in this work must be considered only as tentative.

The site corresponding to Option II in Table 1-2 is shown in Figure 8-1. In this option, the tailings would be emplaced in one or more open pit mines, contoured, and covered with 3 m of soil. The surface would then be covered with 0.3 m of riprap or vegetation established for erosion control, and the entire site would be fenced.

1.9 REMEDIAL ACTIONS AND COST-BENEFIT ANALYSES

1.9.1 Remedial Action Options

The remedial action options examined include stabilization of the tailings pile in its present location, and removal of all radioactive materials to an area where these materials could be isolated from the public.

The options for which cost estimates were made include stabilization on the present site with a 3-m depth of cover material, and the removal of tailings to an open pit mine about 2 mi from the present site. The options are summarized in Table 1-2.

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

Option I represents remedial action activities to stabilize the pile more completely in its present location with the addition of a 3-m depth of cover. This option is considered a viable one because the present site can probably meet tailings stabilization criteria. Radon exhalation would be reduced to less than 2 pCi/m^2-s above background. The site would be available for restricted use only.

1.9.2 Cost-Benefit Analyses

As summarized in Table 9-1, the total costs for the two remedial action options are about $11,700,000 for stabilization in place and about $22,700,000 for disposal in the open pit mine. Each of these options would have associated health and monetary benefits. The options are identified by number in Paragraph 1.1.

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

TABLE 1-1

SUMMARY OF CONDITIONS NOTED AT TIME OF 1980 SITE VISITS

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

TABLE 1-1 (Cont)

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

[a]S - Stabilized but requires improvement

P - Partially stabilized

U - Unstabilized

RMS - Reprocessed, moved and stabilized - contamination remaining

R - Removed - contamination remaining

[b]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

[c]N - None

E - Existing

O - Occupied

P - Partially occupied

TABLE 1-2

SUMMARY OF REMEDIAL ACTION OPTIONS AND EFFECTS

Option Number	Site Specific Cost ($000)	Description of Remedial Action	Benefits	Adverse Effects
I	11,700	The pile would be stabilized in place with 3 m of local earth cover. Natural vegetation would be established or a 0.3-m cover of riprap would be provided. On- and off-site contaminated materials would be cleaned up as necessary.	A-E,H,J	Z
II	22,700	The tailings, contaminated soil, and rubble would be removed by truck to an open pit mine located about 2 mi from the tailings site. The tailings site would be decontaminated and released for unlimited use.	A,C-K	--

Notes

1. All options include on- and off-site remedial action.

2. For Option II, costs include removal of 4 ft of contaminated earth below the tailings.

TABLE 1-2 (Cont)

Definition of Benefits

A. Off-site structures decontaminated
B. Access to the site controlled by fencing and posting
C. Off-site windblown tailings cleaned up
D. Wind and water erosion controlled
E. Gamma radiation reduced
F. The source of gamma radiation and radon gas removed from the area
G. No building restrictions on or near site
H. The prime use of the final disposal location unchanged
I. Disposal site maintenance required only on a limited basis; minimal possibility of contaminating air or water supplies
J. A reduction in rate of radon exhalation to at least 2 pCi/m^2-s
K. Maintenance and fencing of tailings site eliminated

Definition of Adverse Effects

Z. Limited use of the property

CHAPTER 1 REFERENCES

1. "Summary Report, Phase I Study of Inactive Mill Sites and Tailings Piles"; AEC; Grand Junction, Colorado; Oct 1974.

2. "Phase II - Title I Engineering Assessment of Inactive Uranium Mill Tailings, Maybell Site, Maybell, Colorado"; GJT-11; Ford, Bacon & Davis Utah Inc.; Oct 1977.

3. R.J. Countess; "^{222}Rn Flux Measurement with a Charcoal Canister"; Health Physics; Vol 31, p. 455; 1976.

4. F.F. Haywood, et al.; "Radiological Survey of the Inactive Uranium Mill Tailings at Maybell, Colorado"; ORNL 5456; Mar 1980.

5. H.W. Kraner, G.L. Schroeder, and R.D. Evans; "Measurements of the Effects of Atmospheric Variables on Radon-222 Flux and Soil-Gas Concentrations"; The Natural Radiation Environment; J.A.S. Adams and W.M. Lowder, eds; University of Chicago Press; 1964.

6. Argonne National Laboratory and Ford, Bacon & Davis Utah Inc.; "Characterization of Uranium Tailings Cover Materials for Radon Flux Reduction"; NUREG/CR-1081 (FBDU-218-2); Mar 1980.

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

8. B.L. Cohen; "The BEIR Report Relative Risk and Absolute Risk Models for Estimating Effects of Low Level Radiation"; Health Physics 37, 509; 1979.

9. Vital Statistics of the U.S.; Vol II - Mortality; National Center for Health Statistics; HEW; 1968.

CHAPTER 2

SITE DESCRIPTION

CHAPTER 2

SITE DESCRIPTION

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

2.1 LOCATION

The Maybell millsite is approximately 5 mi northeast of the town of Maybell, in Moffat County, Colorado. The site, shown in the aerial photograph in Figure 2-1, is approximately 60 mi east of the Utah-Colorado border and about 25 mi west of Craig, Colorado.

The tailings pile is located in Section 19, Township 7 North, Range 94 West, Sixth Principal Meridian, and at 40 deg 32 min 40 sec north latitude and 107 deg 59 min 30 sec west longitude. The millsite is adjacent to the tailings pile on the north and occupies parts of Sections 18 and 19, Township 7 North, Range 94 West, Sixth Principal Meridian.

2.2 TOPOGRAPHY

The tailings pile is located among rolling hills with drainage into Lay Creek, which drains into the Yampa River southeast of Maybell. The site and the area to the north drain into Johnson Wash, which drains into Lay Creek. The elevation of the site is approximately 6,220 ft above sea level, and the highest elevations in the vicinity are about 6,600 ft. Trees are sparse in the area and the terrain is largely covered with sagebrush.

The tailings pile occupies about 80 acres and the millsite, adjacent to the north edge of the tailings, occupies about 4 acres. Figure 2-2 is a topographic map of the tailings and millsite area.

The area around the site contains many open pit mines, overburden piles, and low-grade ore stockpiles. The ore that was supplied to the mill came from these adjacent open pit mines.

2.3 OWNERSHIP

Present ownership of the Maybell site is shown in Figure 2-3, which has been adapted from the site description and ownership map prepared for DOE and published in the Federal Register.(1) The northern portion of the site is on land owned by the U.S. Bureau of Land Management and the southern portion is on land owned by Janet G. Howsam.[2] Union Carbide Corporation has been the operator of the site since its inception in 1957 and still has control of the site.[2]

2.4 HISTORY OF THE MILLING OPERATIONS AND PROCESSING[3]

The mill was placed in operation in October 1957 with a capacity of 300 tons/day. The operation was shut down in November 1964. Records indicate that 2.6 million dry tons of ore with a grade of 0.098% U_3O_8 were processed. All the concentrate from this operation was sold to the AEC. The ore was produced from nearby open pit mining operations, and most of it was hauled by the equipment used in stripping.

The mill had an upgrader circuit that was used to treat low-grade ore before leaching. Ore containing less than 0.2% U_3O_8 was classified into separate sand and slime fractions in the upgrader circuit, with the sands rejected to waste and the slimes acid leached. Higher grade ore was acid leached directly, and this leached slurry then was treated in a six-stage counter-current classification and washing circuit. The minus-325 mesh slurry separated in this circuit was combined with the leached slimes from the upgrader circuit, and the uranium from the combined product then was extracted by ion exchange.

The resin-in-pulp ion exchange consisted of six absorption stages and 10 elution stages. An ammonium nitrate solution was used to elute uranium from the loaded resin, and the uranium was precipitated from the eluate with anhydrous ammonia.[4]

2.5 PRESENT CONDITION OF THE SITE

Figure 2-4 is a descriptive map of a portion of the site as it now exists. The original mill buildings were removed from the site, but some of the concrete foundations remain.

The concave-shaped tailings pile is on gently sloping land. The pile was reshaped and stabilized in accordance with State of Colorado regulations. This stabilization consisted of the addition of 6 in. of soil that was seeded under a three-phase plan to provide vegetation. The vegetative cover on the pile is about 40%. A dike made of tailings was constructed on the south and east sides of the pile between the pile and Johnson Wash. Grading around the pile has isolated it from surrounding runoff.

Water and wind erosion are evident along the entire eastern edge of the tailings. Water erosion has spread tailings approximately 10 to 30 ft beyond the fence that borders the pile on the east, and windblown contamination was detected as far as 800 ft east of the pile. The rest of the pile appears to be well stabilized.

The reshaped and stabilized pile originally was designed to contain moisture that collected on the pile. A drainage system has been installed at the low point of the pile to drain the surface waters directly into Johnson Wash. The tailings are surrounded with a five-strand barbed-wire fence. Gates are in place and radiation warning signs are displayed on the fence. Other than the windblown area, the pile is well maintained by the owner. Figures 2-5A and 2-5B show typical cross-sections of the tailings pile.

After the field work for the 1977 engineering assessment was completed, Union Carbide Corporation started heap leaching operations on low-grade mine ores and constructed an ion-exchange circuit to treat the leach liquors. The heap leach tailings were contoured and stabilized with a 6-in. soil cover in accordance with Colorado State Regulations.

Overburden from the open pit mines in the area has been placed in large piles to the west and southwest of the tailings.

2.6 TAILINGS AND SOIL CHARACTERISTICS

The types, volumes, and weights of contaminated materials presently on the site are summarized in Table 2-1. The materials are composed of uranium tailings and a small amount of cover material. The tailings are generally finely ground and have a slight clay content. Physical properties and pH of the tailings are given in Table 2-2. The pH is slightly acidic. Assay results of composite tailings samples are shown in Table 5-1.

The soil underlying the tailings consists of silty fine sands and dark brown clay of medium density.

The tailings are a mixture of processed ore material and the chemicals used in the acid leach extraction process. These chemicals produced predominantly sulfate and nitrate ion products. The presence of these ions has resulted in high concentrations of soluble sulfate salts in the tailings.

2.7 GEOLOGY, HYDROLOGY, AND METEOROLOGY

2.7.1 Geology

The Maybell tailings pile is located on a gentle southwestern slope near the head of a small drainage system.[5] The Browns Park Formation underlies the site and is the host rock for the uranium ore in the area. This formation was deposited on an old erosional surface of a sequence of rock strata that earlier had been tilted to the northeast. Its light colored sandstone units are thin- to massive-bedded, fine- to medium-grained, and loosely consolidated. A conglomerate unit lies at the base of the formation, and some shale and mudstone layers are interspersed within the formation. Except for local anomalies, the regional dip of the strata is 2 to 5 deg toward the axis of the Lay Syncline, which is to the northwest of the tailings.[6] However, exposures at the Rob Pit, an inactive mine west of the pile, indicate a gentle dip to the east.[7] The Mancos Shale underlies the Browns Park Formation at the tailings site, and its thick shale units act as a barrier to the downward and upward migration of ground waters. At the tailings pile the Browns Park Formation is 800 to 900 ft thick and is underlain by over 1,000 ft of Mancos Shale. A simplified stratigraphic column of the rock formations is shown in Figure 2-6.

2.7.2 Surface Water Hydrology

While no opportunity was provided for FB&DU to conduct field evaluations of site hydrology, existing information was examined to characterize general hydrologic conditions in the vicinity of the site. The results of this survey are contained in this and Paragraph 2.7.3. A long-term hydrologic study in the vicinity of the Maybell tailings pile has been undertaken by Sandia National Laboratories. The results of this study may provide information that could have an impact on decisions for remedial action at the Maybell site.

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 site and drainage channels into Johnson Wash, a dry wash and tributary of Lay Creek. Lay Creek is an intermittent stream that enters the Yampa River approximately 2.5 mi downstream of Johnson Wash. During active operations, mill effluents reached the Yampa River when Lay Creek was flowing. Today, runoff from the tailings area or the drainage area northwest of the tailings rarely reaches Lay Creek or the Yampa River. Other surface waters near the site are the standing water in the inactive Rob Pit, shown in Figure 2-7, and the waters used in the leach system (about 0.5 mi west of the tailings area). The surface drainage pattern of the area is shown in Figure 2-7.

Contamination of the area's surface waters by the tailings is limited because the pile is not subject to flooding, and a diversion system protects the pile from off-site overland flow. A drainage system collects the precipitation that falls on the pile and drains it into a wash with a minimum of tailings erosion. However, the diversion system has been breached on the western side of the pile, and there has been wind and water erosion of tailings from the eastern slope of the pile. The degree of ongoing physical transport of the tailings pile is limited, but the tailings deposited downstream of the pile during active operations continue to be eroded by storm runoff. Considering the other major sources of contamination of surface waters, including the mine waste rock and the Browns Park Formation itself, ongoing contamination due to the tailings is minimal.

2.7.3 Ground Water Hydrology

The tailings lie on the Browns Park Formation and are separated from bedrock by at most a few feet of unconsolidated eroded or weathered bedrock. The Browns Park Formation is an aquifer although its water yield is limited. In the area of the tailings the unconfined ground waters are within the Browns Park Formation or in unconsolidated valley deposits. The water table at the tailings site is 150 ft below the tailings-soil interface. The flow gradient is to the west-southwest, as depicted in Figure 2-8. The confined ground waters in the area are contained within 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 in ground waters due to the tailings are highly unlikely because percolation through the tailings is limited to the precipitation that falls on the site and to the very limited flow onto the pile from the western diversion ditch. Another source of radionuclides in the ground water system is the percolation of waters through the ore-bearing strata; compared to this source, any potential contamination from the tailings is insignificant.

Ground water in the area is used for agricultural and domestic purposes. Only two wells are located within 2 mi of the site; they lie perpendicular to the flow direction of ground water (one to the north and one to the south of the site). Except for a farmhouse near the Yampa River Bridge on the tailings side of the river, which uses river water, the residents of Maybell obtain domestic water from wells on the opposite side of the Yampa River from the tailings.

The Yampa River water downstream from Maybell is used only for irrigation purposes. No one lives in the Johnson Wash area south of the pile or along Lay Creek between Johnson Wash and the Yampa River. Cattle and sheep graze in the area; during mill operations it was reported they were reluctant to drink from the creek.(8)

Recent(9,10) and ongoing research by the Research Institute for Geochemical and Environmental Chemistry suggests that the presence of soluble sulfate salts in the tailings greatly modifies the hydrologic environment of the pile. The principal investigator(9) states that "the general trend of material transfer within the piles is from the interior to the surface where salts with the contaminants precipitate." It is not yet known how significant the observed migration of salts will be for tailings stabilization. Since the pile is not near any rivers or lakes, there does not appear to be a large source of water to drive this phenomenon.

2.7.4 Meteorology

Rainfall in the Craig area averages 14 in. annually. High intensity rainfall such as that from thunderstorms is infrequent but can occur in the Maybell area from May through October.(11) Cloudbursts are rare events. A rainfall of a 6-hr duration totaling 0.9 in. has a probability of occurring once in five seasons. Such storms could result in further erosion of the eastern margin of the pile and the transport of contaminated streambed material farther downstream.

Very little direct information exists regarding the frequency, duration, and intensities of winds in the immediate vicinity of the tailings. Data from weather stations at Craig and Lay, Colorado, and Rock Springs, Wyoming, indicate that the strongest winds are those that blow from the west, as depicted in Figure 2-9. A wind rose from the Craig airport is given in Figure 2-10. The tailings are more vulnerable to strong easterly winds, which are rare. There is evidence of erosion along the eastern section of the pile, which has been difficult to revegetate.

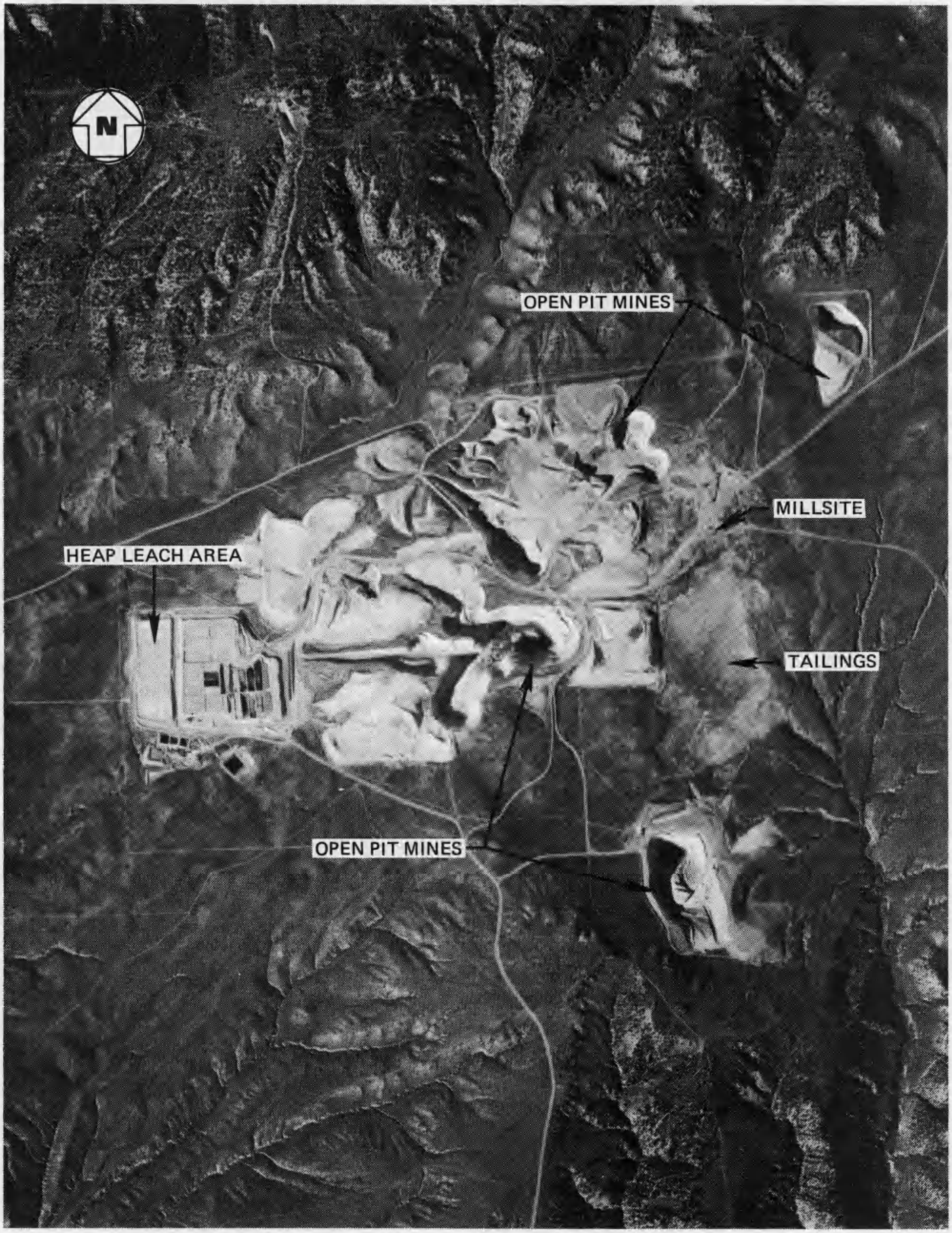
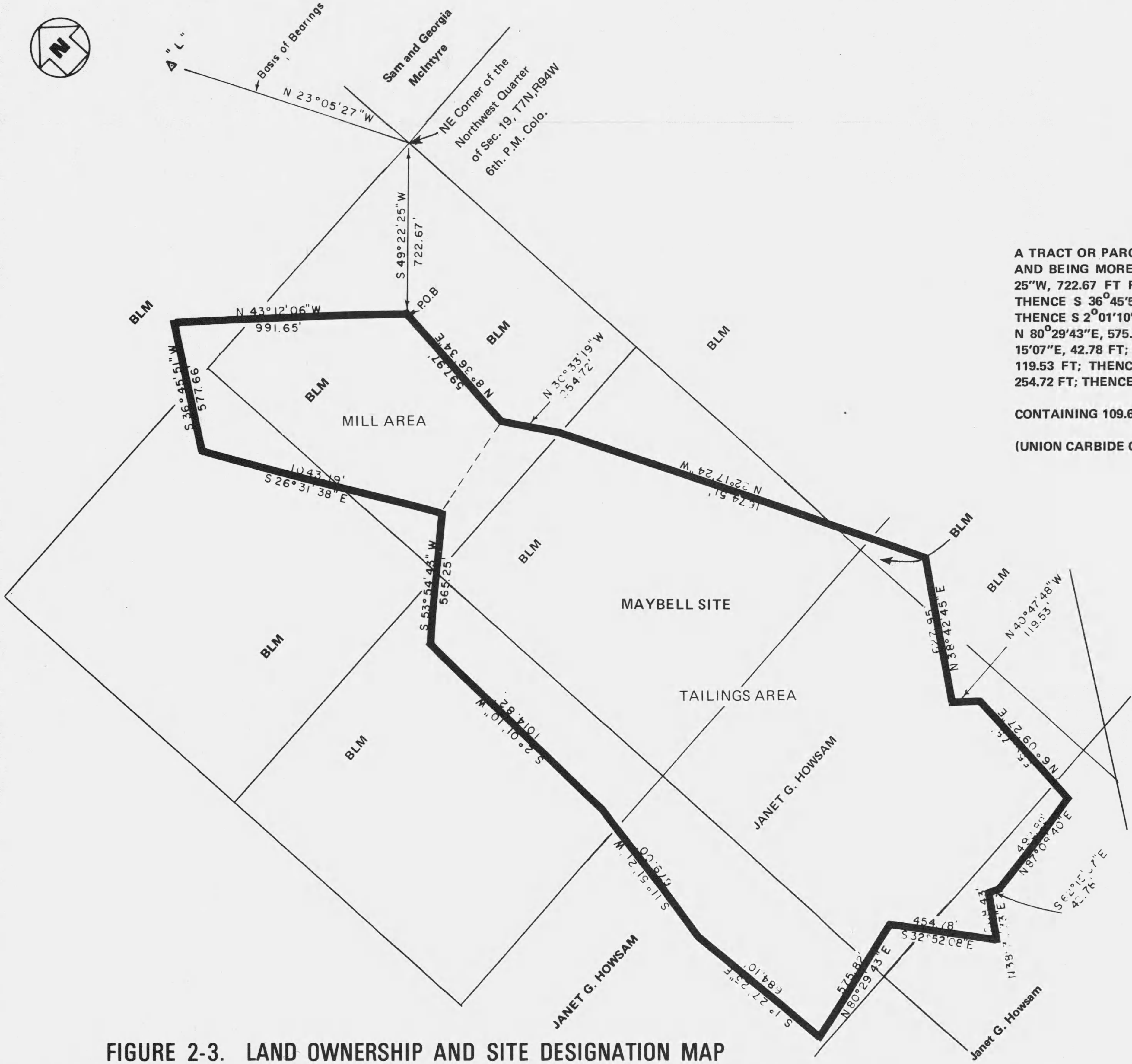


FIGURE 2-1. AERIAL PHOTOGRAPH OF SITE

360-11 6/81

FIGURE 2-2. TOPOGRAPHIC MAP

360-11 10/77



MAYBELL SITE

A TRACT OR PARCEL OF LAND LOCATED IN SECTION 19 AND SECTION 18, T7N, R94W, 6TH P.M. COLORADO AND BEING MORE PARTICULARLY DESCRIBED AS FOLLOWS: BEGINNING AT A POINT WHICH IS S 49°22' 25"W, 722.67 FT FROM THE NE CORNER OF THE NW ¼ SECTION 19; THENCE N 43°12'06"W, 991.65 FT; THENCE S 36°45'51"W, 577.66 FT; THENCE S 26°31'38"E, 1043.19 FT; THENCE S 53°54'43"W, 565.25 FT; THENCE S 2°01'10"W, 1014.82 FT; THENCE S 11°51'21"W, 679.00 FT; THENCE S 1°27'23"E, 684.10 FT; THENCE N 80°29'43"E, 575.82 FT; THENCE S 32°52'08"E, 454.78 FT; THENCE N 38°32'33"E, 208.43 FT; THENCE S 62° 15'07"E, 42.78 FT; THENCE N 87°08'40"E, 492.89 FT; THENCE N 6°09'27"E, 550.78 FT; THENCE N 40°47'48"W, 119.53 FT; THENCE N 38°42'45"E, 627.95 FT; THENCE N 22°17'24"W, 1674.51 FT; THENCE N 30°33'19"W, 254.72 FT; THENCE N 8°36'34"E, 597.97 FT TO THE POINT OF BEGINNING.

CONTAINING 109.623 ACRES.

(UNION CARBIDE OPERATIONAL CONTROLLER)

NOTE: ADAPTED FROM REFERENCE 1

FIGURE 2-3. LAND OWNERSHIP AND SITE DESIGNATION MAP

360-11 2/81

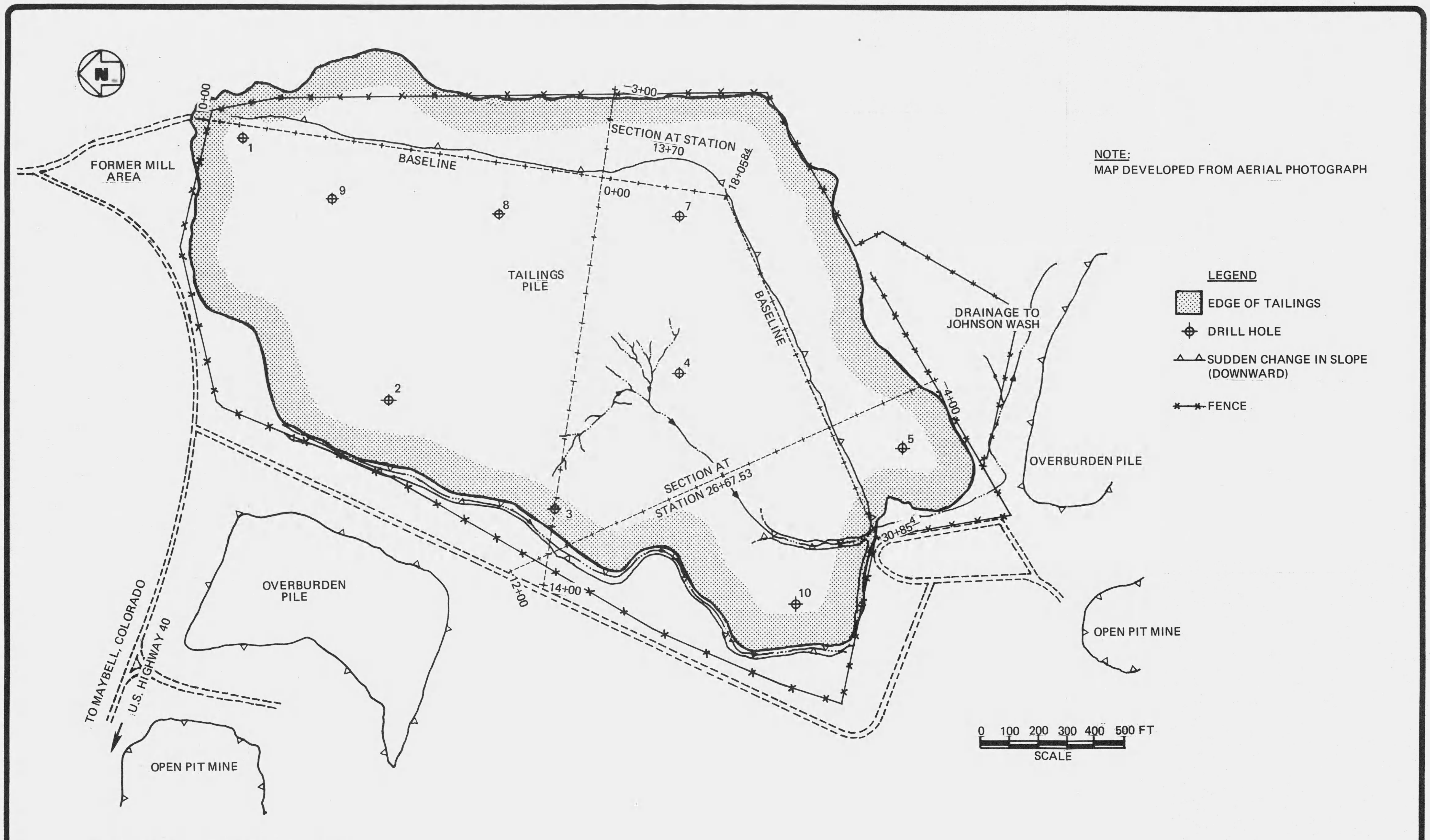


FIGURE 2-4. DESCRIPTIVE MAP

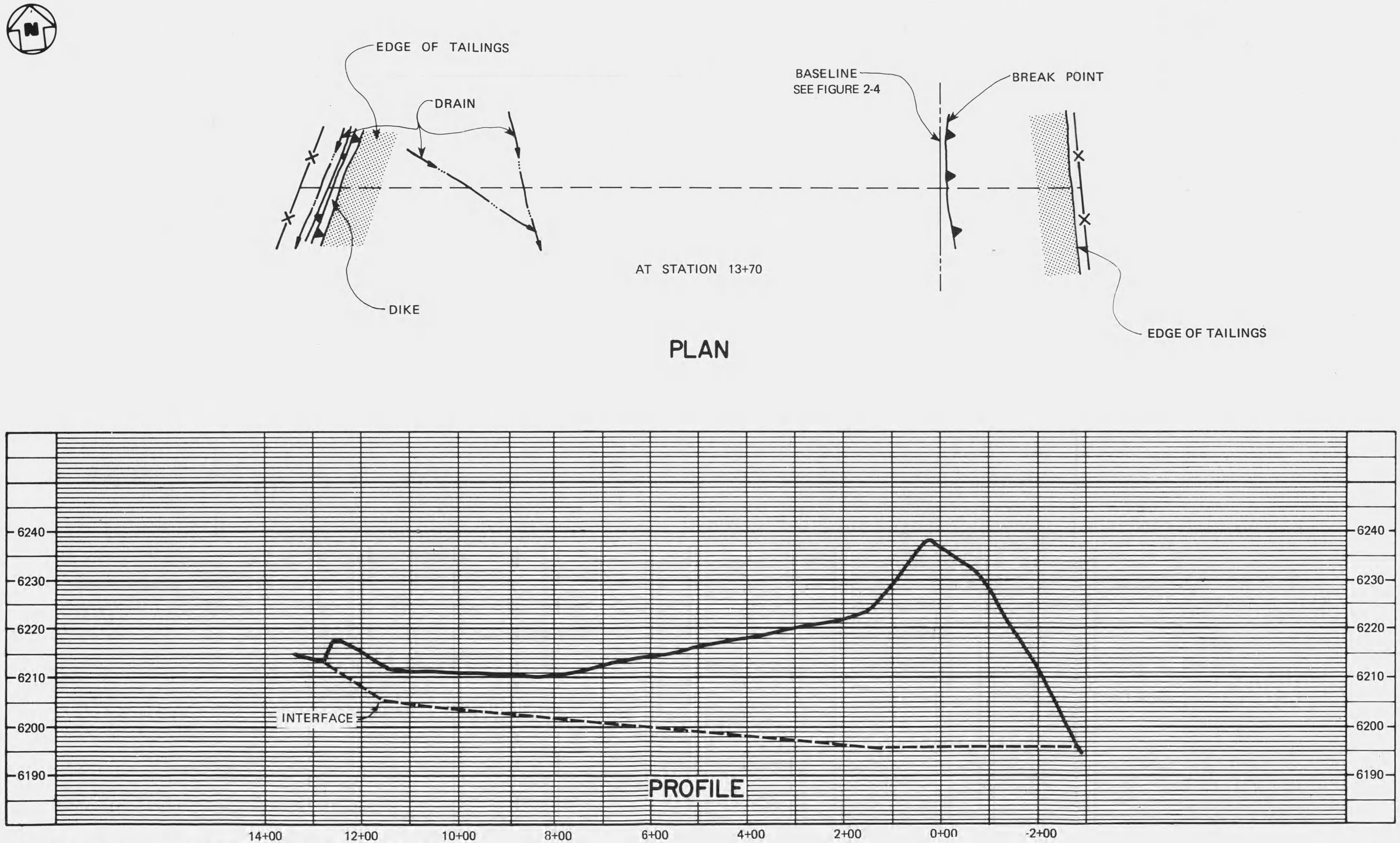


FIGURE 2-5A. CROSS-SECTION AT STATION 13+70

360-11 10/77

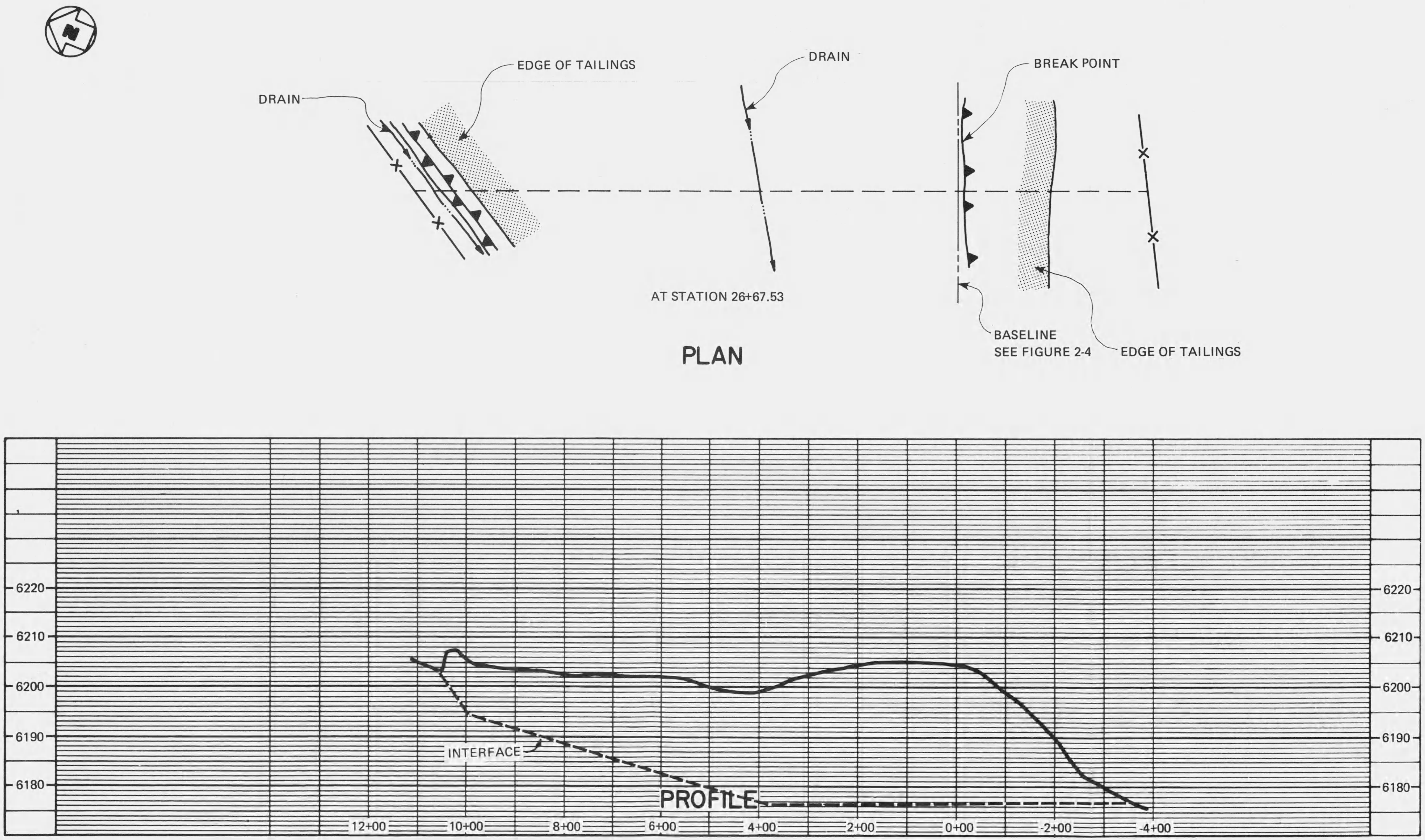


FIGURE 2-5B. CROSS-SECTION AT STATION 26+67.53

360-11 10/77

SYSTEM	FORMATION	THICKNESS (FT)	CHARACTER	POSITION OF TAILINGS
TERTIARY (MIOCENE)	BROWNS PARK FORMATION	500 - 1500	SANDSTONES WITH SOME SILTSTONE AND BASAL CONGLOMERATE; FORMS VALLEYS, AND HILLS; AQUIFER	← MAYBELL TAILINGS
MAJOR UNCONFORMITY				
CRETACEOUS	MANCOS SHALE	2000 - 5000	GREY SHALE; FORMS VALLEYS AND SLOPES; AQUICLUDE	
	DAKOTA SANDSTONE	0-200	GREY AND BROWN SANDSTONE, SHALE AND CONGLOMERATE; CAPS MESAS AND FORMS CLIFFS; LOW QUALITY, LOW QUANTITY, AQUIFER	
OLDER SEDIMENTARY ROCKS				

FIGURE 2-6. SIMPLIFIED STRATIGRAPHIC COLUMN

360-11 10/77

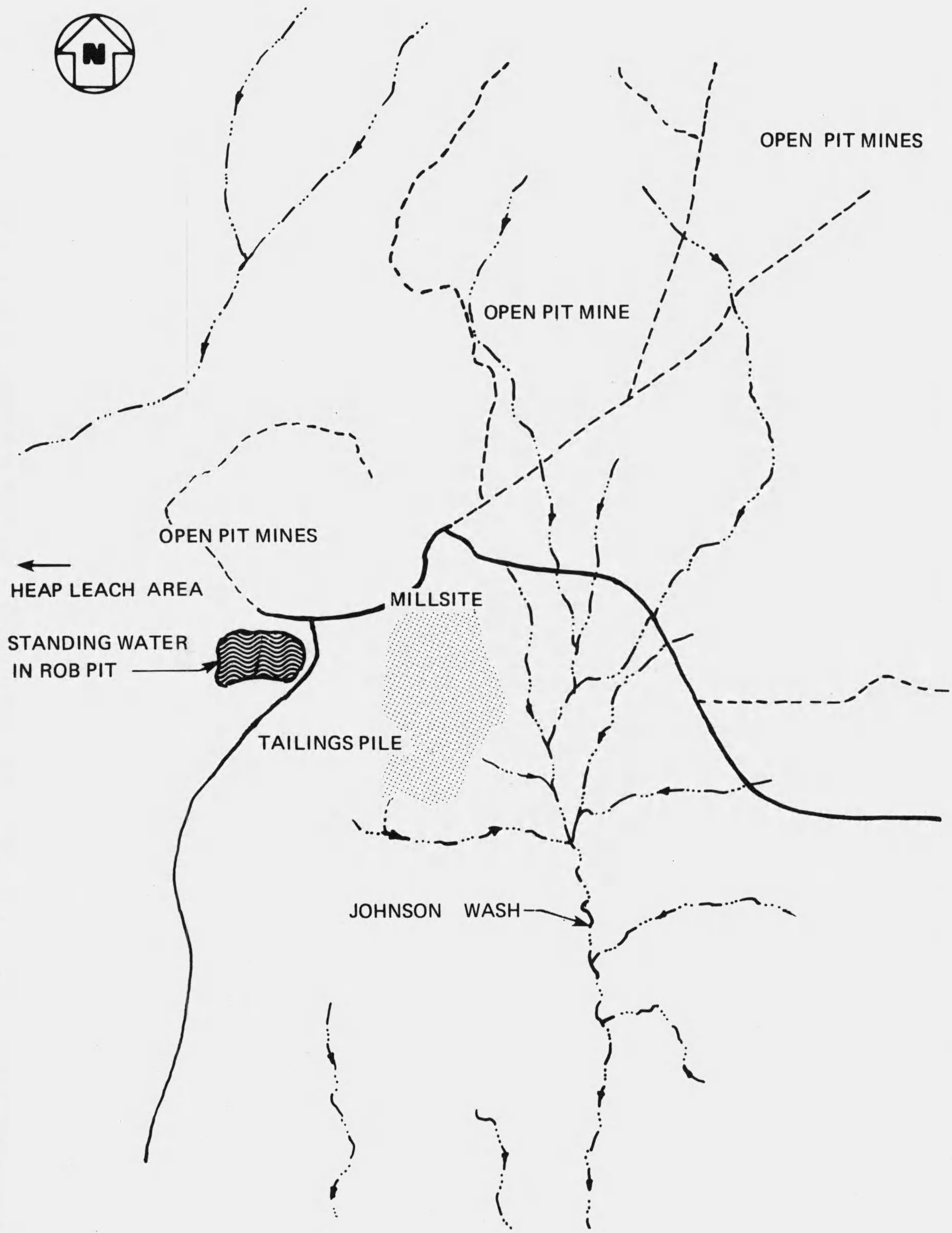


FIGURE 2-7. SURFACE DRAINAGE

360-11 10/77

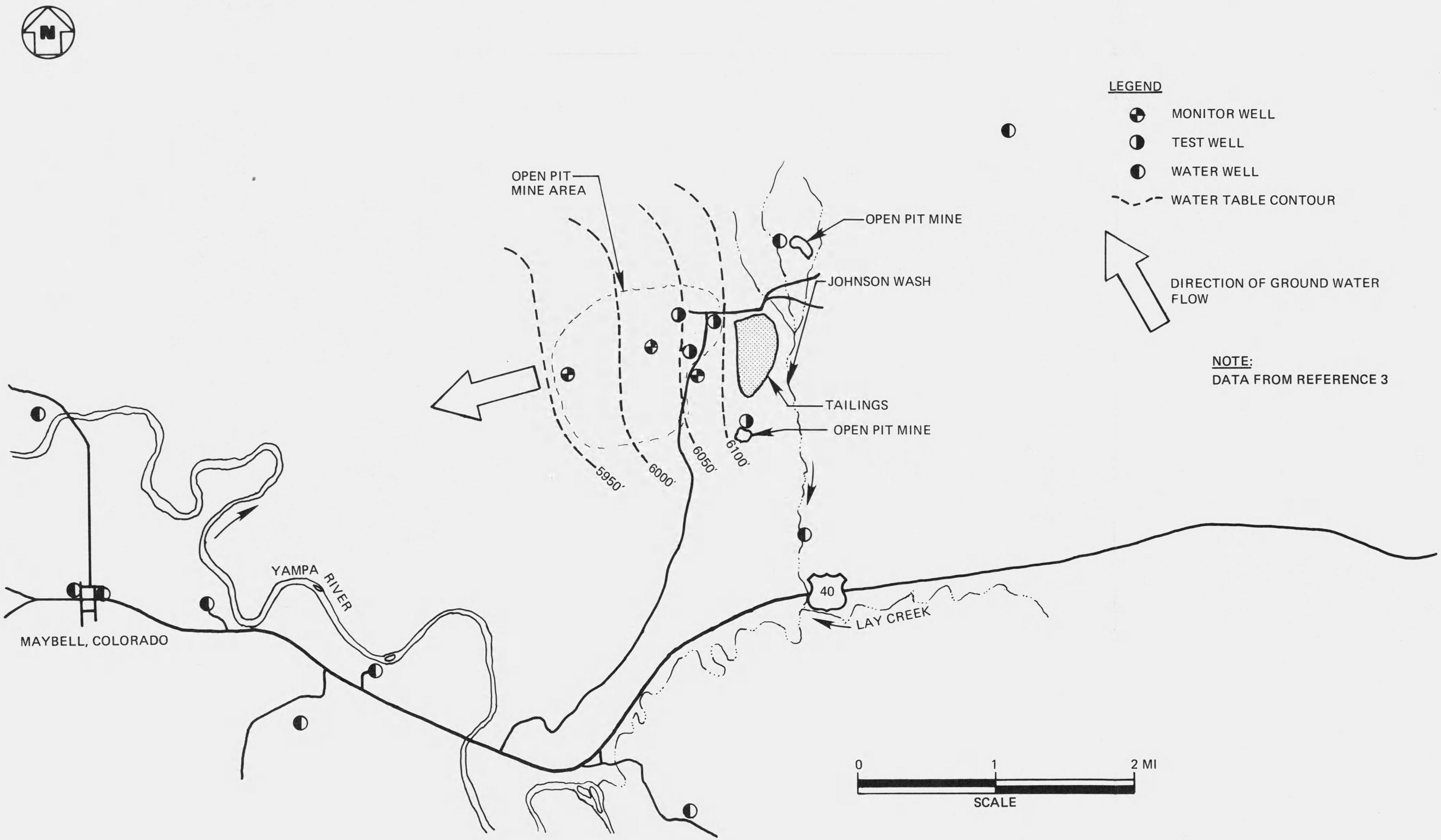


FIGURE 2-8. DIRECTION OF GROUND WATER FLOW

360-11 10/77

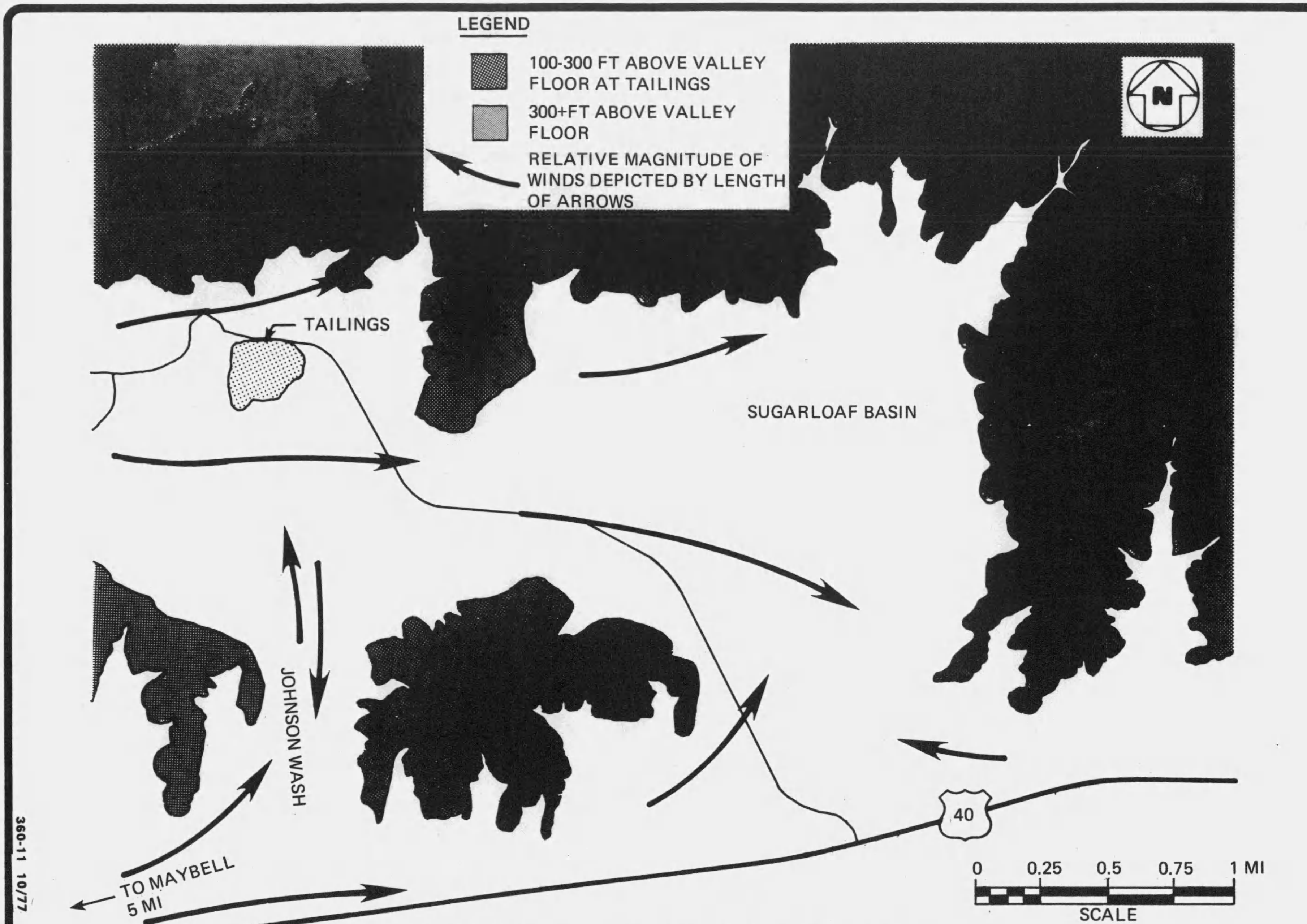


FIGURE 2-9. PREVAILING WIND DIRECTION

Ford, Bacon & Davis Utah Inc.

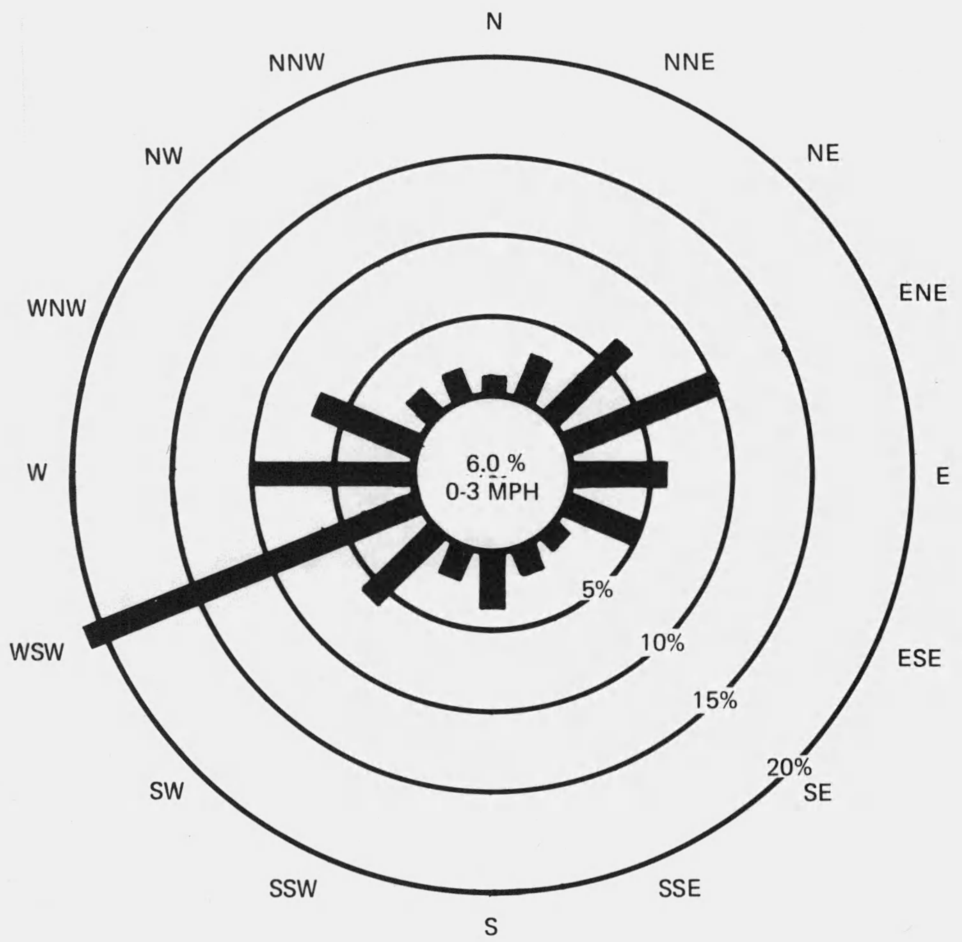


FIGURE 2-10. CRAIG AIRPORT SURFACE WIND ROSE

360-11 10/77

TABLE 2-1

CONTAMINATED MATERIALS AT MAYBELL SITE

Material	Volume (yd^3)	Weight[a] (tons)
Uranium Tailings	1,900,000	2,600,000
Stabilization Cover	70,000	100,000
Contaminated Subsoil Beneath Tailings	580,000[b]	783,000[e]
Contaminated Soil in Mill Area	65,000[c]	88,000[e]
Windblown Contaminated Soil	40,000[d]	54,000[e]
TOTAL	2,655,000	3,625,000

[a] Weight based on average existing field densities, which include moisture, except in the case of tailings.

[b] Volume based on 90 acres contaminated to an average depth of 4 ft beneath tailings interface.

[c] Volume based on 20 acres contaminated to an average depth of 2 ft.

[d] Volume based on 50 acres contaminated to an average depth of 6 in.

[e] Weight based on 100 lb/ft^3 density.

360-11 Rev 3/81

TABLE 2-2

PHYSICAL PROPERTIES AND pH OF THE URANIUM TAILINGS

Sample Location*	Percent Moisture	Bulk Density (lb/ft^3)	pH (5% water by wt)
N edge of pile Drill hole 1	7.56	94	6.81
S edge of pile Drill hole 5	7.80	97	5.40
NW edge of pile Drill hole 2	30.23	84	5.35

*See Figure 2-4.

360-11 10/77

CHAPTER 2 REFERENCES

1. U.S. Department of Energy; "Proposed Designation of Processing Sites and Establishment of Priorities under the Uranium Mill Tailings Radiation Control Act of 1978 (Pub. L. 95-604)"; Federal Register 51894; Vol 44, No. 173; Sep 1979.

2. Moffat County, Colorado Assessor's Records; Moffat County Courthouse; Craig, Colorado.

3. "Phase I Reports on Conditions of Union Carbide Uranium Millsite and Tailings near Maybell, Colorado"; AEC; Grand Junction, Colorado; 1974.

4. R.C. Merritt; The Extractive Metallurgy of Uranium; Colorado School of Mines Research Institute; Golden, Colorado; 1971.

5. "Report of Environmental Studies, Proposed Uranium Heap Leaching Project near Maybell, Colorado, for Union Carbide Corporation"; Dames & Moore; Salt Lake City, Utah; 1975.

6. M.J. Bergin; "Preliminary Geologic Map of the Maybell-Lay Area, Moffat County, Colorado"; USGS open file report; 1959.

7. Field Observations by H. Erker (Zorich-Erker Engineering, Denver, Colorado) and G. Atwood (FB&DU); 1976.

8. "Hydrology for the Inactive Uranium Millsite near Maybell, Colorado"; unpublished for EPA report by ORP/LV; EPA; 1974.

9. G. Markos; "Geochemical Mobility and Transfer of Contaminants in Uranium Mill Tailings"; published in Uranium Mill Tailings Management - Proceedings of the Second Symposium; Colorado State University; Nov 19-20, 1979.

10. G. Markos and K.J. Bush; "Relationships of Geochemistry of Uranium Mill Tailings and Control Technology for Containment of Contaminants"; paper presented at the Second U.S. Department of Energy Environmental Control Symposium; Mar 17-19, 1980.

11. "Meteorology Affecting Uranium Tailings at Maybell, Colorado"; unpublished report by URS Company; Denver, Colorado; 1976.

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 Maybell uranium tailings pile and the resulting potential exposure to the population residing and working in the vicinity of Maybell, Colorado. In addition, this chapter briefly describes the potential radioactive and chemical pollutants and their pathways in the environment. The notations and abbreviations used are given in Table 3-1.

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

3.1 RADIOACTIVE MATERIAL CHARACTERISTICS

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

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

Another important parameter used in characterizing radioactive decay is known as the "half life", $T_{1/2}$. This is the time that it takes for half of any initial quantity of the radioactive atoms to decay to a different isotope. For example, it takes 4.5 x 10^9 yr for half the ^{238}U atoms to decay to ^{234}Th. Similarly, half of a given number of ^{222}Rn atoms will decay in 3.8 days.

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

3.2 RADIATION EFFECTS

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

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

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

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

3.3 NATURAL BACKGROUND RADIATION

There are several sources of radiation that occur naturally in the environment. Natural soils contain trace amounts of uranium, thorium, and radium that give rise to radon gas and to alpha, beta, and gamma radiation. The average background value in 12 off-site soil samples for each member of the uranium decay chain, assuming equilibrium, was 1.5 pCi/g.[1] The sample locations were within a 160-mi radius of Maybell; 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 1.1 pCi/g of soil. Table 3-2 lists the major background radioactive sources. It is noted that background values of the radium and thorium chains vary with locations by factors of 7 and 4, respectively.

During the 1980 field work, soil samples were collected from the topmost 12 in. of earth at three locations between 1.3 and 3 mi from the site. The sample locations are shown in Figure 3-3, along with the corresponding concentrations of ^{226}Ra. The average value for ^{226}Ra in these samples was found to be about 5.7 pCi/g. These samples probably contained naturally occurring ore.

Background values of radon concentrations were measured at two locations using continuous radon monitors supplied by ERDA.[2] An average background value of 3 pCi/l was obtained from the 24-hr samples for the Maybell area. However, the range of these two measurements extended from 2.5 to 3.5 pCi/l.

Background gamma ray levels, as measured 3 ft above the ground, also were determined at several locations within 0.9 mi of the site by using a calibrated and energy-compensated Geiger Mueller detector. A value of 11 μR/hr was established as the average background level.[1] Cosmic rays are part of the measured background radiation levels. The contribution from cosmic rays, generally dependent upon altitude, is approximately

8 uR/hr in the Maybell area,[3] or approximately 70% of the measured average background value.

3.4 RADIATION EXPOSURE PATHWAYS AND CONTAMINATION MECHANISMS

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

(a) Inhalation of the ^{222}Rn daughters, from decay of ^{222}Rn escaping from the pile; the principal exposure hazard is to the lungs.

(b) External whole-body gamma exposure directly from the radionuclides in the tailings pile (primarily from ^{214}Bi) and in surface contamination from tailings spread in the general vicinity of the pile.

(c) Inhalation of windblown tailings; the primary hazard relates to the alpha emitters ^{230}Th and ^{226}Ra, each of which causes exposure to the bones and the lungs.

(d) Ingestion by man of ground or surface water contaminated from either radioactivity (primarily from ^{226}Ra) leached from the tailings pile or from solids physically transported into surface water.

(e) Erosion and removal of tailings material from the pile by flood waters or heavy rainfall; this can create additional contaminated locations with the same problems as the original tailings pile.

(f) Physical removal from the tailings pile also provides a mechanism for contamination of other locations.

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

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

3.4.1 Radon Gas Diffusion and Transport

Field measurements of the radon exhalation flux from the tailings made in 1976 using the charcoal canister technique(4) are depicted in Figure 3-4. The values ranged from 75 to 99 pCi/m^2-s on the tailings pile. The soil was dry at the beginning of the measurement period. The canisters were removed when it began to rain.

Field measurements of the radon exhalation flux from the tailings were also made in 1980. Canisters were set out at five locations throughout the site between 10:00 and 11:00 a.m. on August 7, 1980. These canisters were removed between 8:00 and 9:00 a.m. on August 8, 1980. The weather was warm and dry during the measurement period. The 1980 radon flux values ranged from about 70 to about 190 pCi/m^2-s, with an average of 125 pCi/m^2-s. These data and the locations of flux measurements are also shown in Figure 3-4. The lower values reported during the 1976 field work could have been caused by rain that had fallen prior to the placement of the canisters since radon flux is attenuated by moisture in the tailings. However, when the possible range of variation in flux due to moisture, temperature, and soil characteristics is taken into account, the 1976 values are consistent with those measured in 1980.

Radon flux principally depends 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.

An additional charcoal canister was placed about 1 mi northeast of the pile to determine the approximate background radon flux. This exposure yielded a value of 10 pCi/m^2-s.

Radon gas above background, considered to be from the pile, has been detected at a distance of 0.5 mi from the site. Measurement locations and corresponding 24-hr average radon concentrations are illustrated in Figure 3-5. No satisfactory correlation of radon concentration with distance from the pile was found in Maybell for measurements during this assessment. The presence of stockpiles, spoil piles, and mines preclude definitive separation of effects from the pile alone. The large amount of uranium-bearing ore in the vicinity undoubtedly is responsible for the relatively high background radon values.

Variation of radon concentration at two locations during the measurement period and the concomitant weather conditions are shown in Figures 3-6 and 3-7. The 24-hr measurements were obtained during atmospheric conditions normal for the time of year (October). Data were not recorded during wind or rainstorms. The sample location for Figure 3-6 is 2.6 mi east of the tailings pile. Figure 3-7 illustrates the measurements on the tailings pile.

A diurnal variation of ^{222}Rn concentration is evident in both figures. Radon concentration measurements taken 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.

The radon concentration measurements are plotted in Figure 3-8 as a function of distance from the edge of the tailings pile. Model calculations also were performed with annual meteorology data to provide an additional estimate of the radon concentration in the vicinity of the pile. The FB&DU model first determines radon flux and the total radon released from the pile with diffusion theory using radium soil concentrations, and pile configurations deduced from the drilling and survey data. Then the radon transport off pile is calculated by Gaussian diffusion[5] with local annual wind conditions. Meteorological data from the airport at Craig, Colorado, were used in the model calculations.

The model curve of radon concentration versus distance was used to calculate potential health effects resulting from radon diffusing from the tailings. The model curve is considered to be more representative of pile radon than the data because of the large quantity of ore in the area, which contributes to any measurements but is not reflected in model calculations.

3.4.2 Direct Gamma Radiation

The external gamma radiation (EGR) levels measured on the tailings pile are shown in Figure 3-9. These measurements were taken 3 ft above ground with calibrated, energy-compensated Geiger Mueller detectors.[1] The highest gamma radiation rate (340 μR/hr) was measured toward the center of the western edge of the tailings pile. Gamma measurements on the pile ranged between 1.5 and 30 times background. In the former mill area, gamma radiation rates were measured from 2 times background to 200 μR/hr.

Gamma rate measurements away from the tailings pile, taken at 100-yd intervals, reached background levels at less than 0.4 mi to the northwest and northeast of the pile. These gamma radiation rate measurements are shown in Figure 3-10. The reduction of gamma radiation as a function of distance from the pile is shown in Figure 3-11. The northwest gamma traverse crosses over the former millsite; therefore, the major portion of the gamma radiation level in this direction is due to operations at the former millsite rather than to the pile.

3.4.3 Windblown Contaminants

Another pathway is the result of windblown tailings. Prevailing winds are from the west. Figure 3-12 shows iso-exposure lines due to the residual windblown tailings as determined by the EPA.[6] If scattered tailings and ore are removed from inside the 10 μR/hr line (toward the pile) and if the pile is removed or covered to provide essentially complete gamma shielding, the tailings remaining outside the line (away from the pile) would produce a new gamma exposure rate, 3 ft above ground, approximately equal to 10 μR/hr.

The extension of the iso-exposure lines away from the pile boundary was due to causes other than windblown tailings (e.g., to the north and northwest the lines were extended to include an open pit mine and the former millsite, to the south to include tailings carried off the pile as a result of an inadvertent tailings discharge). Toward the east the iso-exposure line was extended away from the pile mainly as a result of windblown tailings.

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

Traverses with the scintillometer were conducted across open lands adjacent to the tailings pile and were continued until a soil contamination of 5 pCi/g of ^{226}Ra was indicated. Figure 3-13 shows the traverses and the location of the 5 pCi/g of ^{226}Ra level on each traverse. A boundary line connecting these points indicates the estimated area contaminated in excess of 5 pCi/g of ^{226}Ra surrounding the site.

It is apparent from Figure 3-13 that the extent of windblown contamination is greatest to the east of the pile, where the 5-pCi/g level was reached at a distance of 800 ft from the fence enclosing the tailings. This occurrence is a consequence of the prevailing westerly winds in the area. To the south and west of the tailings, the 5-pCi/g level was reached between 100 and 300 ft from the fence. Traverses in the northerly direction, where the mill was located, extended as far as 1,100 ft from the fence before the ^{226}Ra concentration dropped below 5 pCi/g. However, the contamination in this area is believed to be caused by the presence of residual ore from milling operations rather than by windblown contamination.

The 5-pCi/g line includes 50 acres of land outside the site boundaries that are considered to be contaminated by windblown tailings. Cleanup of this land is discussed in Paragraph 7.3. The 10 μR/hr iso-exposure line determined by the EPA gamma survey includes a much larger area than the 5-pCi/g line because the 10 μR/hr line extends to include the overburden piles and open pit mine areas around the site. The windblown survey was not continued when overburden piles were encountered along the traverses. The area of land disturbed by mining operations is several times the area of the tailings pile.

Surface soil samples were taken in the area surrounding the tailings.[1] The sample locations and ^{226}Ra concentrations are shown in Figure 3-14. Toward the northwest the ^{226}Ra content of the soil samples decreased to less than 2 times background at about 4,500 ft. In the northeastern direction the soil contained 16.3 pCi/g of ^{226}Ra at 375 yd from the tailings pile. Soil samples in Johnson Wash indicated above-background levels of ^{226}Ra. The ^{226}Ra content was higher for the soil sample 6 in. below the surface than for the surface sample. At the point where Johnson Wash joins Lay Creek, the ^{226}Ra content of the water sediment is less than 2 times background. Radium concentration in a soil sample from Johnson Wash 0.1 mi upstream from Lay Creek was about 3 times background concentration.

No air particulate measurements were performed at the Maybell site.

3.4.4 Ground and Surface Water Contamination

Six water samples were taken from the vicinity of the Maybell tailings pile and analyzed for ^{226}Ra, as shown in Figure 3-14.[1] Three samples were taken from Lay Creek upstream, downstream, and at the confluence with Johnson Wash. These samples contained 0.18, 0.19, and 0.16 pCi/l of ^{226}Ra, respectively.

Two water samples were taken from Johnson Wash, which provides drainage for the tailings pile. The sample nearest the tailings pile was taken from standing water immediately off the pile. This sample contained 12.8 pCi/l of ^{226}Ra. The second sample, taken about 0.5 mi down Johnson Wash, contained 0.02 pCi/l of ^{226}Ra. A ground water sample was obtained from a well west of the tailings. The well was 160 ft deep and contained 10.4 pCi/l. It is unlikely that the ^{226}Ra came from the tailings; a more likely source is the ore body from which contaminated ground or mine water migrated to the well site. In general, ground water in the vicinity of the tailings area is at a depth of 70 to 90 ft below the land surface and well below the base of the tailings.

All surface water samples except the standing water immediately adjacent to the tailings pile were well below the limit of the EPA Interim Primary Drinking Water Regulations of 5 pCi/l of combined ^{226}Ra and ^{228}Ra, and are not a radiological health hazard. The quality of the Yampa River with respect to ^{226}Ra was monitored from 1961 to 1970. During this period the average ^{226}Ra level downstream from the tailings was 0.08 pCi/l.(7)

Considering other hydrologic factors and the distance between Maybell and the tailings pile, it is essentially impossible for the tailings to increase significantly the radionuclide content of the potable water at Maybell or other areas of substantial population in the vicinity.(8)

3.4.5 Soil Contamination

The amount of ^{226}Ra activity in the tailings and the extent of leaching of radium from the tailings into the soil were determined by drilling holes in and around the tailings pile and into the soil beneath it. The radioactivity profile was measured in these holes with a Geiger tube probe in a lead shield that collimates the radiation. Soil samples also were taken from selected holes for radiometric analyses. The locations of the holes are shown in Figure 2-4.

Typical ^{226}Ra activity profiles in the Maybell tailings and subsoil are shown in Figures 3-15 and 3-16. Figure 3-15 illustrates the ^{226}Ra profile at drill hole 1 located on the northeast corner of the tailings pile. The profile was determined with the gamma probe and by analyses of samples taken from the hole. The analyses of samples from hole 1 indicated that radioactive contamination decreased to less than 2 times the average ^{226}Ra background concentration about 2 ft below the tailings-soil interface.(1)

Figure 3-16 is the profile of radium activity at hole 2, on the northwest quarter of the pile. At that location, the analyses of samples indicated background radium concentration about 2.5 ft below the tailings-soil interface.(1) Radium activity in the tailings ranged up to 600 pCi/g in the holes that were logged. Generally, contamination ranged from 2 to 5 ft beneath the tailings-soil interface.

3.4.6 Off-Site Tailings Use

A mobile gamma survey, operated by the AEC under an interagency agreement with the EPA, 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. The results of these surveys are discussed in Chapter 7.

3.5 REMEDIAL ACTION CRITERIA

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

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

By letter of December 1974, the EPA provided radiological criteria for decontamination of inactive uranium millsites and associated contaminated land areas. These criteria were expressed in terms of the "as low as practicable" philosophy and required that after remedial action has been completed, the residual gamma radiation levels should not exceed 40 μR/hr above background in unusual circumstances and must be near background levels in most cases. Furthermore, these criteria required that cleanup of radium contamination should reduce the soil concentration of radium to less than twice background. The stabilized tailings area should be designated as a controlled area, restricted from human occupancy and fenced to limit access. However, open land areas where residual gamma levels were less than 10 μR/hr above background were allowed to be released for unrestricted use.

Title II, Section 206 of PL 95-604 required the EPA to promulgate standards for the protection of the public and the environment from radiological and nonradiological hazards associated with residual radioactivity (as defined in the Act) at inactive uranium mill tailings and depository sites. The EPA subsequently published both interim cleanup standards (45 FR 27366) and proposed disposal standards (46 FR 2556).

3.5.1 EPA Interim and Proposed Standards

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

(a) For a period of at least 1,000 yr following disposal:

(1) Radon released from the disposal site to the atmosphere would not exceed 2 pCi/m^2-s;

(2) Substances released from the disposal site to underground sources of drinking water would not contaminate the water in excess of limits described in the tabulation below; and,

(3) Substances released from the disposal site to surface waters would not contribute to contamination otherwise existing in the water.

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

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

(c) The levels of radioactivity in any occupied or occupiable building shall not exceed either of the values specified in the listing below, because of residual radioactive materials from any designated processing site.

Average annual indoor radon decay product concentration--including background (WL)	0.015
Indoor gamma radiation--above background (mR/hr)	0.02

3.5.2 NRC Regulations on Uranium Mill Tailings

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

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

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

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

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

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

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

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

(a) Minimization of upstream catchment area

(b) Topographic features for wind protection

(c) Relatively flat embankment slopes

(d) Self-sustaining vegetative or riprap cover

(e) Earthquake impact avoidance

(f) Promotion of soil deposition

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

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

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

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

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

3.6 POTENTIAL HEALTH IMPACT

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

(a) Radon Diffusion - Inhalation of radon daughters from radon diffusion constitutes the most significant pathway and results in the largest estimated population dose.[1,10] Elevated concentrations were measured to 0.5 mi from the tailings pile.

(b) External Gamma Radiation - Gamma radiation above background is measurable to distances up to 0.4 mi from the pile, an area with very few inhabitants. People on site will receive some gamma exposure until the pile is covered with sufficient material to reduce the gamma radiation. Exposure to the local population within 0.4 mi of the pile has been evaluated and found to have negligible health impact compared with exposure from radon daughters.

(c) Airborne Activity - The limited, directional spread of significant quantities of windblown tailings toward inhabited areas indicates that direct inhalation or ingestion of tailings particles may be a minor component of the total population dose. This is a general result also reported at other uranium tailings piles.[11,12] Added stabilization of the Maybell tailings against wind erosion will eliminate any gradual accumulation of tailings off the site.

(d) Water Contamination - The low ^{226}Ra activity in surface water away from the pile indicates little, if any, contamination from the tailings pile, as confirmed by measurements since 1961.

(e) Subsoil Contamination - Leaching of radioactive materials into the ground beneath the pile and at the millsite is on the order of 2 to 5 ft. Water analyses do not indicate significant contamination from this pathway, however.

(f) Physical Removal - Tailings that have been placed near a structure or used in its construction are sources of elevated gamma levels and radon daughter concentrations in the structure.

Radiation exposure to individuals living or working in these structures can be significant. No structures where tailings were used were identified in Maybell.

Only the potential health effects from the inhalation of radon daughters (pathway a) are estimated quantitatively in this assessment, because this pathway produces the most significant exposure.[10-12] Furthermore, the uncertainty in the estimates of the potential health effects from this pathway far exceeds the magnitude of the health effects from the other pathways.

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

3.6.1 Assumptions and Uncertainties in Estimating Health Effects

Since radiation exposure from ^{222}Rn progeny is expressed in terms of working levels (WL) and working level months (WLM), total population exposures as well as health risk estimates are based upon these units; i.e., person-WLM. Exposures and resulting health effects are often expressed in terms of rems; however, estimates of the WLM-to-rem conversion factor for internal lung exposure to alpha particles from ^{222}Rn progeny are observed to vary by over an order of magnitude.[13] Presently, there are significant differences of opinion related to the choice of an appropriate conversion factor. Consequently, disagreements of calculated health effects from RDC occur when these effects are based on the rem.

The BEIR-III[14] risk estimator for lung cancer is based only on the absolute model since the relative risk model is not considered valid.[15]

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

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

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

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

The age-dependent excess risks presented in the BEIR-III report must be adjusted, when applied to the population at large, to account for the fact that the breathing rate of miners on the job is about 1.9 times greater than that of the general population.(16) Since exposure is considered proportional to the breathing rate, the exposure (and hence the excess risk) of the general population would be smaller by this same factor.

The cumulative risk estimator is obtained from the BEIR-III data adjusted for breathing rate by determining cancer risks for each year following an exposure. These risks are summed for the years between age at exposure and age 75. The contribution to the cumulative risk estimator from each age group is weighted by the respective fractions of the U.S. population found in those age groups.(17) For the lifetime plateau to age 75, no cancers were assumed to occur in the years subsequent to age 75. The following cumulative risk estimator for the population at large is obtained using a lifetime plateau to age 75 and weighting by the age distribution of the U.S. population:

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

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

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

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

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

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

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

The risk estimator used for continual exposure to gamma radiation is expressed as:(18)

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

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

3.6.2 Health Effects

The health effects due to radon released from the Maybell site in its present condition were calculated using a flux of 340 pCi/m^2-s for the pile. This value was calculated using diffusion theory and the tailings physical properties. Even though the calculated value for radon flux appears much larger than the measured values, it is considered a more defensible estimate of the radon release rate since measurements of radon flux to date have been made only at a few points in time and give no suggestion of the magnitude of annual variations. In the absence of this information, the conservative estimate was chosen as the basis for health effects calculations.

The transport of radon from the tailings pile was modeled using a Gaussian plume model, meteorology characteristics of the area, and population distribution surrounding the tailings pile as a function of the radius and direction from the edge of the pile. The pile was modeled as a vertical cylinder whose area and volume are equal to those of the actual pile.

Total predicted outdoor ^{222}Rn concentration (resulting from radon release from the pile) is shown as a function of distance from the edge of the pile in an east-northeasterly direction in Figure 3-8. The predicted ^{222}Rn concentration at 0.1 mi from the edge of the pile is about 30% higher than the background levels. The measured value shown in Figure 3-8 is much higher than the model prediction. This may be due to other naturally occurring or technologically enhanced sources of ^{222}Rn in the vicinity.

Figure 3-17 shows the lung cancer risk per year from continuous exposure to radon as a function of distance east-northeast of the tailings pile. The curve shows that the risk for developing lung cancer from radon released from the pile is about 25% higher than the natural occurrence from all causes at a distance of 0.1 mi from the edge of the pile but declines to within about 10% of the natural occurrence within 1 mi.[(19)]

The population distribution within 5 mi of the edge of the pile was developed using 1980 census statistics and other population information for the past decade. This distribution includes virtually all residents close enough to the pile to be noticeably exposed to radon exhalation from the pile, as described in Chapter 4.

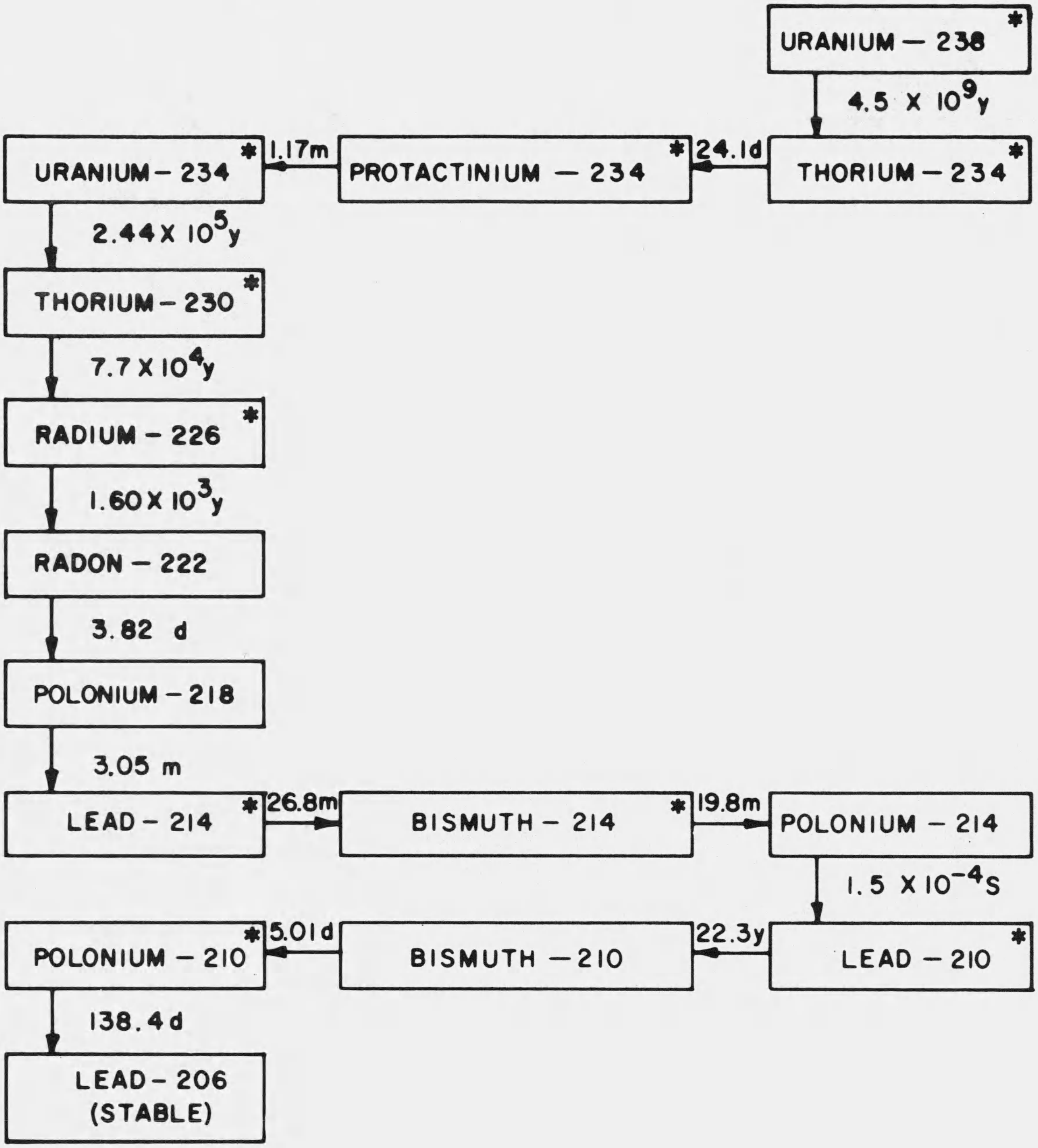
The three population projections used to estimate the cumulative health impacts attributable to the tailings pile were the 0.3% constant growth rate, the 15% declining growth rate, and the 20% composite growth rate described in Paragraph 4.2. All three growth projections assume that the population is distributed in the same proportions as those reflected in Table 4-1.

Table 3-3 presents the estimated health impacts per year from the tailings pile within 5 mi of the edge of the pile, based on the estimated 1980 population distribution presented in Table 4-1. The cumulative health effects for the three growth scenarios .considered for Maybell are also included. In Table 3-3, the health effects from the pile radon are shown to be less than 1% of those caused by background radon for the vicinity within 5 mi of the edge of the pile.

3.7 NONRADIOACTIVE POLLUTANTS

The tailings pile contains other potentially toxic materials. Chemical analyses of samples from drill holes in the Maybell tailings pile showed barium, chromium, and lead in concentrations between 5 and 30 ppm. The highest selenium concentration measured was about 24 ppm; arsenic ranged as high as 3 ppm. Vanadium was present in concentrations of about 40 ppm.

Two water samples were taken from the vicinity of the Maybell tailings pile and chemically analyzed. The locations of these samples are shown in Figure 3-14. Sample A was taken from a 160-ft-deep well west of the tailings. The water contained above acceptable levels of iron, arsenic, lead, and selenium; however, the contamination is most likely from the ore-bearing formation into which it is drilled. In general, ground water in the vicinity of the tailings pile is 70 to 90 ft below the land surface and well below the base of the tailings. Sample B was obtained from standing water in Johnson Wash just below the tailings pile. This water contained above acceptable levels of iron, lead, and selenium. Chemical analyses of these water samples are given in Table 3-4.



NOTE:

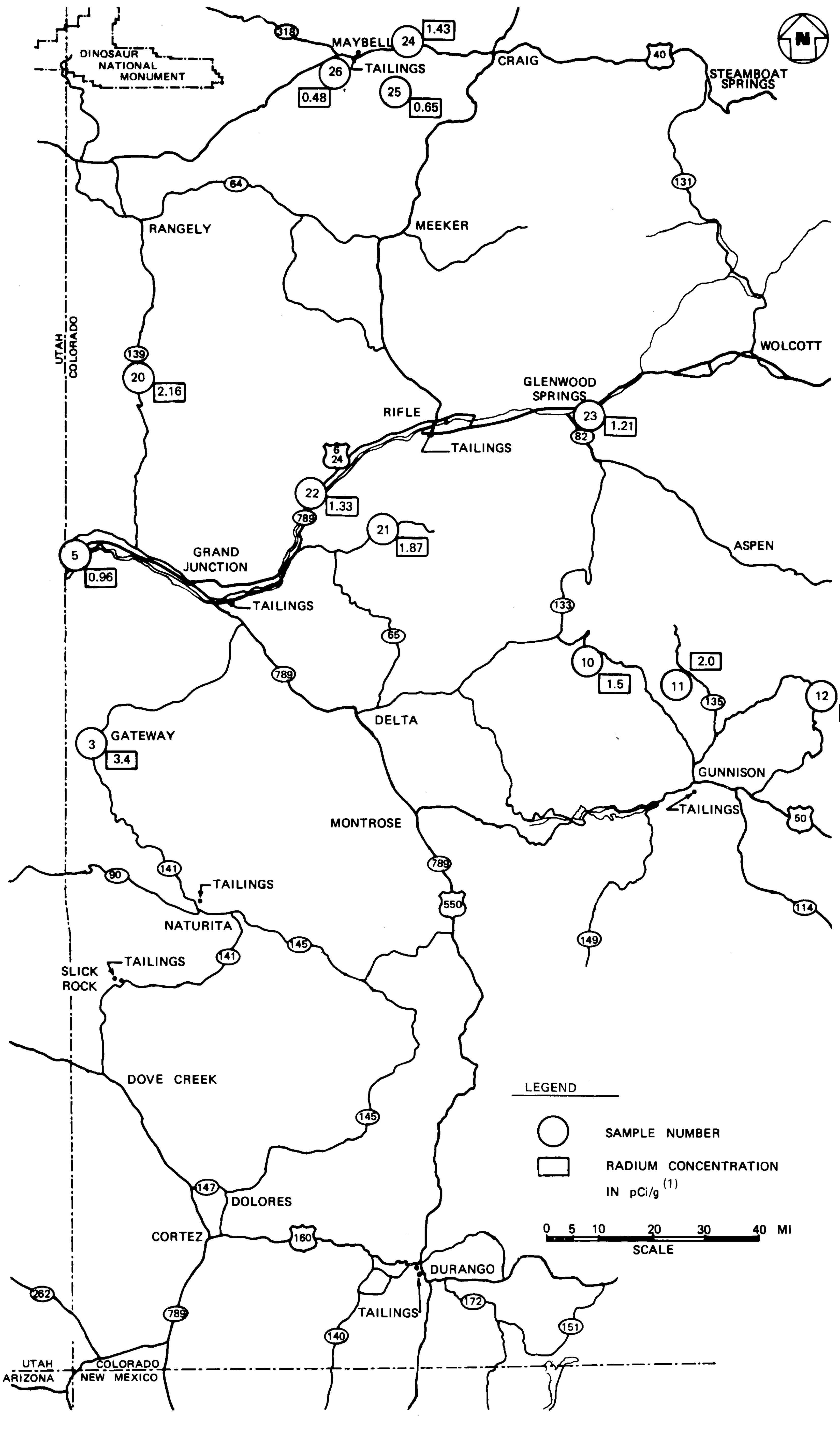
VERTICAL DIRECTION REPRESENTS ALPHA DECAY, HORIZONTAL DIRECTION INDICATES BETA DECAY. TIMES SHOWN ARE HALF LIVES. ONLY THE DOMINANT DECAY MODE IS SHOWN.

* ALSO GAMMA EMITTERS

FIGURE 3-1. RADIOACTIVE DECAY CHAIN OF URANIUM-238

360-11 10/77

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



Ford, Bacon & Davis Utah Inc.

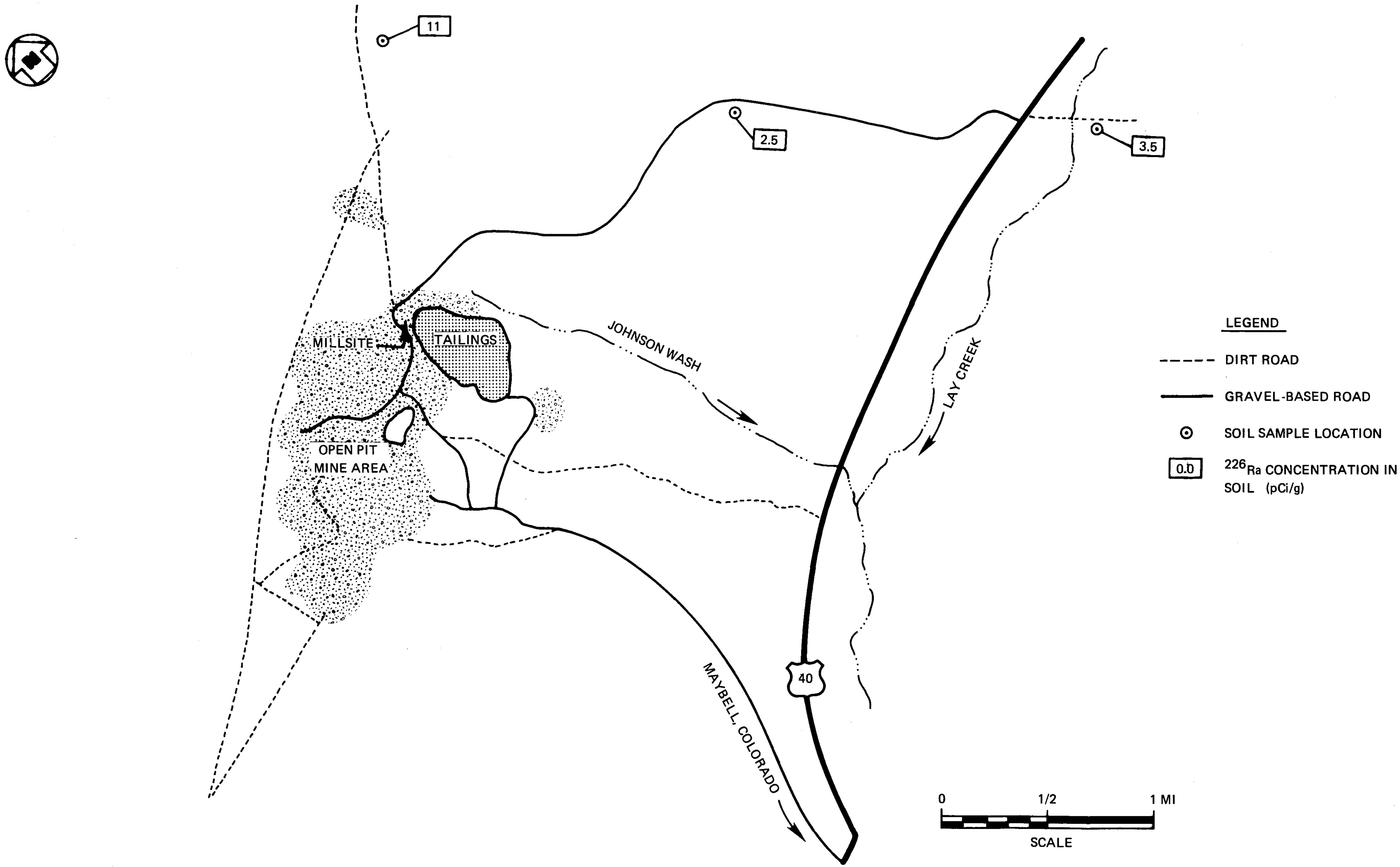


FIGURE 3-3. BACKGROUND SOIL SAMPLE LOCATIONS

360-11 2/81

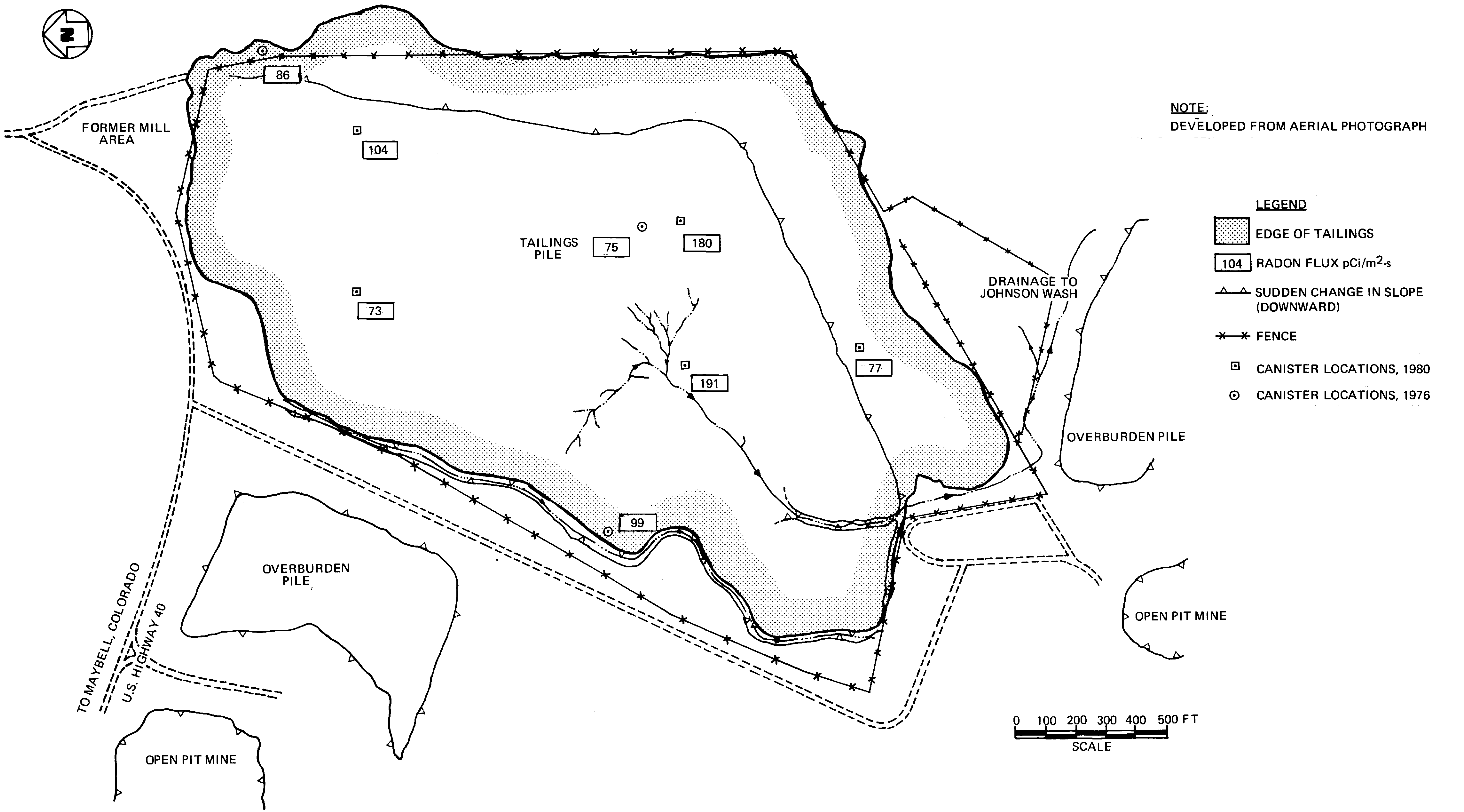


FIGURE 3-4. RADON CANISTER LOCATIONS AND FLUX VALUES

360-11 2/81

SITE NO.	24 HR OUTDOOR (pCi/l)	AVG WIND SPEED (KNOTS)	AVG WIND DIRECTION	LOCATION
1	14.6	2	NE	ON PILE
2	9.6	2	SE	0.5 MI E OF PILE
3	3.5	2	S	2.6 MI E OF PILE
4	2.5	2	SW	2.4 MI SW OF PILE

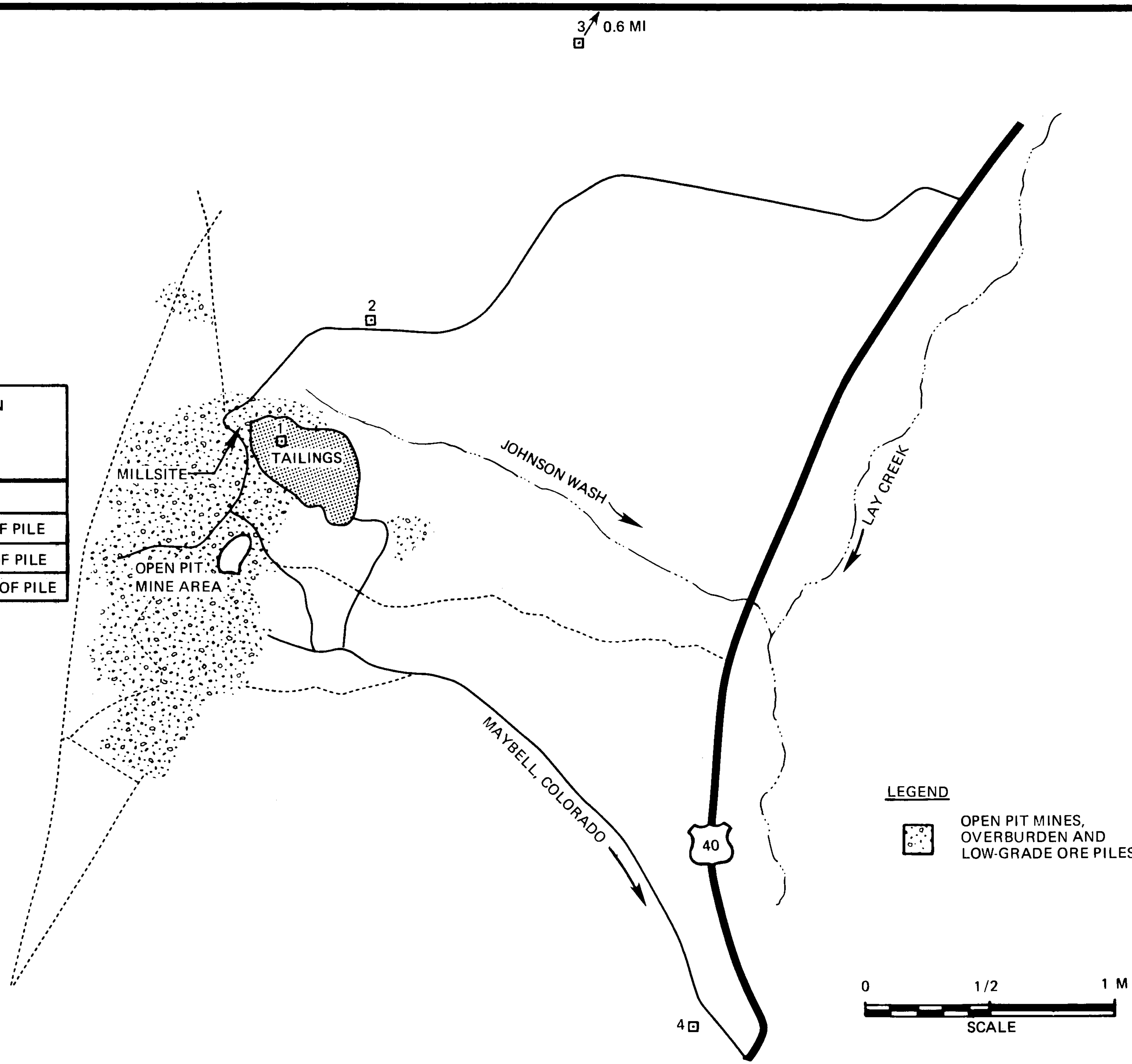


FIGURE 3-5. RADON CONCENTRATION IN VICINITY OF PILE

360-11 10/77

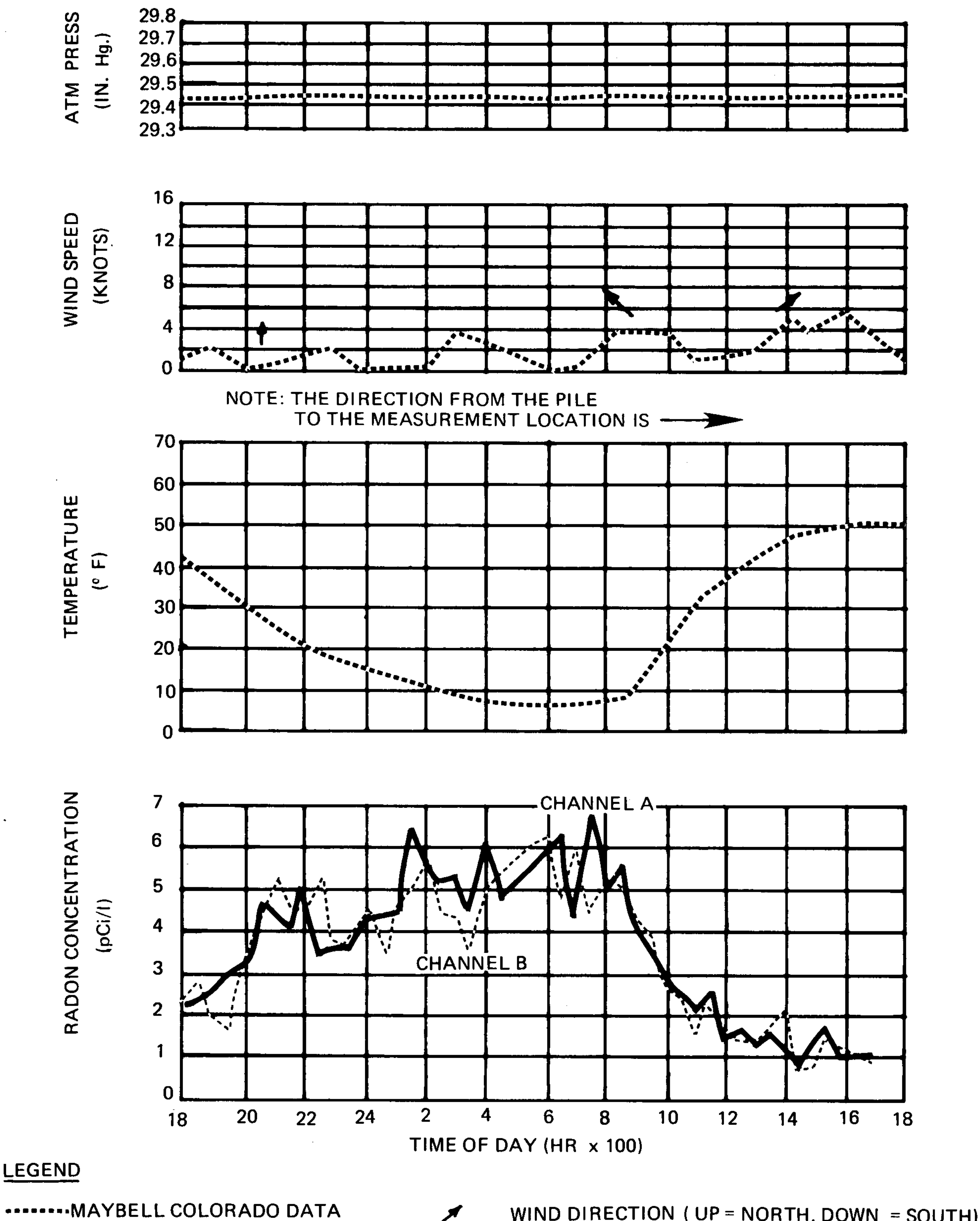


FIGURE 3-6. ^{222}Rn **AND ATMOSPHERIC TRANSIENTS AT 2.6 MI E OF THE PILE ON OCTOBER 19, 1976**

360-11 10/77

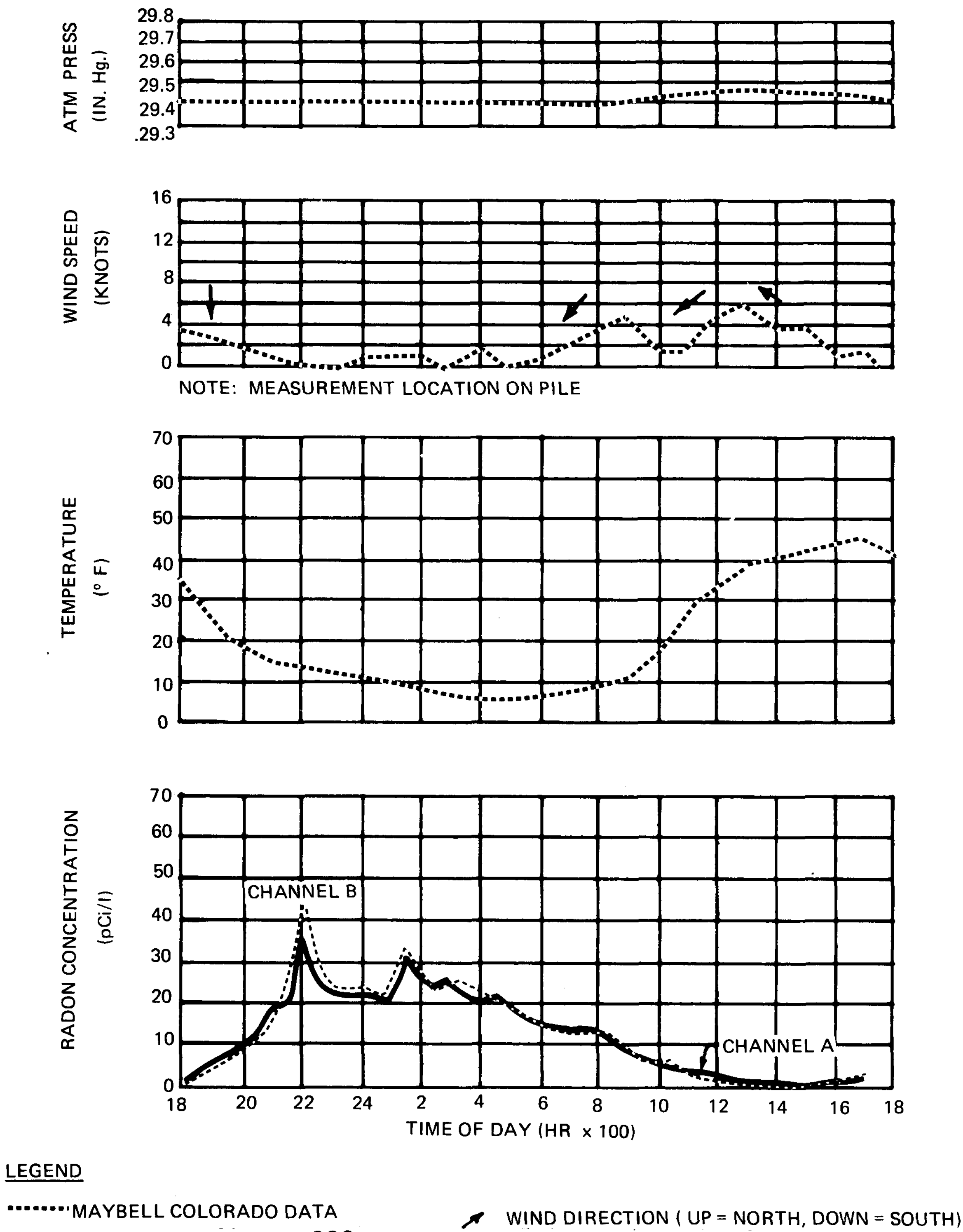


FIGURE 3-7. ^{222}Rn AND ATMOSPHERIC TRANSIENTS ON THE PILE ON OCTOBER 18, 1976

360-11 10/77

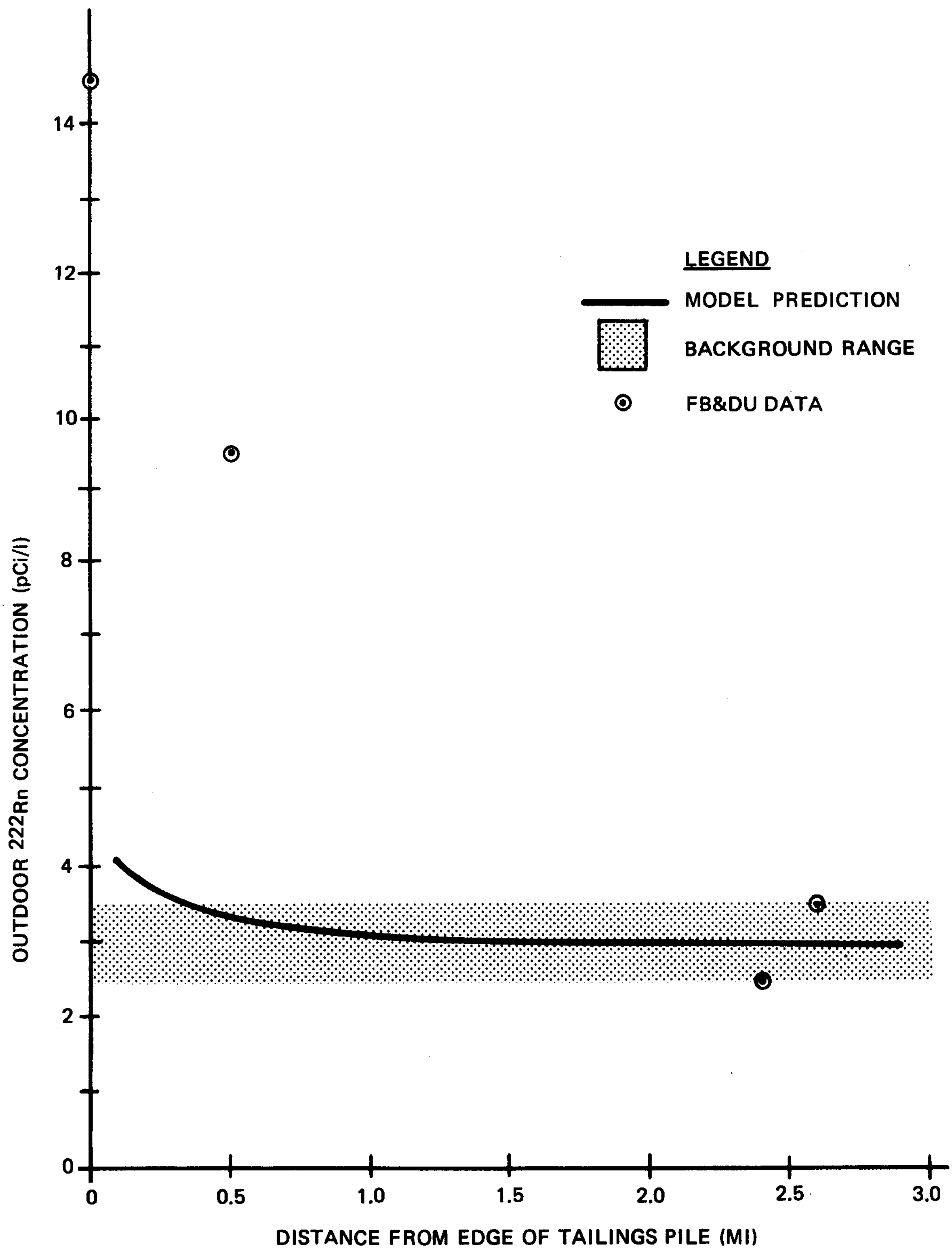


FIGURE 3-8. REDUCTION OF OUTDOOR ^{222}Rn CONCENTRATION WITH DISTANCE FROM THE TAILINGS PILE

360-11 REV 2/81

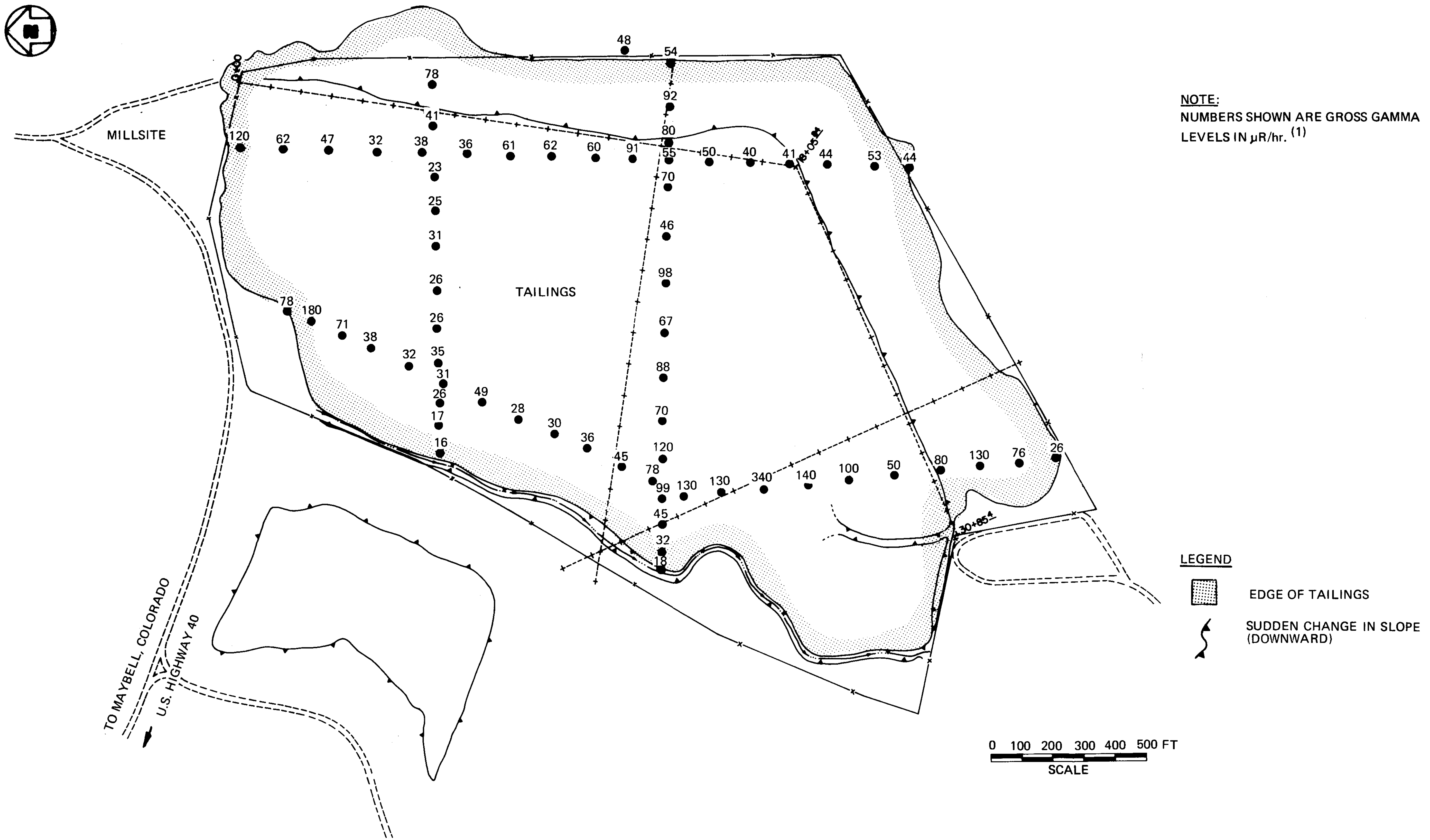


FIGURE 3-9. GAMMA LEVELS AT SITE 3 FT ABOVE GROUND

360-11 10/77

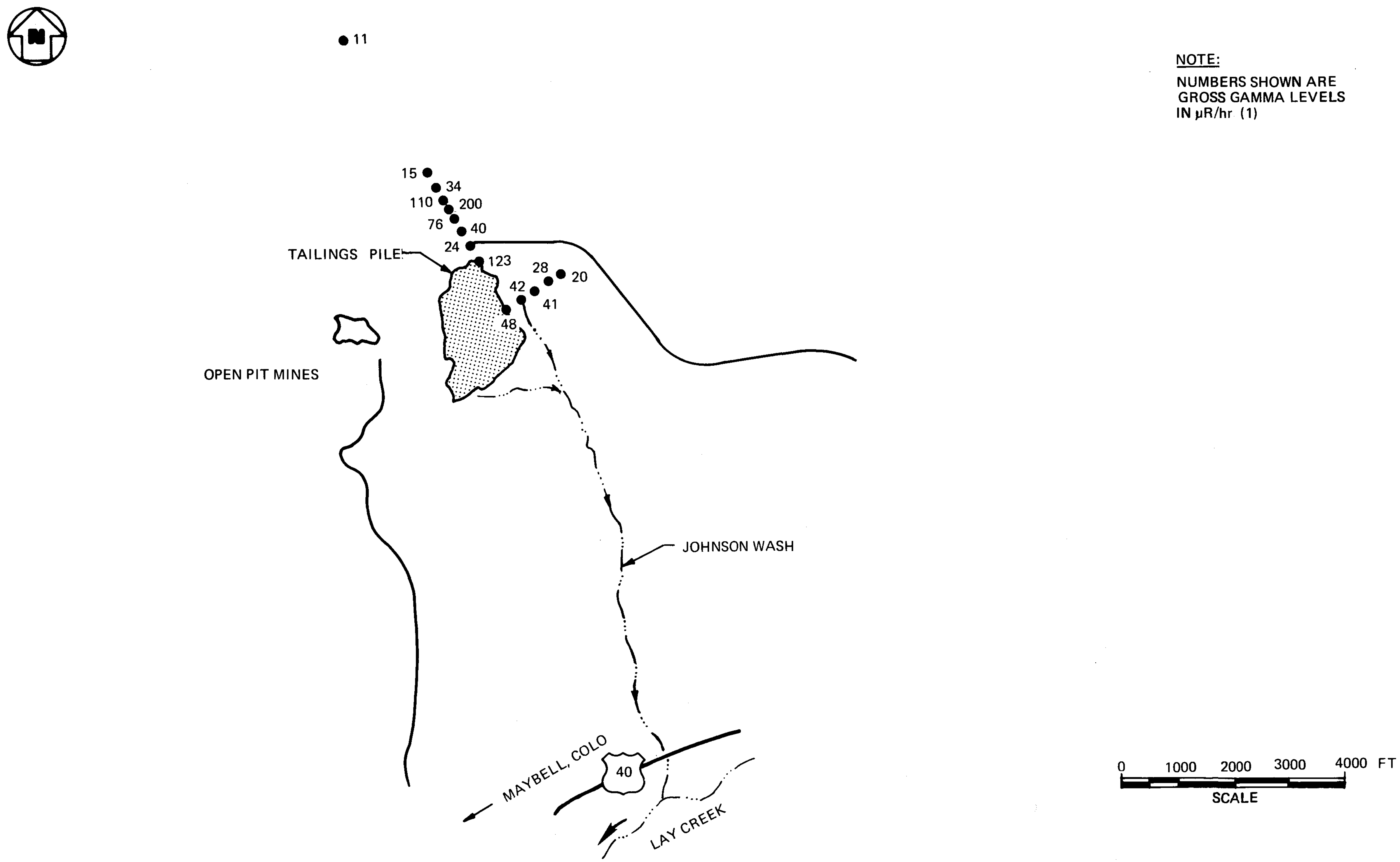


FIGURE 3-10. GAMMA LEVELS IN VICINITY 3 FT ABOVE GROUND

360-11 10/77

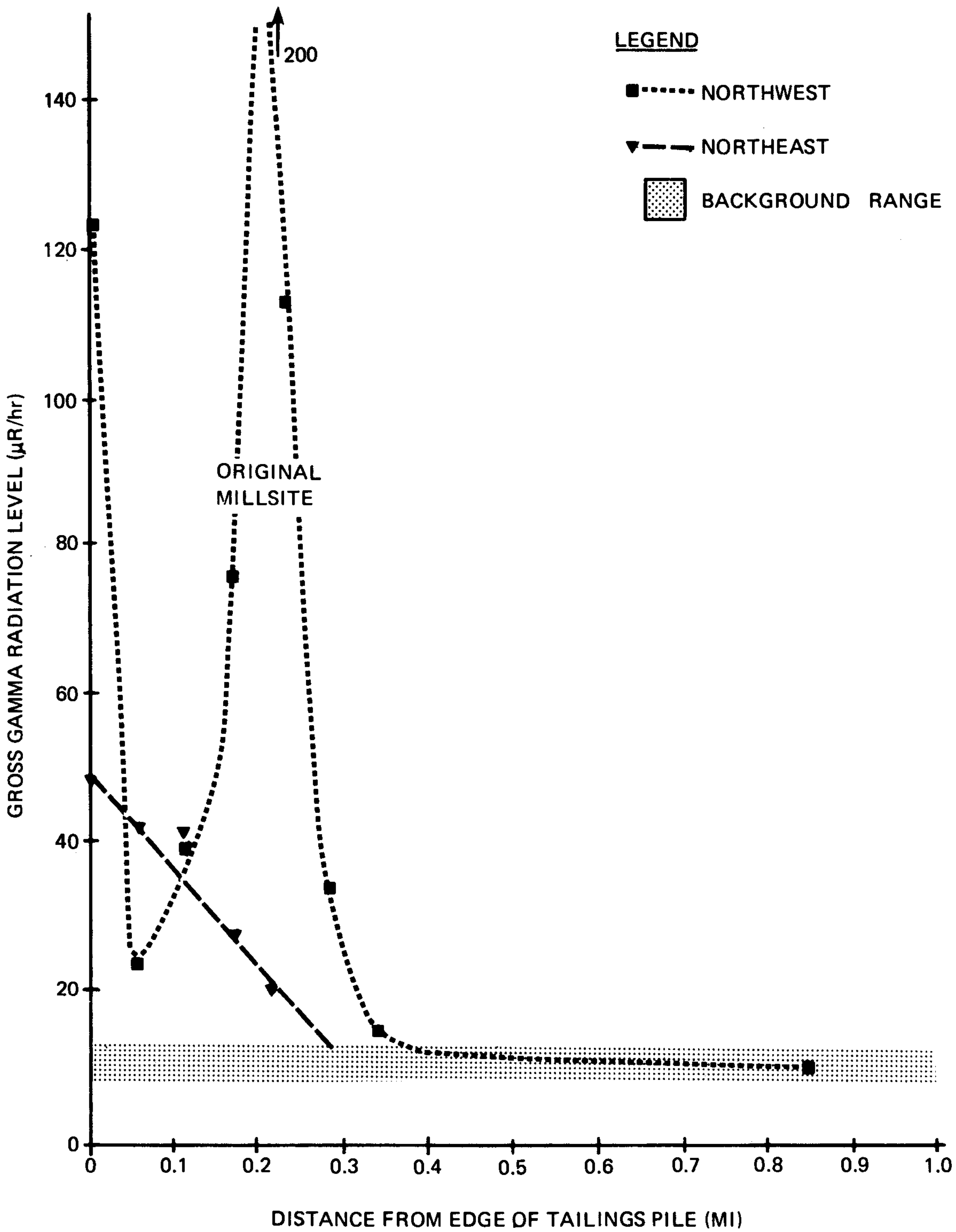


FIGURE 3-11. REDUCTION OF EXTERNAL GAMMA RADIATION LEVELS WITH DISTANCE FROM THE TAILINGS PILE

360-11 10/77

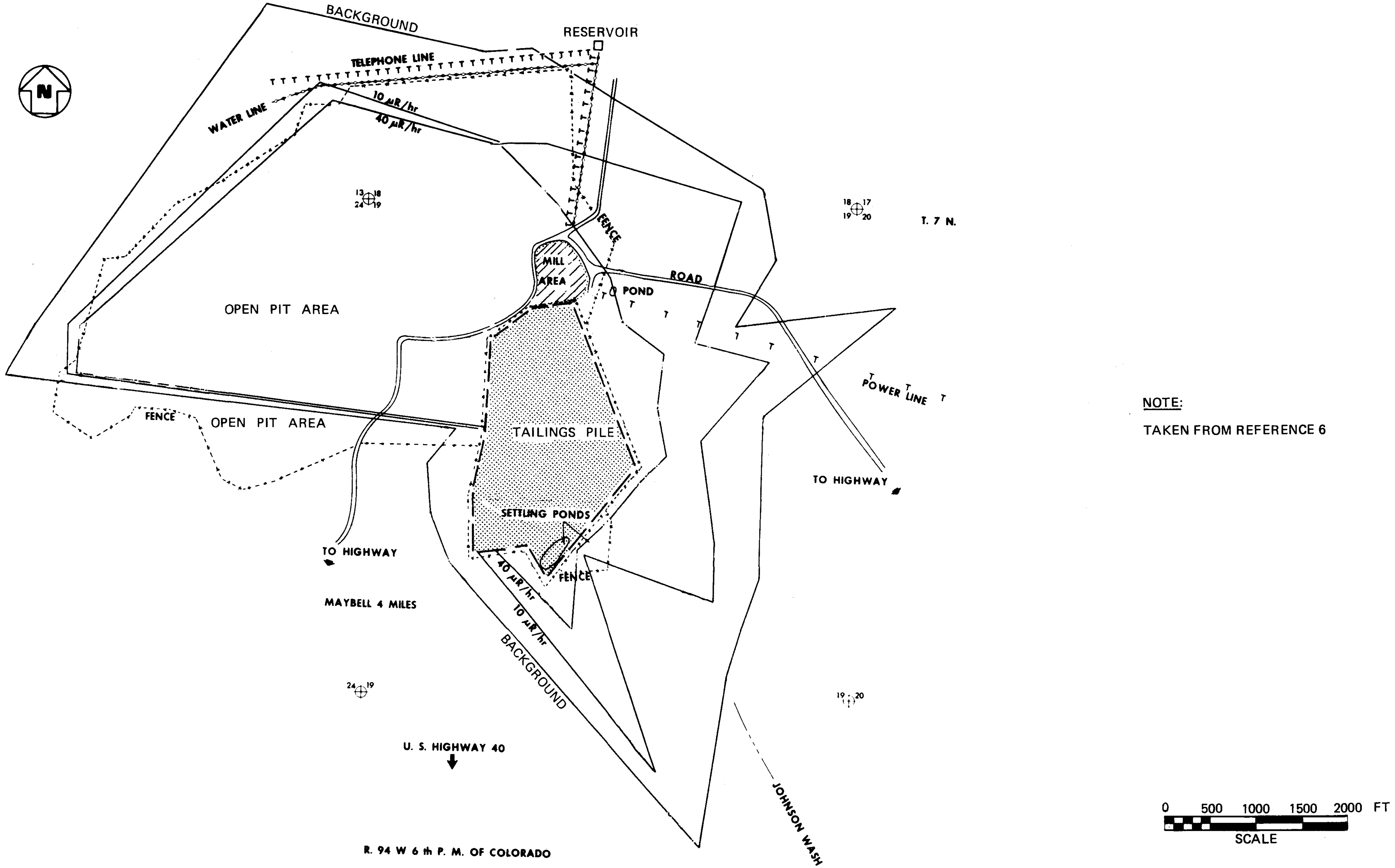


FIGURE 3-12. EPA GAMMA SURVEY SURROUNDING MILLSITE

360-11 10/77

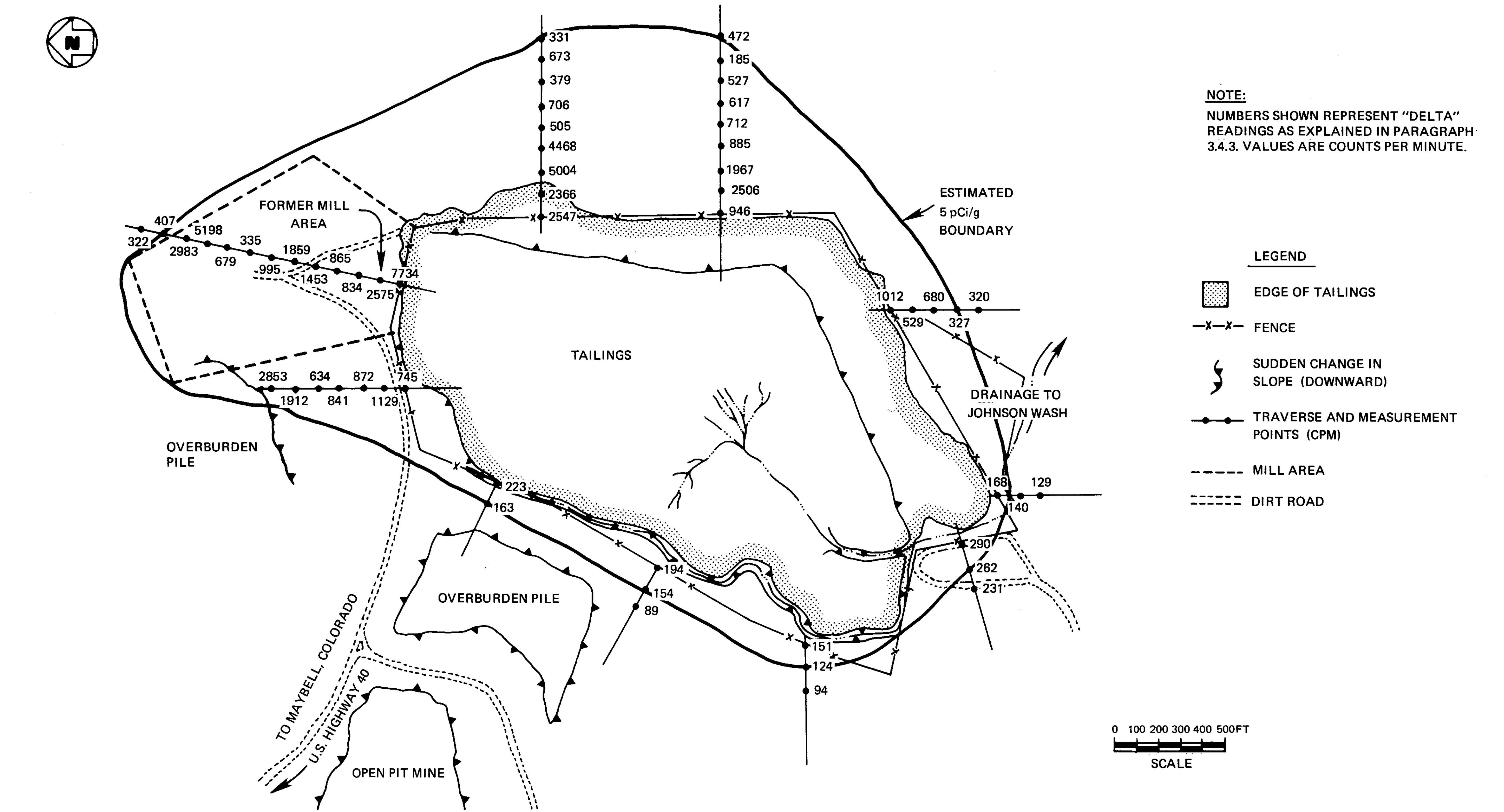


FIGURE 3-13. WINDBLOWN CONTAMINATION SURVEY

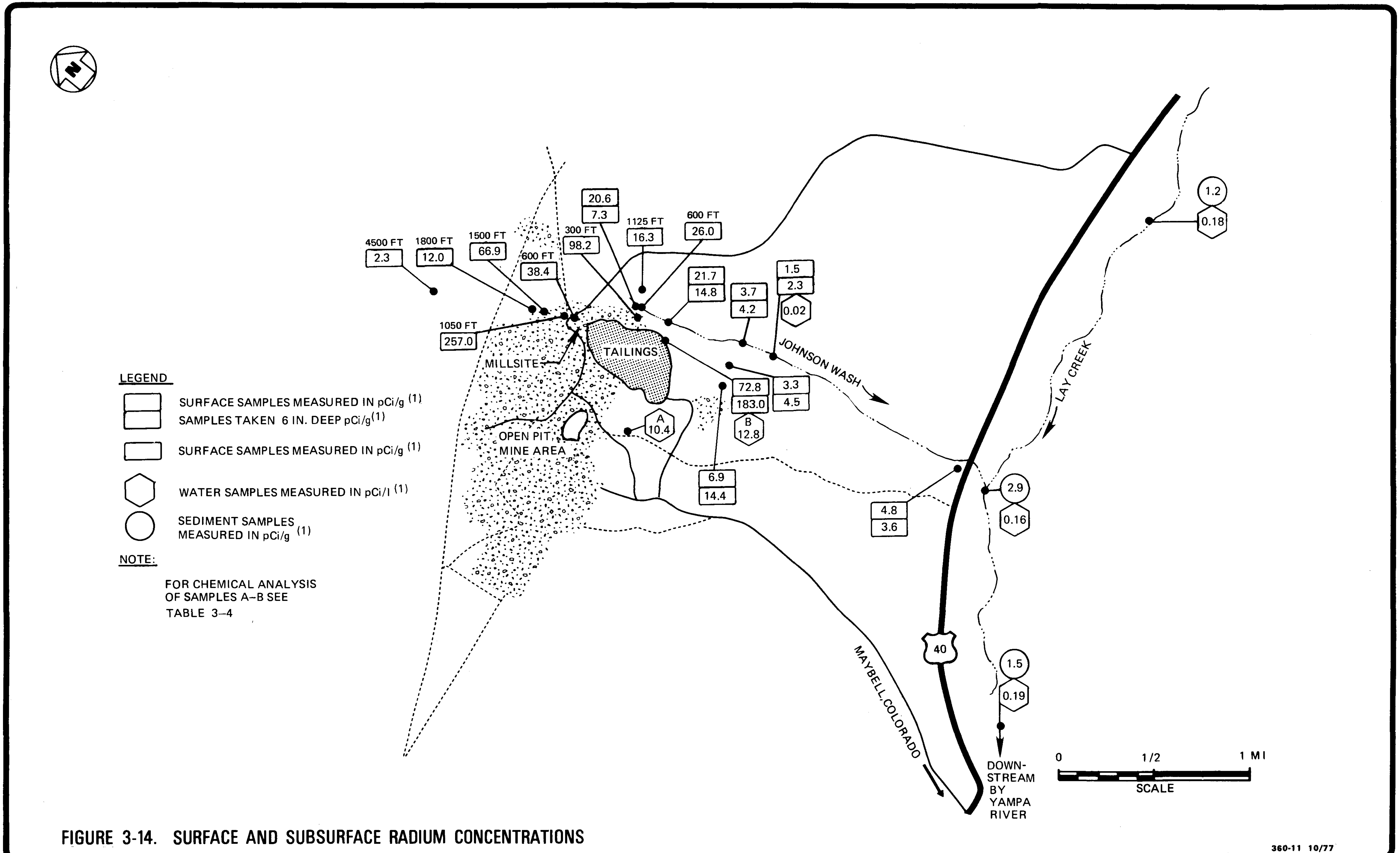


FIGURE 3-14. SURFACE AND SUBSURFACE RADIUM CONCENTRATIONS

360-11 10/77

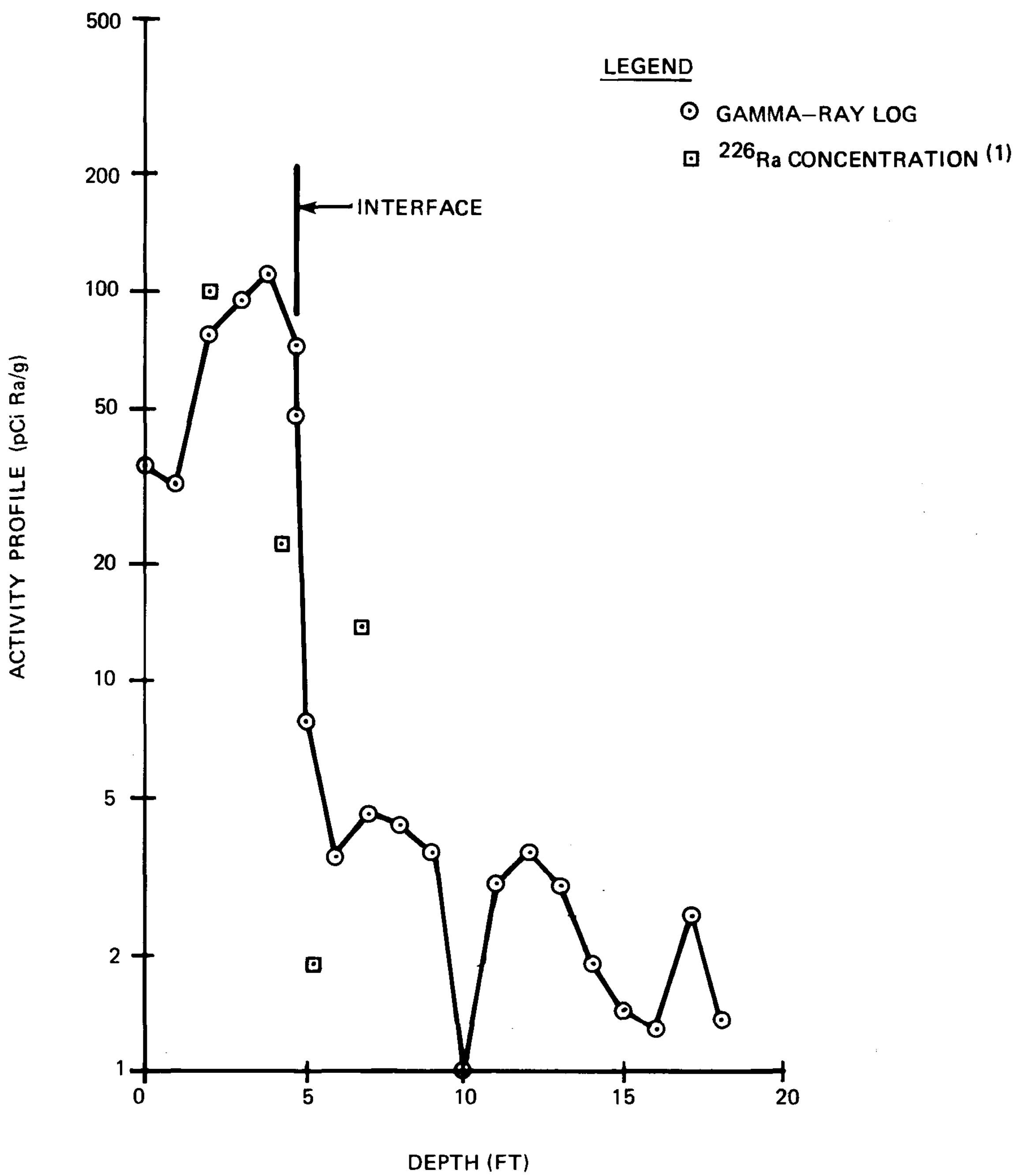


FIGURE 3-15. RADIOMETRIC PROFILE AT DRILL HOLE 1

360-11 10/77

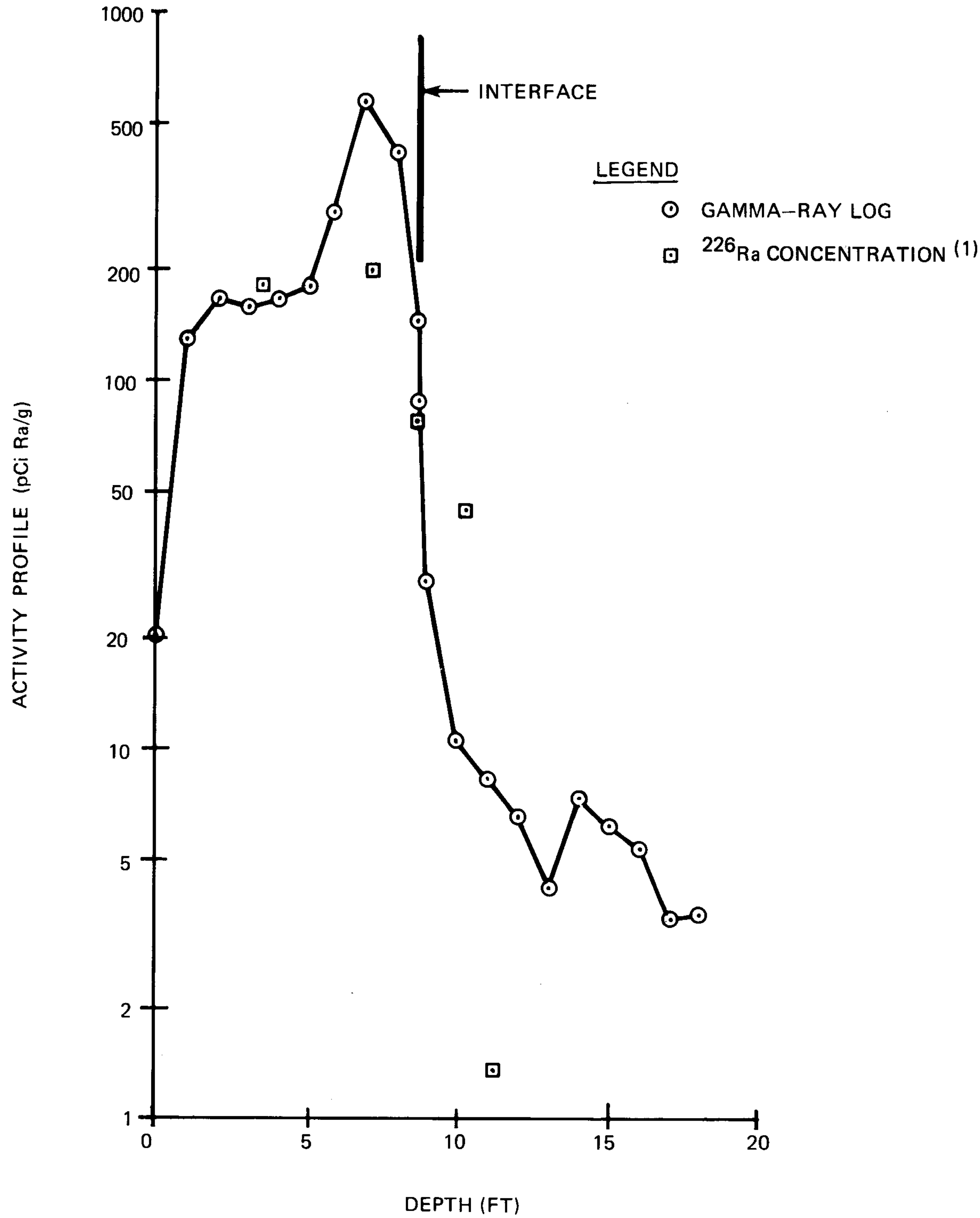


FIGURE 3-16. RADIOMETRIC PROFILE AT DRILL HOLE 2

360-11 10/77

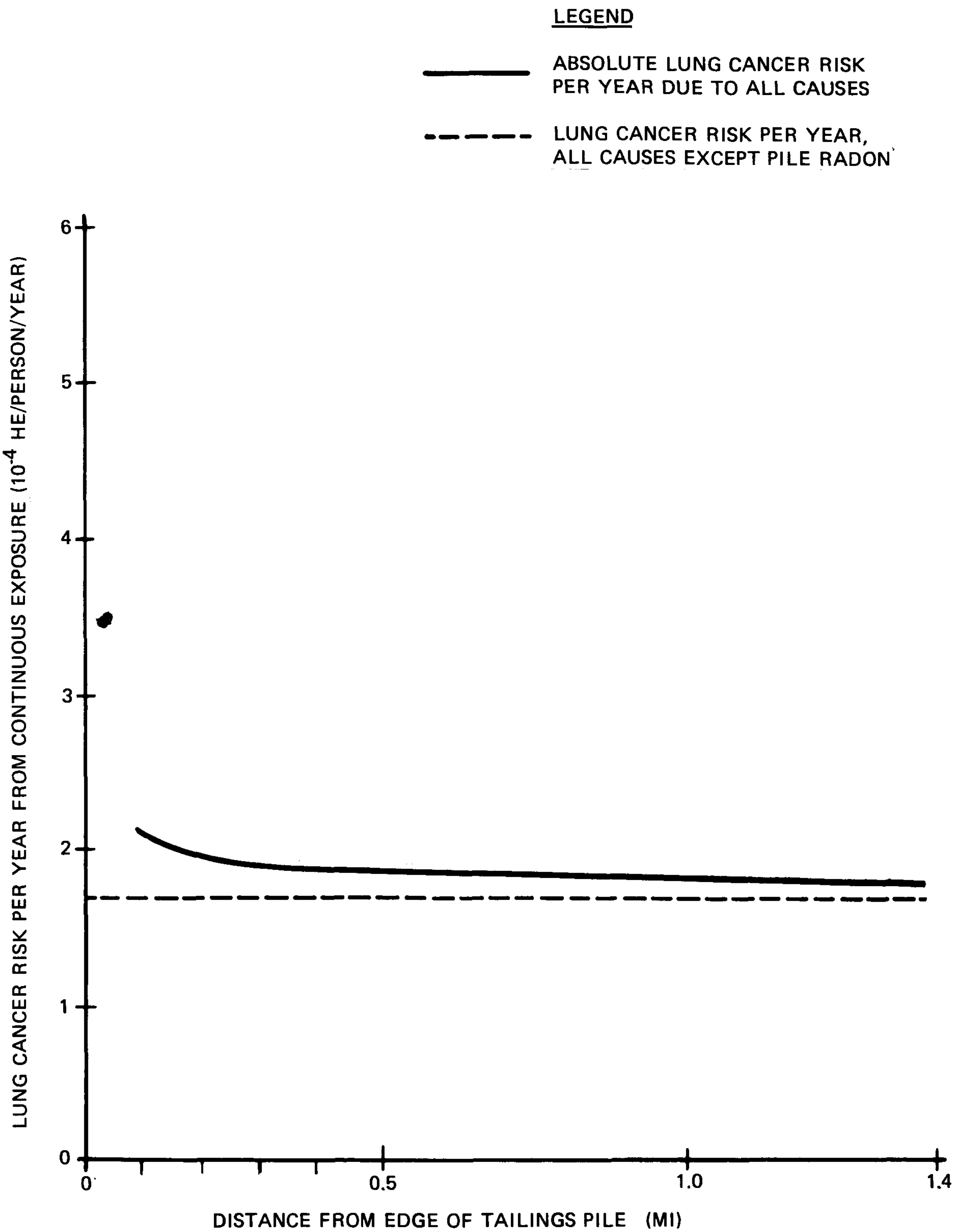


FIGURE 3-17. LUNG CANCER RISK FROM CONTINUOUS EXPOSURE TO RADON

360-11 REV 5/81

TABLE 3-1

NOTATIONS AND ABBREVIATIONS USED IN CHAPTER 3

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

Isotope Abbreviations:

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

Radiations:

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

TABLE 3-1 (Cont)

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

Note: Also see definitions of terms in Glossary.

360-11 11/77

TABLE 3-2

BACKGROUND RADIATION SOURCES IN SOIL FROM NORTHWEST COLORADO[1]

Isotope (Decay Chain)	Average Value (pCi/g)	Range (pCi/g)
^{226}Ra (^{238}U)	1.52 ± 0.78	0.48 - 3.4
^{232}Th (^{232}Th)	1.14 ± 0.52	0.58 - 2.08

360-11 10/77

TABLE 3-3

ESTIMATED HEALTH IMPACT FROM MAYBELL TAILINGS FOR AN AREA WITHIN 5 MILES OF TAILINGS EDGE

Time Period	Population (Persons)	Total Pile-Induced RDC Health Effects/Yr	Background RDC Health Effects/Yr
1980	100	0.000033	0.012
2005 (0.3% constant growth rate)	110	0.000035	0.013
2005 (15% declining growth rate)[a]	640	0.00021	0.073
2005 (20% composite growth rate)[b]	960	0.00032	0.11

Growth Projection	25-Yr Cumulative RDC Health Effects: Pile-Induced	25-Yr Cumulative RDC Health Effects: Background
0.3% constant growth rate	0.0008	0.3
15% declining growth rate[a]	0.0033	1.2
20% composite growth rate[b]	0.0060	2.2

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

[b]Doubles within first 2 yr, is constant at 20% for the next 6 yr, then declines linearly from 20% to zero in the next 5 yr and remains constant at zero thereafter.

360-11 Rev 5/81

TABLE 3-4

CHEMICAL ANALYSES OF MAYBELL WATER SAMPLES (mg/l)

Sample[a]	As	Ba	Cd	Cr	V	Fe	Pb	Se
A - Deep well--160 ft below surface west of pile	0.056	0.077	<0.001	<0.001	<0.001	0.580	0.059	0.162
B - Johnson Wash below tailings pile	0.041	0.038	<0.001	<0.001	<0.001	0.750	4.590	0.060
EPA Interim Primary Drinking Water Regulations[b]	0.05	1.0	0.01	0.05	--	0.3[c]	0.05	0.01

[a]See Figure 3-14 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

CHAPTER 3 REFERENCES

1. F.F. Haywood, et al.; "Radiological Survey of the Inactive Uranium Mill Tailings at Maybell, Colorado"; ORNL-5456; Oak Ridge National Laboratory; Oak Ridge, Tennessee; Mar 1980.

2. M.E. Wrenn, H. Spitz, and N. Cohen; "Design of a Continuous Digital-Output Environmental Radon Monitor"; IEEE Transactions on Nuclear Science; Vol NS-22; Feb 1975.

3. D.T. Oakley; "Natural Radiation Exposure in the United States"; EPA Report ORP/SIO 72-1; June 1972.

4. R.J. Countess; "^{222}Rn Flux Measurement with a Charcoal Canister"; Health Physics; Vol 31, p. 455; 1976.

5. D.H. Slade, editor; Meteorology and Atomic Energy 1968; TID-24190; AEC; July 1968.

6. R.L. Douglas and J.M. Hans, Jr.; "Gamma Radiation Surveys at Inactive Uranium Mill Sites"; Technical Note ORP/LV-75-1; EPA, Office of Radiation Programs; Las Vegas, Nevada; Aug 1975.

7. "Radium-226, Uranium, and Other Radiological Data Collected from Water Quality Surveillance Stations Located in Colorado, Utah, New Mexico, and Arizona"; 8SA/TIB-24; EPA, Region VIII; July 1973.

8. Summary Report, Phase I Study of Inactive Mill Sites and Tailings Piles; AEC, Grand Junction, Colorado; Oct 1974.

9. "Radiological Criteria for Decontamination of Inactive Uranium Mill Sites, Phase I"; USEPA/ORP; Washington, D.C.; Dec 1974.

10. F.F. Haywood, et al.; "Assessment of Radiological Impact of the Inactive Uranium Mill Tailings Pile at Salt Lake City, Utah"; ORNL/TM-5251 (Nov 1977).

11. A.J. Breslin and H. Glauberman; "Uranium Mill Tailings Study"; AEC Technical Memorandum; HASL-64-14; July 1964.

12. "Engineering Assessment of Inactive Uranium Mill Tailings, Vitro Site, Salt Lake City, Utah"; DOE/UMT-0102; FB&DU; Apr 1981.

13. A.K.M.M. Haque and A.J.L. Collinson; "Radiation Dose to the Respiratory System Due to Radon and Its Daughters"; Health Physics; Vol 13, p. 431; 1967.

14. "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation: 1980"; Report Advisory Committee on Biological Effects of Ionizing Radiation, NAS, Natl. Res. Council; 1980.

15. B.L. Cohen; "The BEIR Report Relative Risk and Absolute Risk Models for Estimating Effects of Low Level Radiation"; Health Physics; Vol 37, p. 509; 1979.

16. "Indoor Radiation Exposure Due to Radium-226 in Florida Phosphate Lands"; U.S. Environmental Protection Agency; Washington, D.C.; EPA 520/4-78-013; July 1979.

17. Statistical Abstract of the United States; 100th Edition; p. 29, Table 29.

18. "Health Effect Risk Estimators for Radon Daughters"; report to Ford, Bacon & Davis Utah Inc., by Rogers and Associates Engineering Corp.; Jan 1981.

19. Vital Statistics of the U.S.; Vol II; Mortality; National Center for Health Statistics; HEW; 1968.

CHAPTER 4

SOCIOECONOMIC AND LAND USE IMPACTS

CHAPTER 4

SOCIOECONOMIC AND LAND USE IMPACTS

The Maybell tailings and millsite are located in Moffat County, Colorado. Craig, the county seat, is about 25 mi to the east of Maybell via U.S. Highway 40. Two dirt roads connect the tailings site to U.S. Highway 40. The boundaries of Moffat County are shown in Figure 4-1.

4.1 SOCIOECONOMIC BACKGROUND[1,2]

Moffat County is one of the youngest counties in Colorado. The area was Indian land and inaccessible to early settlers. Gold was discovered in 1861 but not developed until 1866. Communities became established in the 1890's including Maybell in 1894, but early settlers fought among themselves to decide whether the cattle operators or the homesteaders would control the area. In 1911, Moffat County was created from a part of Routt County. Today, Maybell is located in a highly rural county whose economy is based on agriculture, construction, and the provision of services.

Ethnically the population of Moffat County is predominantly Caucasian. Educational attainment and the median income are low when compared to the state as a whole. Most workers are classified as farmers, managers, clericals, craftsmen, and service providers, but farmers and farm laborers show a drastic decline in both real numbers and percentage of the total. Traditionally, farming and stock raising have provided almost half of Moffat County's industrial output. More recently, services, schools, and construction have played a more important role in the area's economy.

The recent development of coal resources in the vicinity of Craig has resulted in rapid growth in this area, straining the community's services such as schools, housing, and sewage disposal. Although this development is expected to continue, it will not affect the Maybell area because the coal formations do not underlie the uranium host formations.

Two developments planned for the Maybell area would have a great effect on its growth and economy. The proposed Federal Coal Leasing Program, with an early 1981 starting date, is expected to have a significant impact on Moffat County. The program involves the lease of several tracts of land administered by the U.S. Bureau of Land Management to private companies for coal mining purposes. Of the 16 tracts proposed for lease in the Green River-Hams Fork Coal Region, 11 are located within 25 mi of Craig, Colorado. The Lay Coal Tract is located approximately 4 mi northeast of the Maybell site and 12 mi northeast of the town of Maybell. The proximity of these coal tracts will bring pressure for growth to the town of Maybell.

The Juniper-Cross Mountain Dam, a hydroelectric project, is planned for the Yampa River near Maybell. The project includes the construction of two dams: the Juniper Dam will be located 9 mi upriver, and the Cross Mountain Dam 18 mi downriver, from Maybell. The reservoir formed by the Cross Mountain Dam will extend to the town. The reservoirs created by the dams will diversify recreation in the area with the addition of fishing, boating, and water skiing. Project construction and operation and maintenance of the completed hydroelectric plants will cause an influx of workers to the Maybell area. Applications and reports on this project have been submitted to the Federal Energy Regulatory Commission, and construction is anticipated to begin in about 2 yr.

Although the projects described above are expected to cause extensive growth in the near future, there is presently a moratorium on building in the Maybell area because of the water contamination problems caused by the combination of a high ground water table and lack of a sewer system. However, the Moffat County Planning Commission has completed a study demonstrating the necessity of a sewer system at Maybell and has been issued a certificate of need by the Colorado State Department of Local Affairs. A local engineering firm designed the system, and construction should be completed during the summer of 1981. The building moratorium will be lifted with the addition of the sewer system, and Maybell will be able to expand to meet the needs of growth created by the new projects.

4.2 POPULATION ESTIMATES

The 1980 census showed that the population of the Maybell Powderwash Census District, which includes the town of Maybell, increased about 3% over its 1970 population, from 433 persons to a total of 445 persons. The 1980 population of the town of Maybell is estimated to be approximately 100 people.(3) A population projection(3) by the Moffat County Engineer and Planning Director estimates that the population of Maybell will double (to about 200 people) by the end of 1982. This increase is expected to result from installation of the public sewer system and the housing construction that will follow the lifting of the moratorium on building.

Taking into account the coal leasing and hydroelectric projects described in Paragraph 4.1, the same projection estimates an average annual growth rate of 20% from 1982 through 1988.(3) This projection would mean a Maybell population of approximately 345 people in 1985 and 600 people in 1988. The public sewer system for Maybell is therefore designed to serve a population of 600 people. If either the Lay Coal Tract lease or the Juniper-Cross Mountain Dam project does not develop in this time frame, a smaller growth rate after 1988 is anticipated by the estimator.[3]

It is difficult to project the population of an area with such a small population base and rapid growth potential as Maybell. However, in light of the above and other information, three possible growth projections for the Maybell area are presented in Figure 4-2.

The lowest growth rate in Figure 4-2, a 0.3% constant annual growth rate, is based on the growth history experienced by the Maybell Powderwash Census District during the last decade, as indicated by the census reports. If this growth pattern were realized, the population of Maybell would increase at a rate of 0.3%/yr and reach a population of about 110 people by the year 2005. This projection is considered as a lower bound on the population of the area.

The most optimistic growth projection presented in Figure 4-2 is a combination of the Moffat County Planning Department's projection[3] through 1988 followed by a 20% declining annual growth rate. If this projection were accurate, the population would double to reach a figure of 200 people by the year 1982, then increase at a constant annual growth of 20%/yr through 1988 to reach a figure of 600 people, as projected by the Moffat County Planning Department. The population is then assumed to increase at a rate that declines linearly from its 1988 rate of 20%/yr to zero growth over the next 5 yr. Maybell would have a static population of about 960 people from 1993 to 2005. This population projection is considered as a realistic upper bound on the future growth rate of Maybell.

Perhaps the most probable projection presented is the 15% declining annual growth rate, which occupies the intermediate position in Figure 4-2. If this projection were experienced, the population of Maybell would increase at a rate that declines from its initial rate of 15%/yr to zero growth over a 25-yr period. In this growth scenario the population of Maybell would double in less than 6 yr and reach a static population of about 640 people by the year 2005.

The estimated 1980 population distribution at Maybell, Colorado as a function of distance and direction from the tailings pile is presented in Table 4-1. This table includes the equivalent of 25 full-time employees[4] who work in Union Carbide's mining and leaching operations near the tailings site. This total was divided by a factor of 4 to account for the fact that the workers are at their place of employment only 25% of the time.

4.3 LAND USE

The presence of the tailings limits the use of the site itself, but has no apparent effect on the use of the surrounding property. Union Carbide operates several open pit uranium mines and a heap leach operation in the neighboring area. The overburden from these mines is stockpiled around the tailings site on the south and west sides.

Except for the mineral-related activity near the pile, virtually all the land near the tailings site is used for grazing. As shown in Figure 4-3, there are two small concentrations of population in the vicinity. Maybell has approximately 20 dwellings and commercial buildings for food and automotive services. The other residential site consists of four trailers and one house located east of Maybell near the Yampa River bridge.

4.4 IMPACT OF THE TAILINGS ON LAND VALUES

The latest assessment of the land near the site was performed in 1974, and most of the land in the vicinity of the tailings was given a market value of about $7/acre.[5] The presence of the tailings restricts the use of the actual pile area by prohibiting its use for grazing. However, this loss of usable land is minimal compared to the much larger areas occupied 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 area.

The Federal Government (through the Bureau of Land Management) still administers several tracts of land near the site; however, the number of private or corporate groups that own major portions of land near the site has increased to about 12.[5]

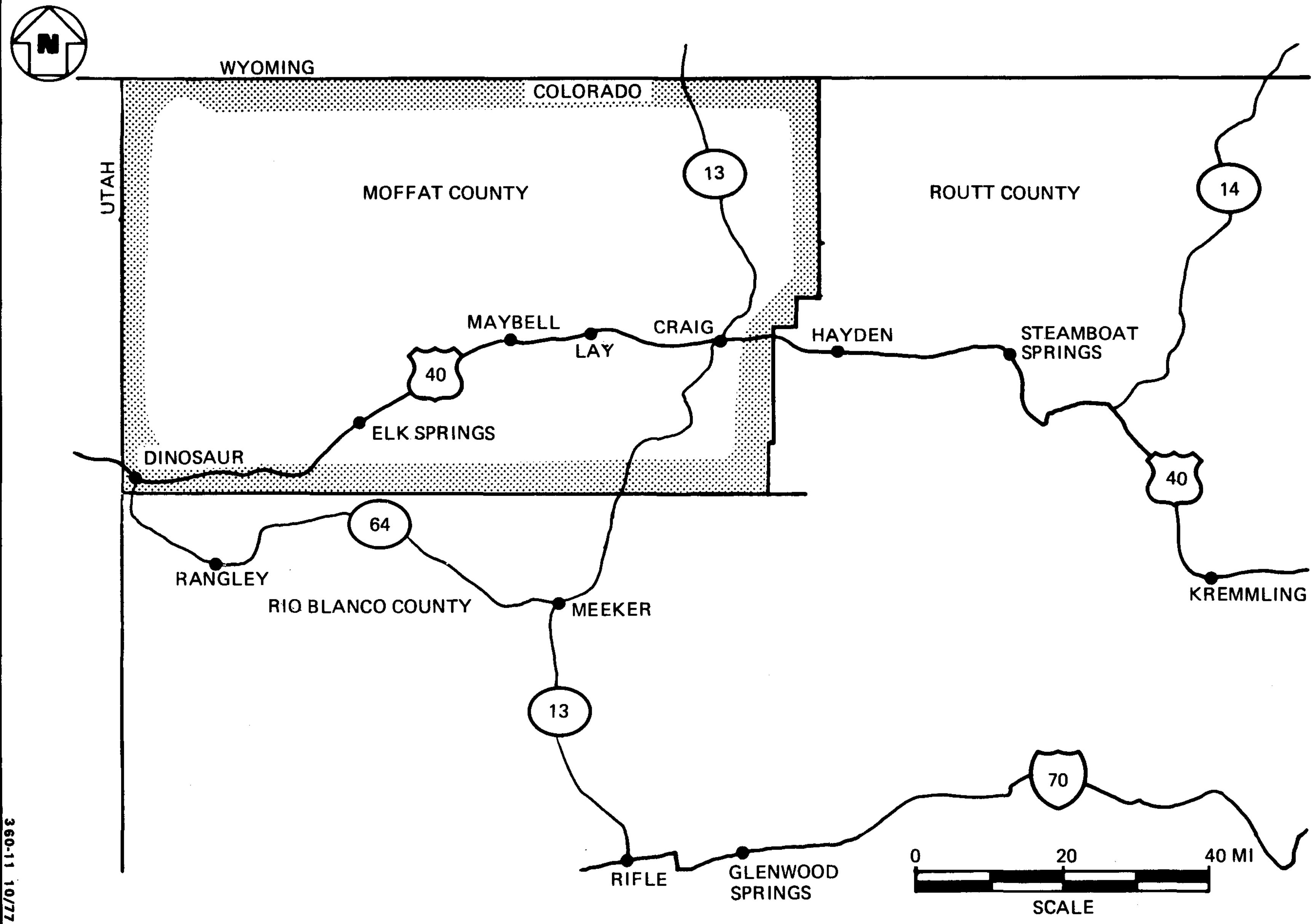


FIGURE 4-1. MAP OF MOFFAT COUNTY BOUNDARIES

360-11 10/77

Ford, Bacon & Davis Utah Inc.

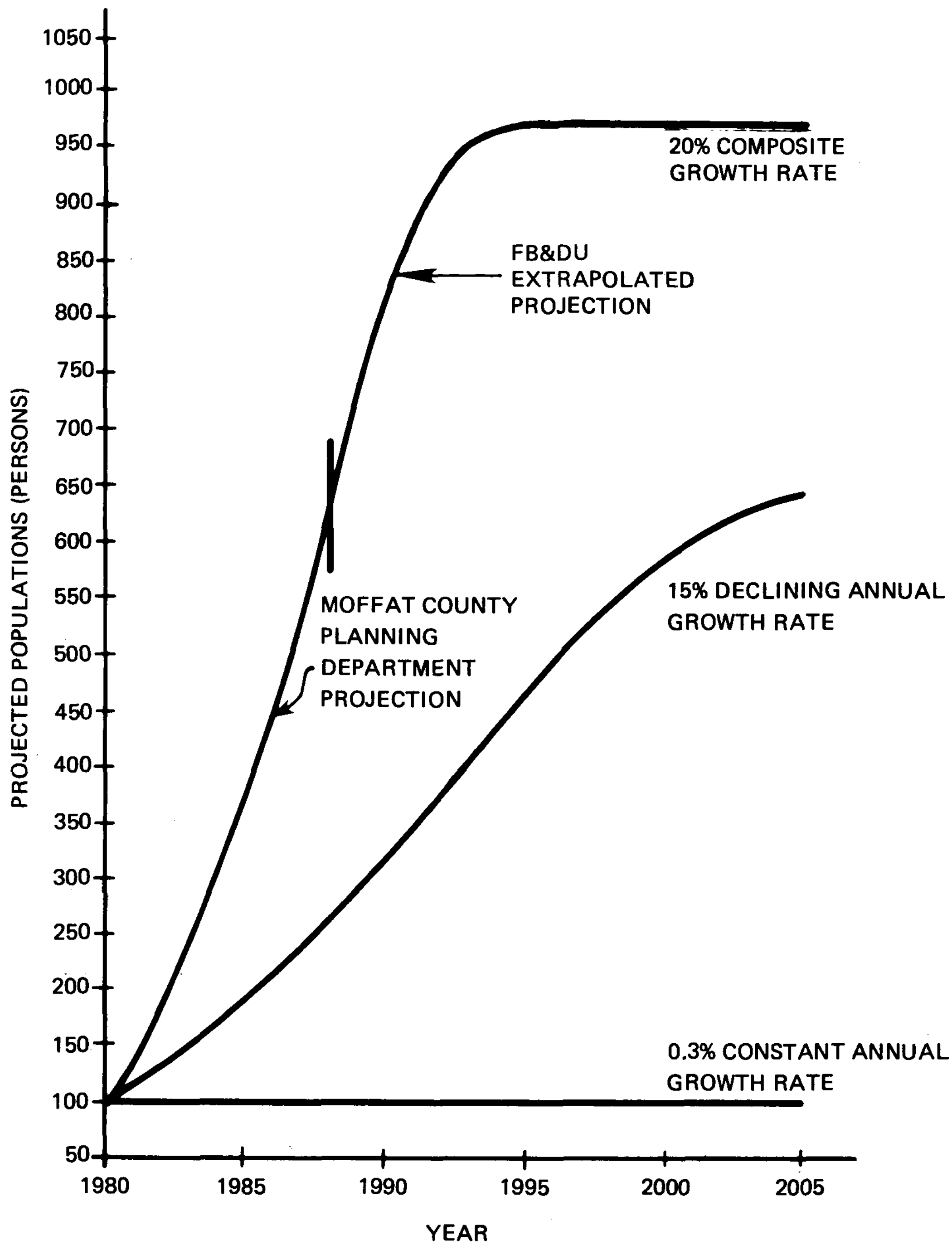
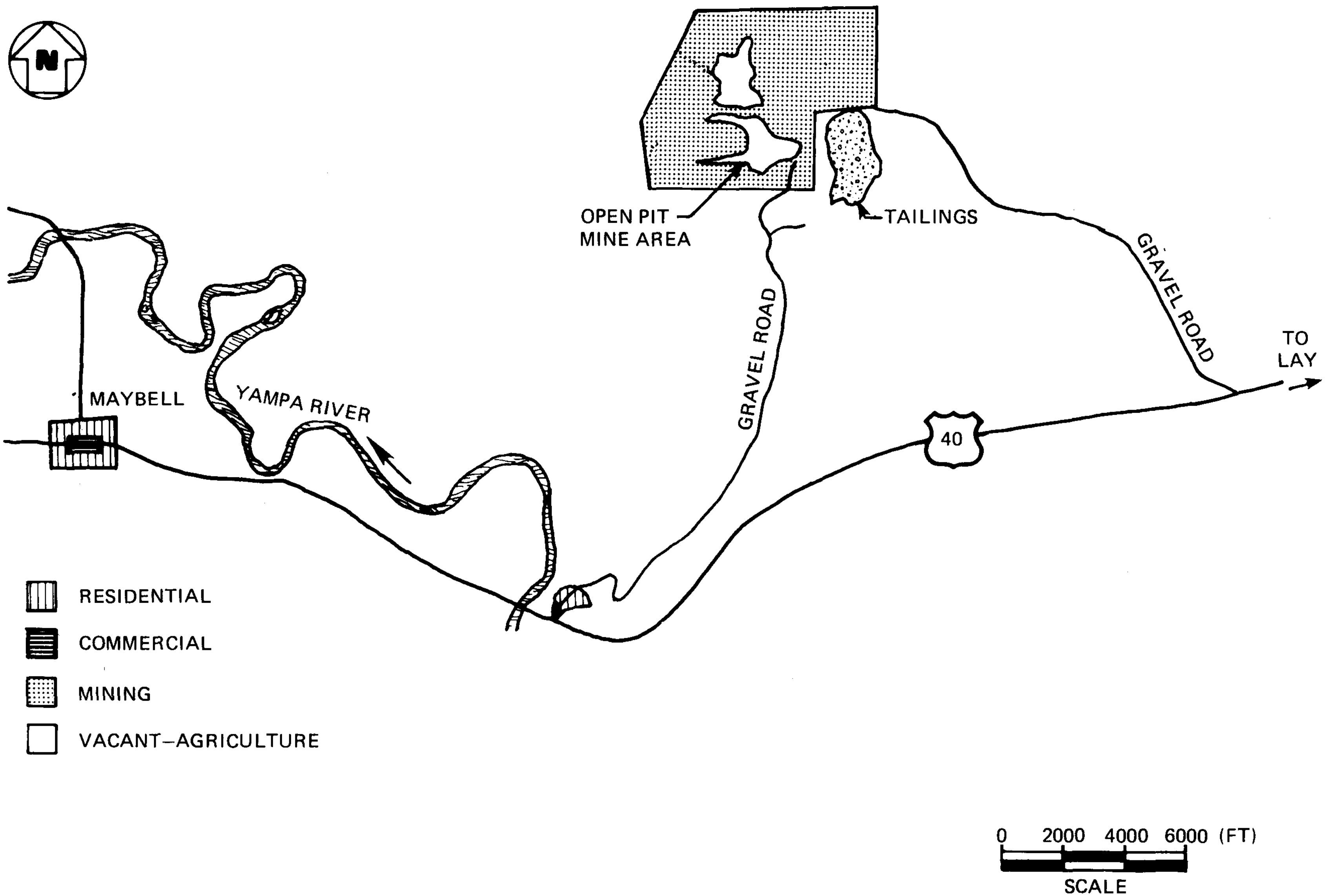


FIGURE 4-2. POPULATION PROJECTIONS

360-11 REV 2/81



360-11 10/77

FIGURE 4-3. VICINITY LAND USE

Ford, Bacon & Davis Utah Inc.

TABLE 4-1

ESTIMATED 1980 POPULATION DISTRIBUTION AT MAYBELL, COLORADO

Number of People	Distance and Direction from Tailings Pile
6*	0.5 mi, NW
10	3.0 mi, SW
84	5.0 mi, WSW
100 TOTAL	

*Represents the number of workers at Union Carbide's mining and leaching operation divided by a factor of 4 to account for the fact that these workers are at their place of employment only 25% of the time.

360-11 3/81

CHAPTER 4 REFERENCES

1. J.L. England; "Baseline Data and Land Use Impact of the Maybell Uranium Tailings Site"; Center for Health and Environmental Studies, Brigham Young University; Provo, Utah; 1976.

2. R. Sorensen, Planner; personal communication; Moffat County, Colorado; Aug 7, 1980.

3. James E. Pankonin; Moffat County Engineer/Planning Director; letter to Chuck Sundby of Dismuke & Dismuke Engineers; July 16, 1980.

4. J. Kirchner; Union Carbide Corporation; personal communication; Oct 20, 1980.

5. Moffat County Assessor's records; Moffat County Courthouse; Craig, Colorado.

CHAPTER 5

RECOVERY OF RESIDUAL VALUES

CHAPTER 5

RECOVERY OF RESIDUAL VALUES

The Maybell plant(1) was originally designed to handle low grade ore which comprised the bulk of the deposits at the site. The mill was built adjacent to the large open pit mining area, thus minimizing ore haulage cost. Over the life of the mill the grade of ore processed averaged 0.098% U_3O_8, one of the lowest in the industry. AEC records indicate there are 2,600,000 tons of tailings on the site with an average grade of 0.015% U_3O_8. Table 5-1 gives the results of analyses of a composite sample of the tailings taken in 1977. It contained 0.012% U_3O_8 and also 0.012% V_2O_5. There are no other metals present in significant concentrations.

In the last few years, Union Carbide Corporation has built and operated a heap leach facility on the western side of the open pit mining area, using as feed some low grade overburden material and also some low grade ore from the walls of the old pits. However, they did not attempt to reprocess any of the tailings from the former mill. As the following analysis shows, the low concentrations of uranium and vanadium in the tailings make the possibility very remote that additional metals can be recovered profitably.

No amenability testing has been performed on Maybell tailings to determine the recovery of uranium or vanadium that could be achieved in a reprocessing operation. In the absence of specific testing, the estimate of uranium recovery from retreatment of the tailings is based on the graph provided by the DOE Grand Junction Office, as shown in Figure 5-1. For the purpose of this chapter it is assumed that the uranium content of 0.015% U_3O_8 indicated by AEC records is correct. It is expected that recovery of uranium by a conventional process will be about 38% or 0.11 lb of U_3O_8/ton of tailings. By pelletizing with acid and heap leaching, recovery would be about 30% or 0.09 lb/ton. By normal heap leaching, the recovery would be about 23% or 0.07 lb. At November 1980 prices of $28/lb of U_3O_8, the total income from uranium recovery would be $2 to $3.10/ton processed. Vanadium was not recovered from ores processed at Maybell. The composite tailings sample contains 0.012% V_2O_5. At 40% recovery and a price of $3/lb of V_2O_5, the recoverable vanadium would be worth about $0.30/ton of tailings treated, which is too low to consider recovery.

5.1 PROCESS ALTERNATIVES

There are three principal alternatives for the reprocessing of uranium-bearing tailings:

(a) Heap leaching

(b) Treatment at an existing mill

(c) Reprocessing at a new conventional mill constructed for tailings reprocessing

5.1.1 Heap Leaching

There are two process variations in use for heap leaching. In the first method, which has been used successfully to treat low-grade ore which otherwise would not warrant treatment, a pad is prepared with an impermeable layer at the bottom. A pipe drainage system is laid down and covered with gravel and sand. The tailings are deposited on this base in a layer up to about 20 ft thick. The surface of the tailings is then contoured into shallow basins to contain the leach solution. An acid solution, sometimes with added oxidant, is allowed to flow into the surface basins and to percolate through the bed. The solution collected is treated, usually by ion exchange or solvent extraction, to recover the uranium. When present, vanadium can be recovered in a second solvent extraction circuit. The recovery that can be achieved with this method is dependent upon the porosity and uniformity of the ore on the pad which affects the extent of channeling. Because of these factors, recovery of values is considerably lower (roughly half) than by conventional plant processes, as shown in Figure 5-1. Since there is a heap leach facility very close to the millsite, no new construction would be needed.

In the second procedure the ore, crushed to minus 0.75-in. size, is premixed with a strong sulfuric acid solution and pelletized before being placed for leaching. Water is percolated through the bed, and the recovered solution is processed to recover the solubilized uranium and vanadium. If vanadium is to be recovered, a higher concentration of acid is required than if the tailings are being processed only for uranium. The pelletizing procedure involves increased handling and higher plant cost, but is likely to result in improved recovery of values over the first method described above as a result of better contact of the ore with the acid and improved uniformity of porosity. It is possible that part of the nearby heap leach facility could be used, lowering capital cost.

Careful blending is needed to produce permeable heap leach piles. The feasibility of the pelletizing procedure depends on whether or not the pelletized tailings retain their shape or disintegrate when flooded in the leaching operation. This should be evaluated as part of the amenability testing. Recovery of values in the pelletized heap-leach process is unlikely to exceed two-thirds of that in a conventional plant.

5.1.2 Treating in an Existing Plant

For reprocessing in an existing conventional plant to be economically feasible, a mill with significant excess capacity must be located reasonably close to the present tailings site. The mill must also have a tailings disposal site with sufficient capacity to handle the additional tailings and to allow for adequate long-term stabilization. In addition to the 2.6 million tons of tailings, there is a vast quantity of contaminated waste at the Maybell site, mainly overburden from previous mining operations adjacent to the mill as well as the open pits themselves.

The site has fair access. Trucks could remove material from the site at a rate of about 2,000 tons/day. At this rate, all tailings materials could be removed from the site in about 4 yr. However, the nearest operating mills are about 230 mi away at Jeffrey City, Wyoming, and 260 mi away at Uravan, Colorado. The transportation costs would be prohibitive.

5.1.3 Treating in a New Plant

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

The Maybell tailings would feed a 1,000 ton/day plant for about 8 yr. Normally, amortization of a plant is based on planned operation for 10 to 20 yr. The Department of Energy studies indicate a low probability for significant intermediate grade resources in the adjacent area. This indicates that the prospects of development of significant new reserves to augment the ore supply to such a mill are not very good.(2)

5.2 MAYBELL 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 Market for Uranium

The demand and price for uranium from 1976 to 1980 have gone through a rapid rise and fall cycle. Spot prices for uranium as indicated by the exchange values reported by NUEXCO(3) rose from \$30/lb of U_3O_8 in November 1975 to \$43/lb in November 1977 and essentially held constant until the end of 1979. The price dropped precipitously to \$28.50/lb of U_3O_8 by September 1980 and to \$25/lb early in 1981. Prices in individual long-term uranium sales contracts have varied over a broad range.

A variety of factors has contributed to this pattern, including the Three Mile Island accident and the subsequent delays in nuclear plant licensing, rapidly escalating power plant costs, and the inflexibility of uranium production operations. Total uranium inventories held by U.S. companies as of January 1, 1979 were 44,700 tons equivalent U_3O_8, representing nearly 3 times the current annual consumption rate. Projected domestic uranium supply exceeds apparent buyer requirements each year through 1985.(4) Under these circumstances, no basis is evident for a turnaround in uranium prices for about 5 yr.(3) The supply and market for uranium as estimated by the DOE Assistant Secretary for Resource Applications are given in Table 5-2.

5.2.2 Escalation of Plant Construction Costs

The estimated construction costs of both heap-leach plants and conventional mills without crushing and grinding facilities, as provided by the DOE Grand Junction, Colorado Office, were included as figures in the Phase II - Title I Engineering Assessment report.(1) The costs were adjusted to January 1977. Since then, relatively few plants have been built, and reported costs have been strongly influenced by new tailings control and stabilization requirements under NRC licenses. Recent estimates by R.B. Coleman of construction costs for conventional plants have been in the range of $13,000 to $30,000/ton of daily plant capacity.(5) In view of the many significant site-specific problems that can influence capital costs, for this report it was decided to apply suitable escalation factors to the 1977 Grand Junction Office estimates, which are based on construction costs of many plants.

The Engineering News Record(6) publishes reports quarterly on various construction cost indexes. The following data are derived from this source:

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

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

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

From the above indexes, an increase in plant construction cost of 25% from January 1977 to mid-1980 has been applied as a conservative estimate. As indicated in Figure 5-2, the capital cost of a 1,000 ton/day heap leach facility would be about $7.8 million. As indicated in Figure 5-3, the cost for a conventional mill of similar capacity would be about $9.8 million. If these capital costs were to be amortized on the Maybell tailings only, the unit costs would be $3 to $3.80/ton, or from $33.30 to $34.50/lb of U_3O_8 recovered. However, if the existing heap leach facility can be used, capital cost would be minimal.

5.2.3 Escalation of Plant Operating Costs

The operating costs of uranium mills appear to have risen much more steeply than construction costs. In the October 1977 engineering assessment report, the direct operating costs of a 1,000 ton/day facility were estimated at $3.30 and $5.60/ton for heap leach and conventional acid leach mills, respectively. However, R.B. Coleman(5) reports that 1980 operating costs of conventional mills are in the range of $8.70 to $18.40/ton.

Ranchers Exploration and Development Corporation reported their operating costs for heap leaching at Naturita, approximately a 1,200 ton/day facility, at about $34/lb of U_3O_8 recovered, equivalent to $20.50/ton of tailings processed. Costs of vanadium recovery were reported separately. In Figure 5-4, Grand Junction Office DOE 1977 estimates for heap leach plant operating costs are compared with Ranchers' 1978-1979 experience at Naturita. In Figure 5-5, conventional acid leach plant operating costs are compared with 1980 data reported by Coleman. The data indicate that conventional milling costs have risen by 250%, and the cost of heap leaching is higher by a factor of 400 to 500%. However, the slope of the 1977 heap leach line is not confirmed by later information. Consequently, the dotted line in Figure 5-4 is considered more representative, and has been used as a basis of estimates.

Considering the differences in plant designs, it is estimated that average mill operating costs have increased by a factor of 2.5 from the January 1977 data to mid-1980.

This would result in operating costs for Maybell tailings in a 1,000 ton/day conventional mill of about $14.25/ton, or $130/lb of U_3O_8 recovered (assuming 0.11 lb recovered/ton). For a heap leach plant of the same size, the corresponding figures would be $11.25/ton and $125/lb recovered. In view of these operating costs, which far exceed the market price, no detailed analysis of optimum plant size is warranted.

5.2.4 Competitive Market Factors

The average grade ore processed in conventional mills has decreased from 0.15% U_3O_8 in 1977 to 0.11% in 1979. The average recovery rate for the industry has been 91 ± 1% during this period.(7) However, since tailings have been processed previously, the recoveries in reprocessing are likely to be much lower, as reflected in Figure 5-1. To produce a given quantity of uranium, about 7 times as much Maybell tailings material would have to be processed as would when a mill is operating on ore of the average grade treated in 1979. Thus, the volume of tailings to be stabilized is also 7 times as great. The fact that there are no mining costs is a substantial off-setting advantage. However, it is not sufficient to compensate for the low grade of the Maybell tailings.

5.3 CONCLUSION

Based on the foregoing analysis, it is concluded that the processing of Maybell tailings for the recovery of additional uranium and vanadium in connection with the tailings stabilization operations either by heap leach or conventional plant processes is not practicable, nor is it likely to be practicable under any foreseeable conditions. Even if all of the uranium could be recovered, the cost of the uranium produced, exclusive of any transportation cost, would still exceed the current market price. For processing this material, assuming a plant of about 1,000 tons/day capacity, the cost of the uranium recovered would be about $125 to about $165/lb of U_3O_8, depending on the process used. A comparison of costs by process method is given below.

	Conventional Plant		New Plant Heap Leach		Existing Plant Heap Leach	
	$/ton	$/lb U_3O_8	$/ton	$/lb U_3O_8	$/ton	$/lb U_3O_8
Capital Cost	3.80	34.50	3.00	33.30	0.00	0.00
Operating Cost	14.25	130.00	11.25	125.00	11.25	125.00
Total	18.05	164.50	14.25	158.30	11.25	125.00

The grade of the Maybell tailings is so low that reprocessing is not feasible. Vanadium recovery is also unattractive and will not improve the economics of reprocessing.

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

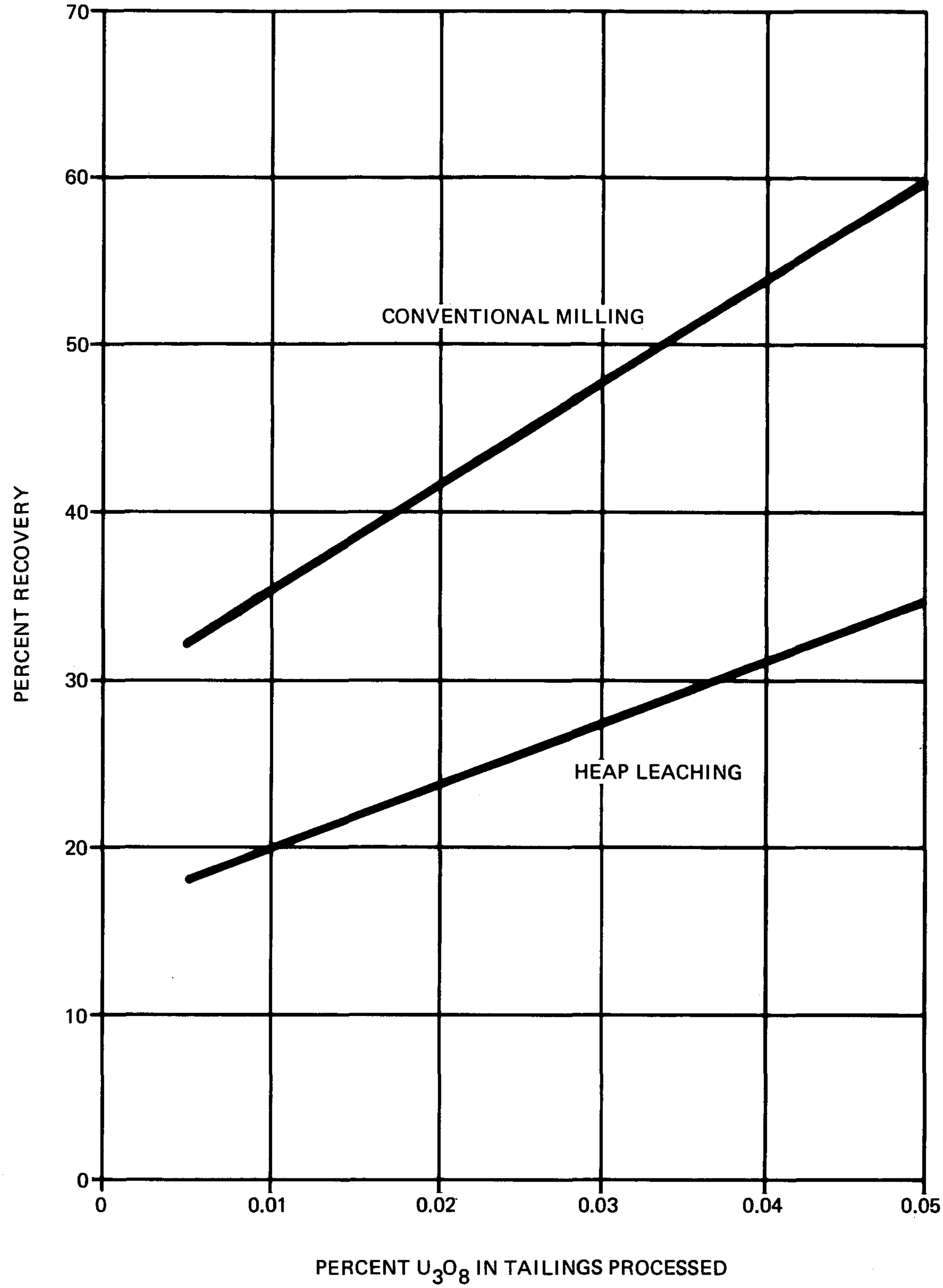


FIGURE 5-1. URANIUM RECOVERY FROM MILL TAILINGS AS A FUNCTION OF U_3O_8 CONTENT IN TAILINGS

360-11 2/81

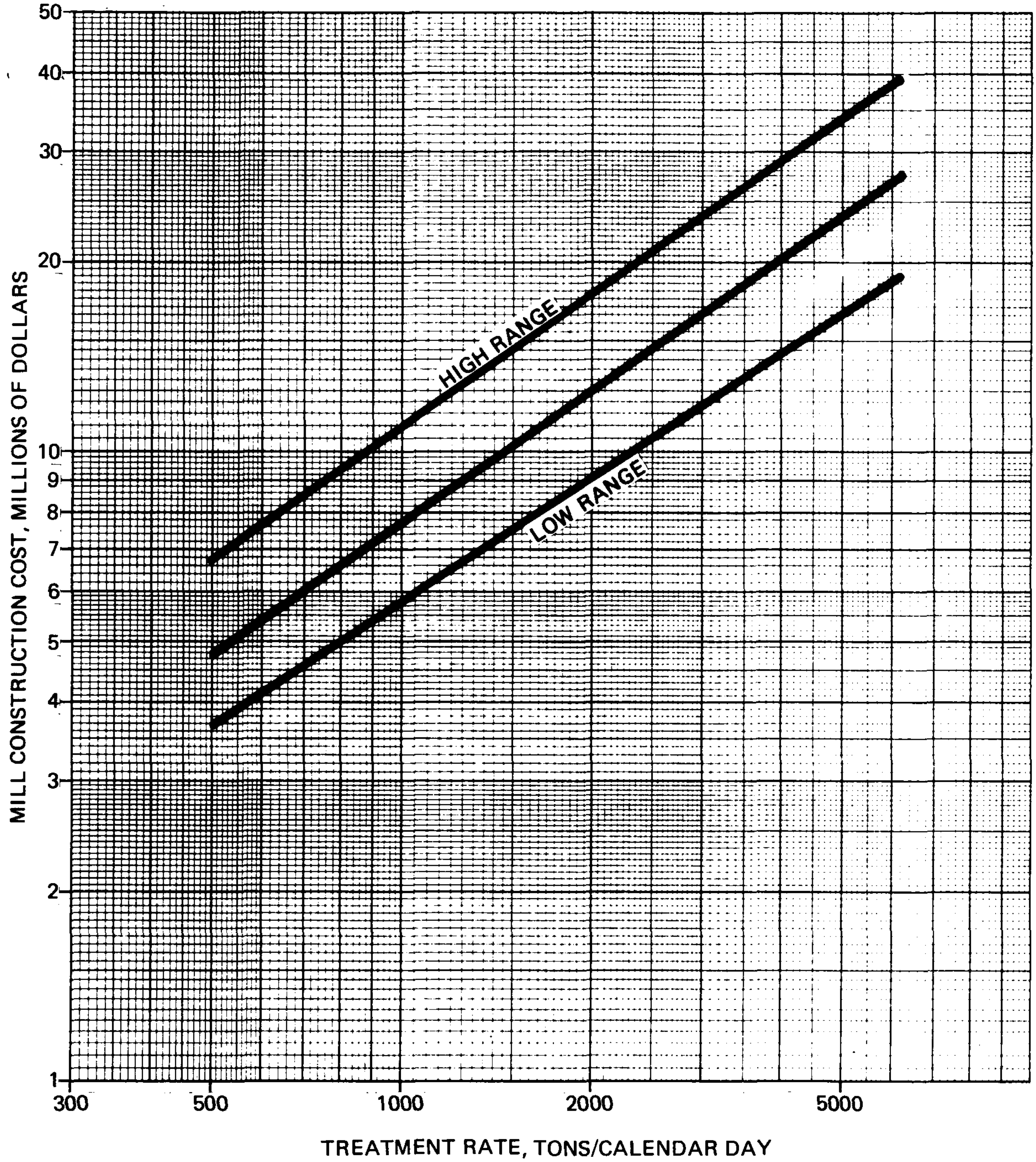


FIGURE 5-2. CONSTRUCTION COSTS OF HEAP LEACHING PLANT TO REPROCESS URANIUM MILL TAILINGS (COST ADJUSTED TO JULY 1980)

360-11 2/81

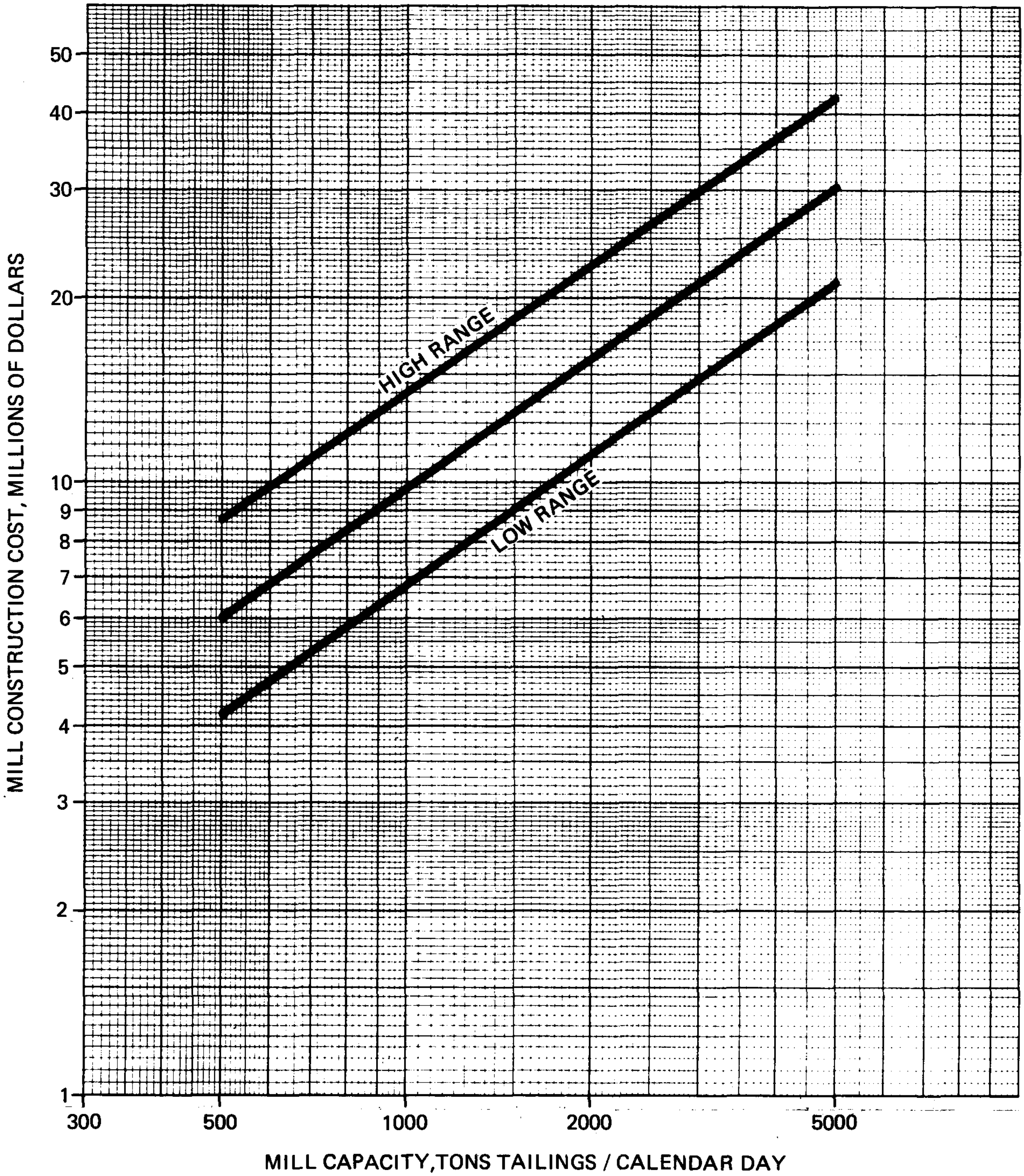


FIGURE 5-3. CONSTRUCTION COSTS OF A CONVENTIONAL URANIUM MILL TO REPROCESS TAILINGS W/O CRUSHING AND GRINDING FACILITIES OR TAILINGS STABILIZATION COSTS (COST ADJUSTED TO JULY 1980)

360-11 2/81

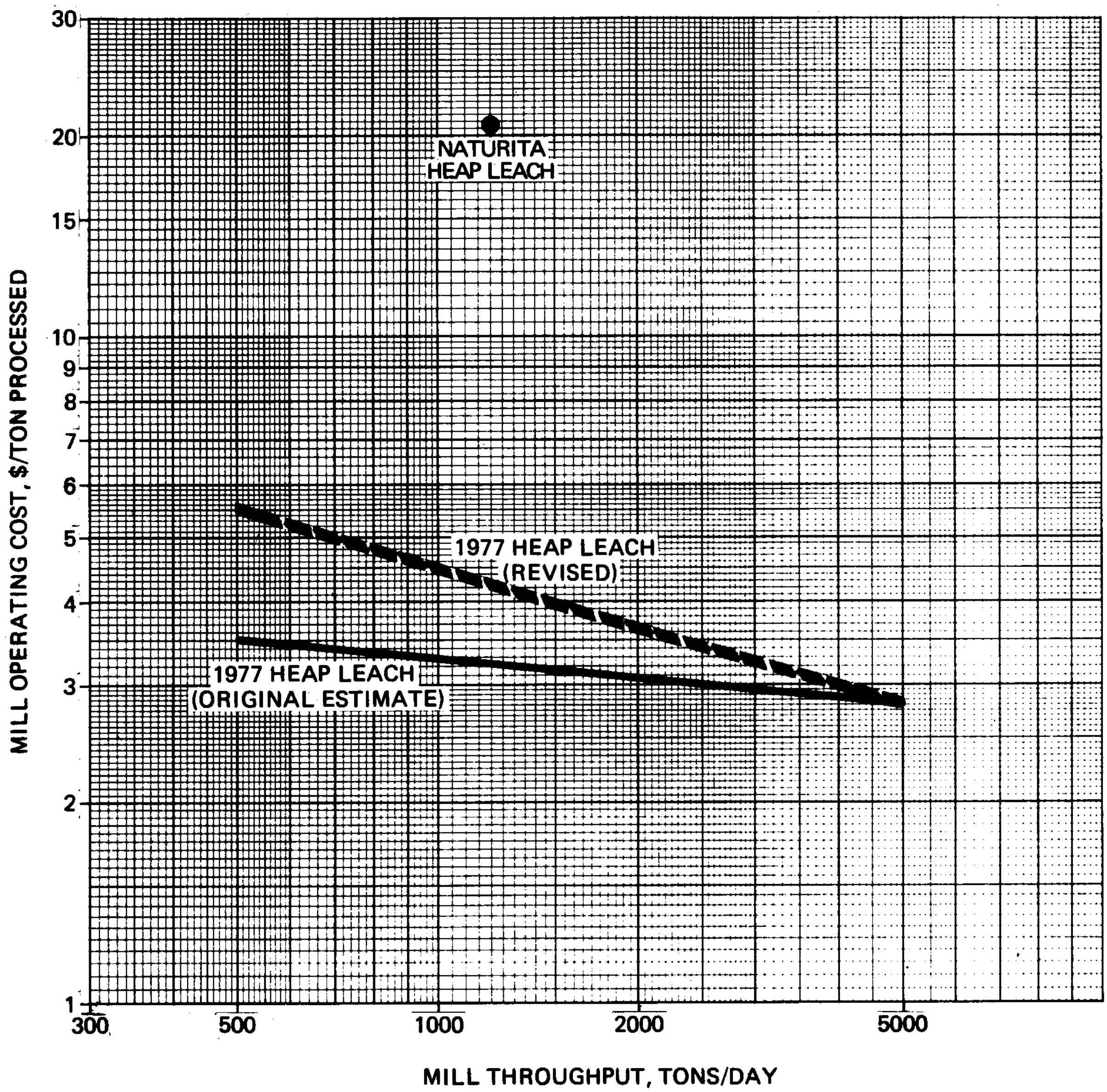


FIGURE 5-4. OPERATING COSTS OF HEAP LEACHING OF URANIUM MILL TAILINGS

360-11 2/81

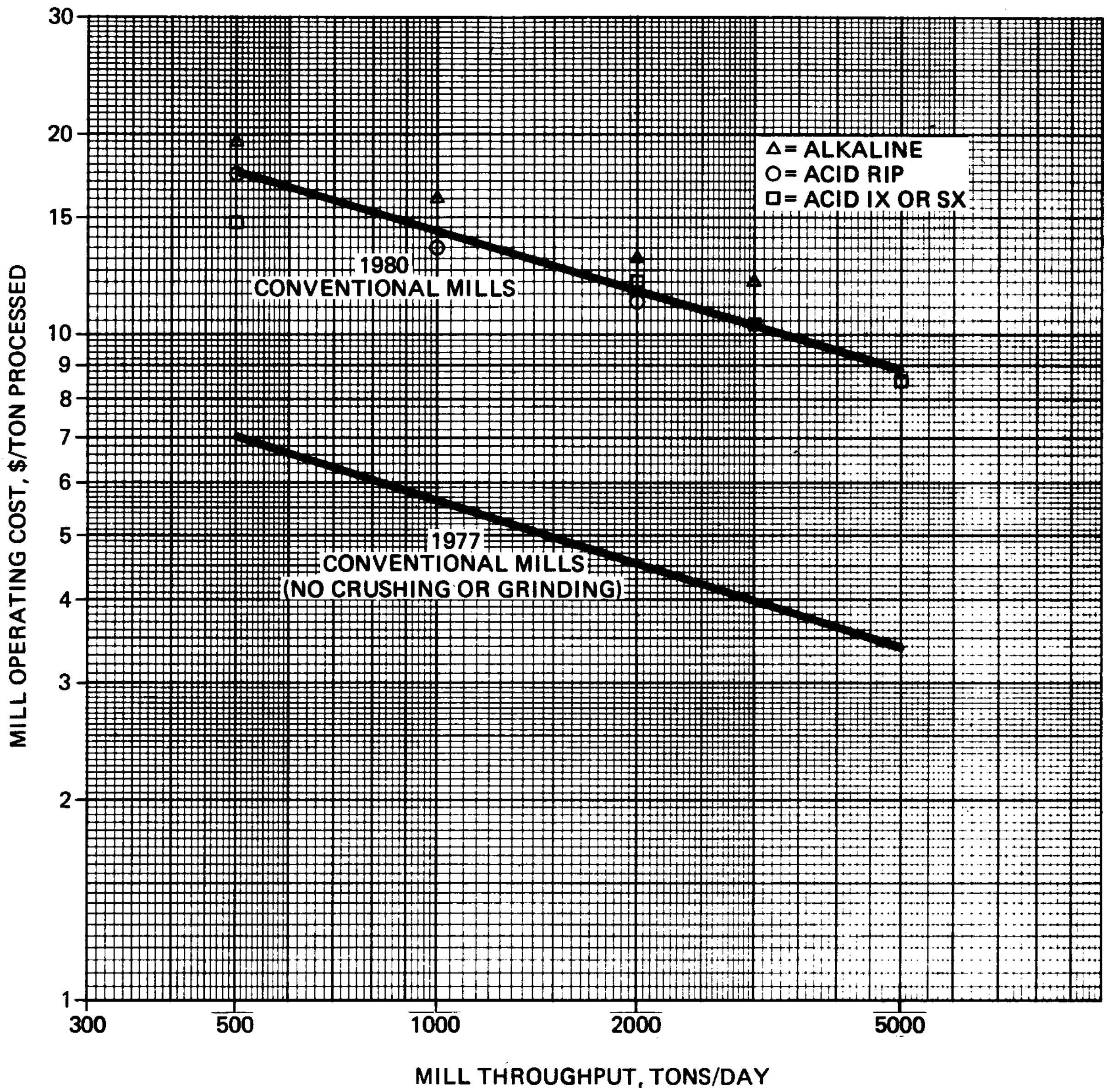


FIGURE 5-5. OPERATING COSTS OF CONVENTIONAL MILLING W/O CRUSHING AND GRINDING FACILITIES TO REPROCESS TAILINGS (COST ADJUSTED TO JULY 1980)

360-11 2/81

TABLE 5-1

ASSAY RESULTS OF MAYBELL TAILINGS AND BACKGROUND SAMPLES

	Percentage by Weight				
Element	Atomic Absorption	Spectrographic	Chemical	AEC* Estimate	Background Composite
Aluminum	--	1.0-0.01	--	--	--
Arsenic	0.00015	--	--	--	0.000022
Barium	0.00175	--	--	--	--
Boron	--	<0.01	--	--	--
Cadmium	0.0000092	--	--	--	--
Calcium	--	1.0-0.01	--	--	--
Chromium	0.00093	--	--	--	--
Cobalt	0.00019	--	--	--	--
Copper	0.00031	--	--	--	--
Cyanide	<0.000001	--	--	--	--
Gallium	--	<0.01	--	--	--
Iron	0.21	--	--	--	--
Lead	0.0013	--	--	--	--
Magnesium	--	1.0-0.01	--	--	--
Manganese	--	1.0-0.01	--	--	--
Mercury	0.0000093	--	--	--	--
Molybdenum	--	<0.01	--	--	--
Nickel	--	--	--	--	--
Potassium	--	1.0-0.01	--	--	--
Selenium	0.00126	--	--	--	<0.0000001
Silicon	--	>1.0	--	--	--
Silver	0.0000148	--	--	--	--
Sodium	--	1.0-0.01	--	--	--
Titanium	--	<0.01	--	--	--
Uranium (U_3O_8)	--	--	0.012	0.015	<0.0000001
Vanadium (V_2O_5)	--	--	0.012	--	0.00023
Zinc	0.0017	--	--	--	--

*Calculated tailings assay based on plant operation(1)

TABLE 5-2

U.S. URANIUM SUPPLY AND MARKET SUMMARY

Year	(1) Sales Commitments To Domestic Buyers	(2) Sales Commitments To Foreign Buyers	(3) Est. U_3O_8 To Be Available For Sale	(4) Procurement of Foreign Uranium	(5) Reported Unfilled Requirement	(6) Total Domestic Production Potential (1+2+3)	(7) Total Domestic Supply (1+3+4)	(8) Apparent Buyer Requirements (1+4+5)
1980	21,500	2,000	2,600	1,800	400	26,100	25,900	23,700
1981	20,000	1,000	3,100	2,700	800	24,100	25,800	23,500
1982	19,400	1,000	4,300	2,800	1,300	24,700	26,500	23,500
1983	17,400	900	7,100	2,500	1,800	25,400	27,000	21,700
1984	16,000	500	7,800	2,500	4,000	24,300	26,300	22,500
1985	13,900	500	8,800	2,400	4,300	23,200	25,100	20,600
1986	11,200	300		1,000	9,900			22,100
1987	11,400	300		1,000	11,700			24,100
1988	10,500	300		1,000	12,000			23,500
1989	9,500	100		1,000	15,100			25,600
1990	7,300	100		1,000	14,400			22,700

Source: DOE/RA-0053
Survey of United States Uranium Marketing Activity, July 1980 (p. 17)

CHAPTER 5 REFERENCES

1. "Phase II - Title I Engineering Assessment of Inactive Uranium Mill Tailings, Maybell Site, Maybell, Colorado"; GJT-11; Ford, Bacon & Davis Utah Inc.; Oct 1977.

2. An Assessment Report on Uranium in the United States; GJO-111; p. 115; 1980.

3. NUEXCO No. 144, p. 27; published by Nuclear Exchange Corporation, 3000 Sand Hill Road, Menlo Park, California 94025; Aug 1980.

4. Survey of United States Uranium Marketing Activity; DOE/RA-0053; U.S. Department of Energy; July 1980.

5. Uranium Milling Costs by R.B. Coleman, Hazen Research, Inc.; presented at Colorado School of Mines Seminar; Mar 12, 1980.

6. Engineering News Record; Vol 204, No. 25; pp. 75 and 79; June 19, 1980.

7. Statistical Data of the Uranium Industry; GJO-100; pp. 93 and 94; 1980.

CHAPTER 6

MILL TAILINGS STABILIZATION

CHAPTER 6

MILL TAILINGS STABILIZATION

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

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

(a) Wind and water erosion

(b) Leaching of radioactive materials and other chemicals

(c) Radon exhalation from the tailings

(d) Gamma radiation emitted from the tailings

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

6.1 PREVENTION OF WIND AND WATER EROSION

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

6.1.1 Surface Stabilization

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

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

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

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

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

"Cut-back" asphalt and asphalt-in-water emulsions also have been tested for use in protecting soils against wind and water erosion.(7) Both were shown to be effective for short periods of time when applied as a fine spray on sandy soils. On clay soils, the film disintegrated within a few weeks of application, apparently because of expansion and contraction of the clays during cycles of wetting and drying. The film was porous, allowed infiltration of water, and did not interfere with germination of wheat, grass, or legume seeds. The film is damaged by insects and rodents, and respraying may be necessary. Three to five years after application of the asphalt treatment, the amount of dry erodible surface area in the tested soils had increased, suggesting that asphalt treatments may not be desirable under all conditions.

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

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

6.1.2 Volumetric Stabilization

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

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

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

6.1.3 Physical Stabilization

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

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

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

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

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

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

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

6.1.4 Vegetative Stabilization

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

Criteria for plant selection provide that the plants will:[11]

(a) Be tolerant of local environmental conditions.

(b) Have properties that will aid in erosion control.

(c) Have propagules that are readily available.

(d) Be relatively easy to establish.

(e) Be perennials, or annuals with good reproductive capabilities.

(f) Have minimal rooting depth requirements.

(g) Be of low food value and/or palatability.

(h) Have low value as habitat for wildlife.

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

(a) Evapotranspiration is not excessive.

(b) Landscapes are properly shaped.

(c) Nontoxic soil media capable of holding moisture are provided.

(d) Irrigation and fertilization appropriate to the area are applied to initiate growth.

Growth of vegetation at sites receiving less than 10 in. of annual precipitation and with high evapotranspiration rates requires initial irrigation and fertilization. At Maybell, precipitation averages about 14 in. annually.

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

6.2 PREVENTION OF LEACHING

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

(a) Employ surface, volumetric, or physical stabilization to minimize infiltration of water, which would prevent leaching of hazardous elements into underground aquifers.

(b) Physically compact the tailings to reduce the percolation of water through the materials.

(c) Contour the drainage area and tailings surface to minimize the potential for water to penetrate into the tailings.

(d) For a new site, line the disposal area with a low-permeability membrane.

(e) Condition tailings to reduce leachability or contaminant content.

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

(a) Natural soil amended with sodium-saturated montmorillonite (Volclay*)

(b) Typical local clay with an asphalt emulsion radon-suppression cover

*Registered trademark.

(c) Typical local clay with a multibarrier radon-suppression cover

(d) Rubberized asphalt membrane

(e) Hydraulic asphalt concrete

(f) Chlorosulfonated polyethylene (Hypalon*) or high-density polyethylene

(g) Bentonite, sand and gravel mixture

(h) Catalytic airblown asphalt membrane

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

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

6.3 REDUCTION OF RADON EXHALATION

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

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

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

---

*Registered trademark.

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

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

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

6.4 REDUCTION OF GAMMA RADIATION

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

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

6.5 ASSESSMENT OF APPLICABILITY

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

If remedial actions are taken, combinations of the methods described in this chapter for preventing erosion, leaching to ground water, radon exhalation, and gamma radiation will be implemented based on climatic, hydrogeological, economic, and demographic factors. The method of stabilizing uranium mill tailings whereby 3 m of well-engineered cover is placed on the pile is apparently the primary method currently available that satisfies both U.S.[1] and Canadian[22] regulatory requirements.

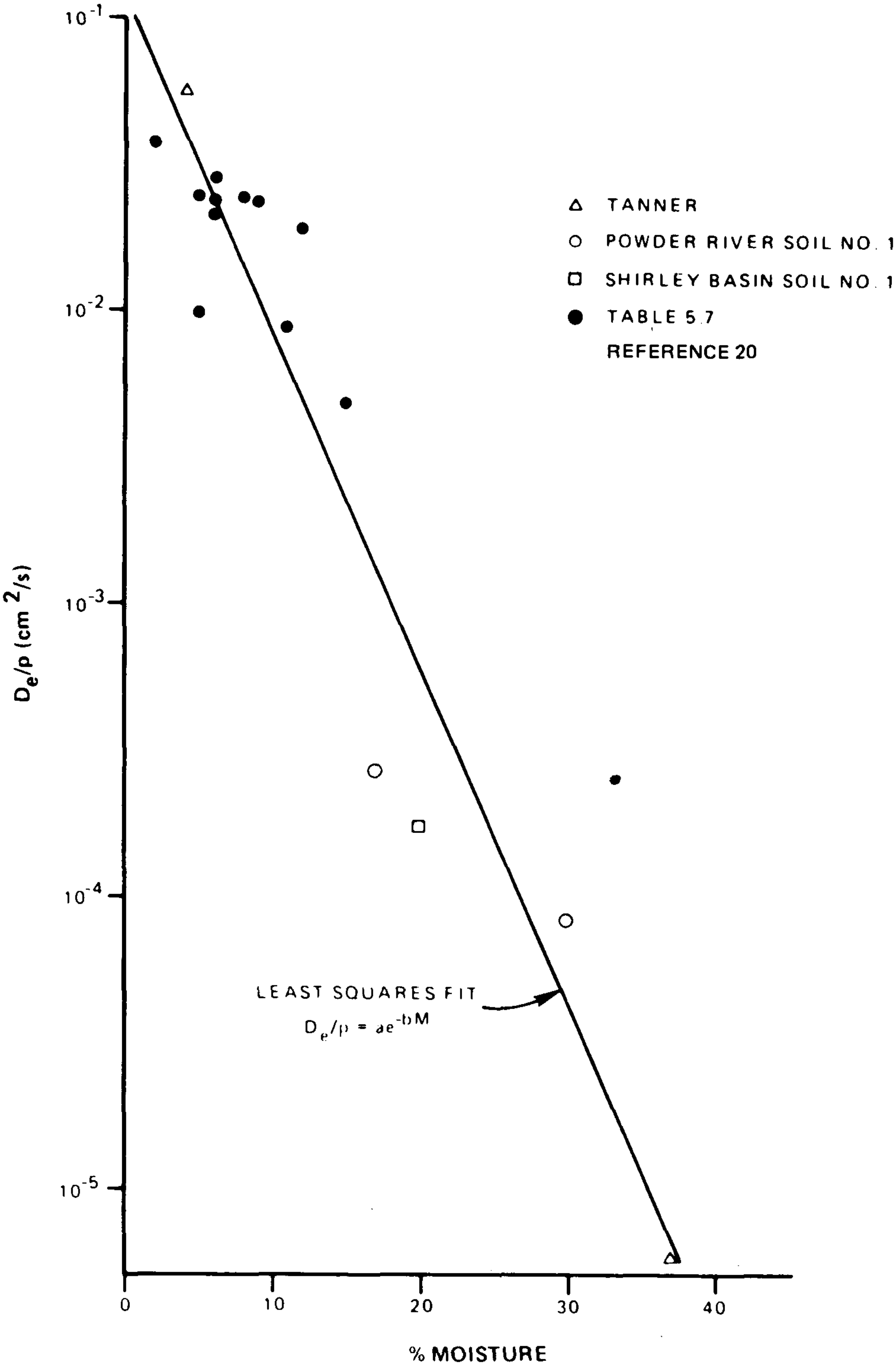


FIGURE 6-1. EXPONENTIAL MOISTURE DEPENDENCE OF THE DIFFUSION COEFFICIENT

360-11 6/81

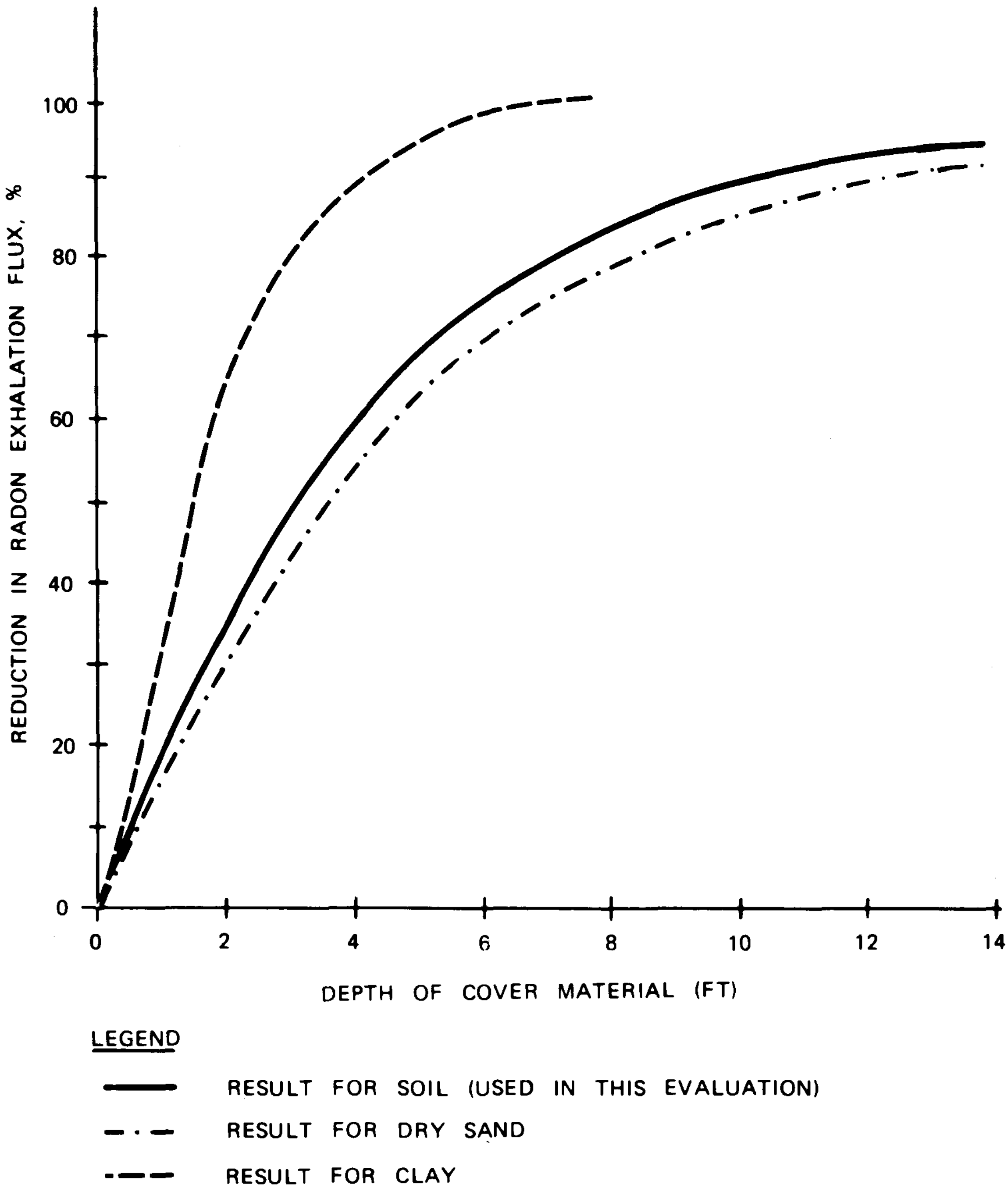


FIGURE 6-2. REDUCTION OF RADON EXHALATION FLUX WITH DEPTH OF COVER

360-11 2/81

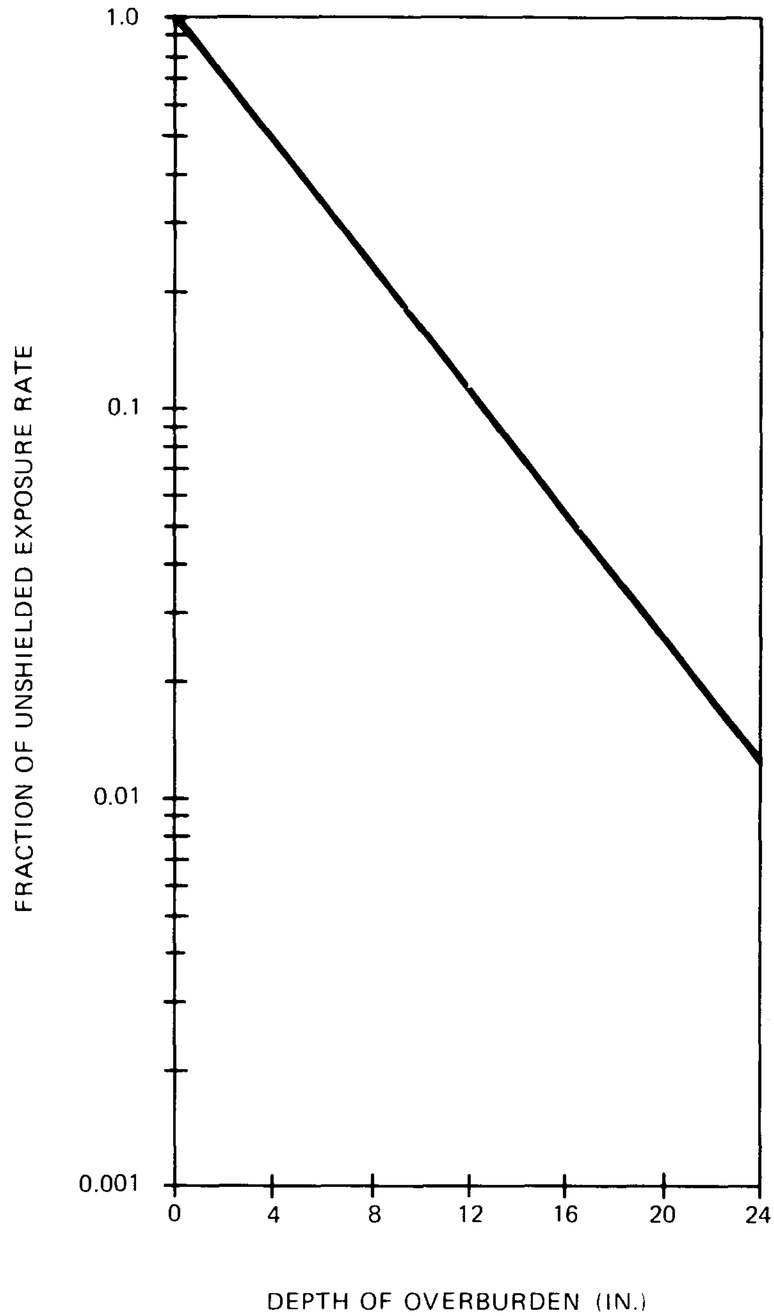


FIGURE 6-3. REDUCTION OF GAMMA EXPOSURE RATE RESULTING FROM PACKED EARTH SHIELDING

360-11 2/81

CHAPTER 6 REFERENCES

1. "Proposed Disposal Standards for Inactive Uranium Processing Sites, Invitation for Comment"; U.S. Environmental Protection Agency; Federal Register; Vol 46, No. 6; p. 2556; Jan 9, 1981.

2. "Methods and Costs for Stabilizing Fine Sized Mineral Wastes"; Bureau of Mines Report of Investigation; RI7896; 1974.

3. P.L. Koehmstedt, J.N. Hartley, and D.K. Davis; "Use of Asphalt Emulsion Sealants to Contain Radon and Radium in Uranium Tailings"; BNWL-2190; Battelle Pacific Northwest Laboratories; Richland, Washington; Jan 1978.

4. D.R. Dreesen and J.M. Williams; "Monthly Report, November 1980"; Los Alamos Scientific Laboratory, Environmental Science Group.

5. R. Havens and K.C. Dean; "Chemical Stabilization of the Uranium Tailings at Tuba City, Arizona"; U.S. Department of the Interior, Bureau of Mines; 1969.

6. K.C. Dean, et al.; "Progress in Using and Stabilizing Mineral Wastes"; Salt Lake Metallurgical Research Center; 1970.

7. W.S. Chepil; "Effects of Asphalt on Some Phases of Soil Structure and Erodibility by Wind"; Soil Science Society of America Proceedings 19:125-128; 1955.

8. P.J. Macbeth, et al.; "Laboratory Research on Tailings Stabilization Methods and Their Effectiveness in Radiation Containment"; GJT-21; Ford, Bacon & Davis Utah Inc.; Salt Lake City, Utah; Apr 1978.

9. B.J. Thamer, et al.; "Radon Diffusion and Cover Material Effectiveness for Uranium Tailings Stabilization"; FBDU-258; Ford, Bacon & Davis Utah Inc; Salt Lake City, Utah; May 1980.

10. J.N. Hartley, P.L. Koehmstedt, and D.J. Esterl; "Asphalt Emulsion Sealing of Uranium Mill Tailings"; Battelle Pacific Northwest Laboratories; Richland, Washington; 1979.

11. T.D. Chikalla, Compiler; "Quarterly Uranium Tailings Report, October through December 1980"; Pacific Northwest Laboratory; Feb 1981.

12. J.N. Hartley, et al.; "Uranium Mill Tailings Stabilization"; Feb 1980; presented at Waste Management 80; Tucson, Arizona; Mar 10-14, 1980.

13. W.S. Chepil, N.P. Woodruff, F.H. Siddoway, D.W. Fryrear, and D.V. Armburst; "Vegetative and Nonvegetative Materials to Control Wind and Water Erosion"; Soil Science Society of America Proceedings 27:86-89; 1963.

14. J.D. Nelson and T.A. Shepherd; "Evaluation of Long-Term Stability of Uranium Tailing Disposal Alternatives"; Civil Engineering Department, Colorado State University, Fort Collins, Colorado; prepared for Argonne National Laboratory; Apr 1978.

15. D.R. Dreesen, M.L. Marple, and N.E. Kelley; "Containment, Transport, Revegetation, and Trace Element Studies at Inactive Uranium Mill Tailings Piles"; Proceedings of Symposium on Uranium Mill Tailings Management, Colorado State University, Fort Collins, Colorado; Nov 20-21, 1978.

16. G.W. Gee, et al.; "Interaction of Uranium Mill Tailings Leachate with Soils and Clay Liners"; NUREG/CR-1494; Battelle Pacific Northwest Laboratories, Richland, Washington; May 1980.

17. P.J. Macbeth, et al.; "Research on Radon Gas Diffusion and Attenuation from Uranium Mill Tailings"; Paper Presented at International Conference on Uranium Mine and Mill Tailings Disposal; Vancouver, B.C., Canada; May 19-21, 1980.

18. 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.

19. H.W. Kraner, G.L. Schroeder, and R.D. Evans; "Measurements of the Effects of Atmospheric Variables on Radon-222 Flux and Soil-Gas Concentrations"; The Natural Radiation Environment; J.A.S. Adams and W.M. Lowder, eds; University of Chicago Press; 1964.

20. V.C. Rogers, et al.; "Characterization of Uranium Tailings Cover Materials for Radon Flux Reduction"; NUREG/CR-1081 and FBDU-218-2; Jan 1980.

21. K.J. Schiager; "Analysis of Radiation Exposures On or Near Uranium Mill Tailings Piles"; Radiation Data and Reports; Vol 15; July 1974.

22. K.E. Hanney, et al.; "Reclamation Concepts and Practice for Uranium Tailings Impoundments"; Paper Presented at International Conference on Uranium Mill Tailings Disposal; Vancouver, B.C., Canada; May 19-21, 1980.

CHAPTER 7

OFF-SITE REMEDIAL ACTION

CHAPTER 7

OFF-SITE REMEDIAL ACTION

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

Discussed in this chapter are those locations where tailings have been transported off site. Such off-site locations are classified as off-site windblown properties and off-site properties other than windblown. Costs associated with the cleanup of on-site contaminated areas, i.e., windblown, tailings pile, millsite, and ore storage, are considered in Chapter 9.

7.1 DATA SOURCES

A mobile scanning unit operated by the AEC performed a gamma radiation survey of the Craig, Colorado, area in 1973. Of the 1,280 structures scanned, 86 anomalies were discovered. A joint team from the EPA Office of Radiation Programs, Las Vegas, Nevada, (EPA-ORP-LV) and the Colorado Department of Health performed individual gamma surveys of locations to determine the source of the anomalies and, if tailings, how they had been used.(1) High and low inside and outside gamma readings were recorded. A gamma map was drawn of areas where gamma readings inside the structures exceeded 20 μR/hr.

The estimated 5-pCi/g boundary mentioned in Paragraph 3.4.3 was the data source used for consideration of remedial action for off-site windblown areas.

7.2 REMEDIAL ACTION FOR OFF-SITE PROPERTIES OTHER THAN WINDBLOWN

A follow-up survey of the anomalies(1) indicated three locations where tailings had been used. Of the tailings use locations, one had tailings used or otherwise deposited in areas under and/or within 10 ft of a habitable structure, and two were classed as possible tailings use locations that require further investigation. Of the remaining anomalies, seven were caused by the presence of radioactive material in instruments or in ore, 46 resulted from natural radioactive materials, 25 could not be verified as anomalies above background, and five were the result of roof eave drip, presumably from fallout from the Chinese weapons tests.

Costs for remedial action at off-site properties other than windblown have been estimated to be $81,000, exclusive of engineering and contingency allowances. This cost is based upon available information and adjusted Grand Junction off-site remedial action costs and includes cleanup, backfill, restoration, and health physics and monitoring services. The estimated cost includes remedial action for the three locations where tailings use has been identified.

7.3 REMEDIAL ACTION FOR OFF-SITE WINDBLOWN PROPERTIES

At Maybell, Colorado, contamination from overburden piles and from low-grade ore stockpiles is so far-reaching that it is difficult to determine the extent of contamination attributable to windblown tailings; however, an attempt has been made to define this boundary, as explained in Paragraph 3.4.3.

The estimated extent of windblown tailings is indicated by the 5-pCi/g line in Figure 3-13. Decontamination of the area containing windblown tailings consists of removing 6 in. of soil and replacing it with clean fill. The result of this action is assumed to satisfy the remedial action criteria discussed in Paragraph 3.5. It is possible, however, that backfilling excavated windblown areas may be unnecessary, in which case vegetation would be established without backfill.

The cost for cleanup and restoration of approximately 50 acres of off-site land contaminated by windblown tailings was estimated to be $660,000, exclusive of engineering and contingency allowances.

CHAPTER 7 REFERENCES

1. "Summary Report of the Radiation Surveys Performed in the State of Colorado at Craig, Colorado"; EPA, Office of Radiation Programs; Las Vegas, Nevada; Mar 1973.

CHAPTER 8

DISPOSAL SITE SELECTION

CHAPTER 8

DISPOSAL SITE SELECTION

One remedial action option considered in this engineering assessment would involve moving the Maybell tailings to a disposal site within 2 mi of the tailings site. With the presently proposed regulations requiring at least 3 m of cover for the disposal of tailings, potential sources of these large amounts of cover material have been located for each of the presently viable disposal sites. The relative locations of actual sources of cover material to the various disposal sites will impact the costs.

8.1 CRITERIA FOR DISPOSAL

In 1980 a report consisting of input from the Colorado Department of Health, the Colorado Geological Survey, and the State Attorney General's Office, which addressed the generation and disposal of hazardous waste within the State of Colorado, was issued(1) to the Colorado State Legislature. According to the report, uranium mill tailings might be considered hazardous waste. The recommendations of the report stated that the evaluation of potential tailings disposal sites should include the collection of extensive hydrologic, geologic, and physiographic data on the particular site and that the following criteria should be followed in the selection process:

(a) Contaminants should not degrade ground or surface water quality.

(b) The disposal site should be at least 1 mi from the probable maximum flood plain.

(c) The disposal site should be located in suitable geologic strata.

(d) Excavations should be developed completely within the bedrock units and sealed with an engineered impermeable cap.

(e) The disposal site should be in seismically and structurally sound areas.

(f) Geochemical reactions between the host rock and the waste should be considered.

The criteria identified are generally consistent with those described in Paragraph 3.5. Although the disposal sites suggested in this report were not identified as a specific response to these criteria, they are believed to generally satisfy the intent of the criteria.

Figure 8-1 shows the relative locations of the open pit mines in the area that might be considered as disposal sites. These pits were evaluated to a limited extent on the basis of hydrology, meteorology, geology, ecology, and economics. Preliminary economic estimates were made of support facilities such as highways, the distance from the tailings site, and the extent of site preparation and long-term maintenance required at the site.

8.2 DESCRIPTION OF THE DISPOSAL SITE CONSIDERED AS AN OPTION

Several open pit mines located within a 2-mi radius of the present tailings location (as shown in Figure 8-1) would serve as good disposal sites for the tailings. Some of these mines are being worked by Union Carbide Corporation. For the purpose of estimating costs, a pit located 2 mi from the site was chosen as a disposal site.

The use of this pit as a disposal site would provide for below-grade disposal of the tailings at a location remote from any population centers. The pit is accessible from gravel-based roads that are adequate for hauling the heavy loads of tailings. A more detailed study of the ground water hydrology and the permeability of the soils in the vicinity would be necessary to determine whether the placement of a clay or synthetic liner along the bottom and sides of the pit would be required to meet disposal criteria.

Overburden from the open pit mines is stockpiled throughout the area and could presumably serve as cover material for the tailings. In lieu of the overburden piles, a source of clay located approximately 4 mi southeast of the site, along Lay Creek, would provide a low-permeability cover that would be excellent for the reduction of radon exhalation from the tailings.

Alluvial terrace deposits along the Yampa River could provide gravel for the riprap cap that protects the stabilized tailings from water and wind erosion. The gravel would have to be hauled about 5 mi.

The costs for the remedial action presented above are discussed in Chapter 9 and are presented under Option II in Table 9-1.

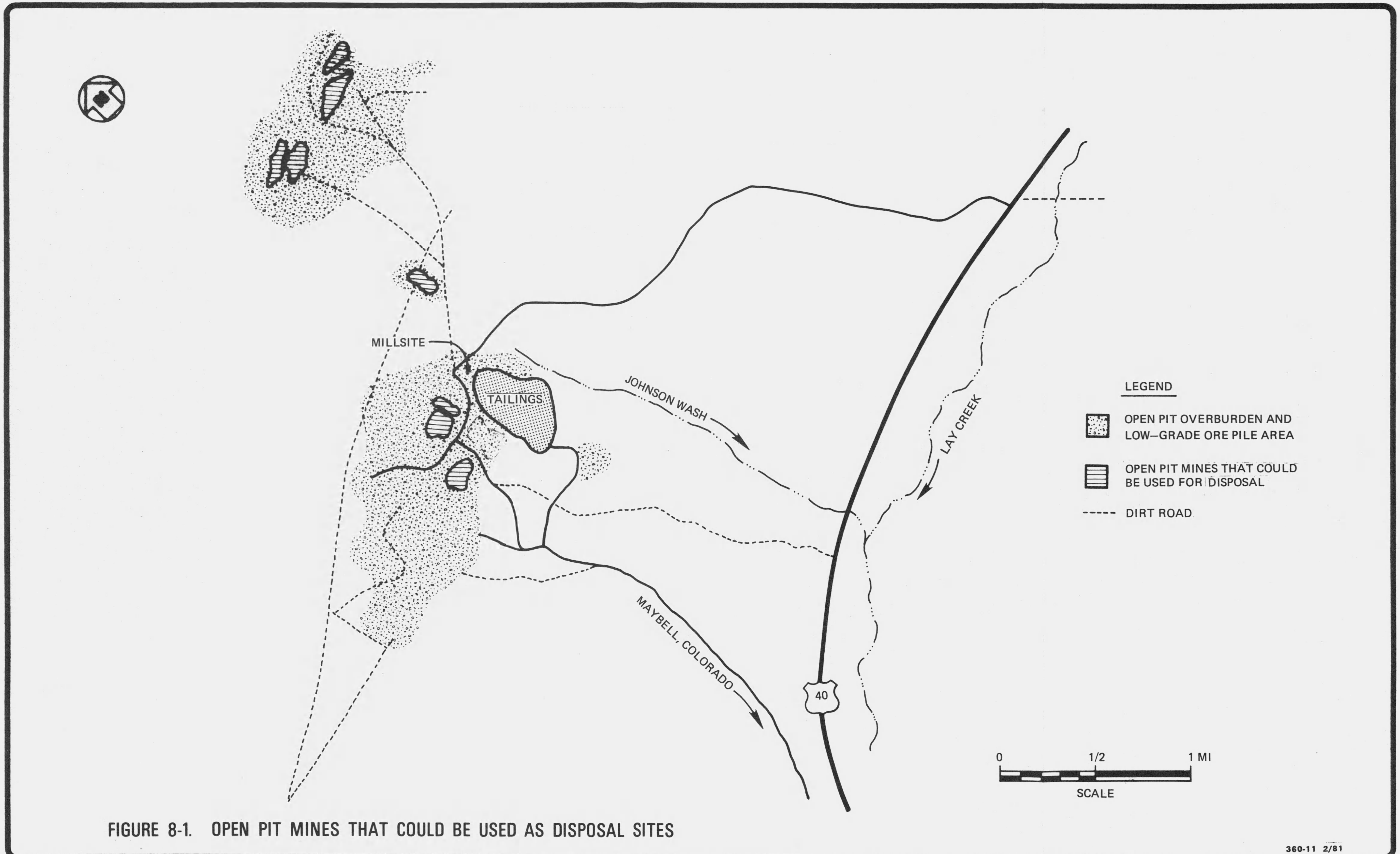


FIGURE 8-1. OPEN PIT MINES THAT COULD BE USED AS DISPOSAL SITES

360-11 2/81

CHAPTER 9

REMEDIAL ACTIONS AND COST-BENEFIT ANALYSES

CHAPTER 9

REMEDIAL ACTIONS AND COST-BENEFIT ANALYSES

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

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

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

Remedial actions designed to meet the EPA interim remedial action criteria were investigated. As outlined in Chapter 8, disposal of the tailings in an open pit mine located 2 mi from the tailings site was evaluated in terms of the cost of disposal. Although the disposal site has unique characteristics that were considered in estimating costs, great care must be exercised in the use of the cost estimate since there are insufficient data and information to characterize the site completely for estimating site development costs.

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

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

The option for disposal in the open pit mine 2 mi from the tailings site would provide for the relocation of all debris and contaminated materials from the tailings pile and off-site locations. Thus the entire site and off-site areas would be left free of any tailings or contaminated materials in excess of the allowed 5 pCi/g of ^{226}Ra above background.

A discussion of the concepts involved in tailings stabilization and their applicability to the Maybell site has been detailed in Chapter 6. It is assumed that vegetation will be established or a 0.3-m cover of riprap provided whether the tailings are stabilized on site or disposed of at an open pit mine within 2 mi of the tailings site.

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

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

9.1.1 Conceptual Design

Stabilization of the Maybell tailings on the present site is considered to be a viable option because the existing site can probably meet the criteria specified for tailings stabilization. In preparing the cost estimate for this option, the possible problem of migration of contamination via ground water was not considered and the cost does not include the placement of a clay or synthetic liner under the tailings. The cost of this option would increase significantly if the liner were required.

Under this option the tailings would remain on site. The tailings site would be contoured, graded, and stabilized with 3 m of cover material, which has been shown under certain conditions to be adequate to reduce radon flux to less than 2 pCi/m^2-s. However, local soils probably could not meet the flux reduction because of their high natural uranium content. With the cover material in place, the pile would rise approximately 25 ft above natural grade.

All of the newly stabilized areas would be seeded with self-regenerating vegetation native to the area or a riprap cover would be provided to limit surface erosion.

If the Maybell pile were stabilized in place, the site would have limited future use.

9.1.2 Costs

As shown in Table 9-1, the cost for stabilization at the Maybell site is estimated to be $11,700,000. Costs include cleaning up of off-site locations, covering all contaminated materials with 3 m of cover, contouring the surface, establishing vegetation or providing a riprap cap, and reclaiming of all areas.

9.2 REMOVAL OF TAILINGS AND ALL CONTAMINATED MATERIALS FROM THE SITE (OPTION II)

Option II would provide for the complete removal of all tailings, contaminated soil, existing stabilization cover, buildings, materials, and rubble from the tailings site and off-site areas to the disposal site. The amount of soil to be removed depends on the depth of contamination. In Figure 9-1, the areas that would require cleanup are presented along with an estimated depth of soil removal to reach the allowed level of 5 pCi/g of ^{226}Ra above background concentrations. The removal of 4 ft of subsoil below the interface under the tailings pile, 2 ft of topsoil from the former mill area, and 6 in. of topsoil from the windblown contaminated area has been estimated to reduce the residual radium concentration to less than 5 pCi/g above background. Finally, the site would be backfilled to natural grade and released for unrestricted use.

9.2.1 Excavation and Loading of Tailings and Soils

Roadways established to serve Union Carbide's mining operations in the area provide excellent access to the site. Different methods of excavation are possible, with a single-bench open pit method being the most feasible. To eliminate any possible dispersion of tailings during loading and transportation operations, dust control equipment could be provided.

The Maybell site would be backfilled to natural grade. Local materials, such as the overburden piles, might be used as backfill. No special treatments of the final surface other than establishing native grass or providing a riprap cover at the decontaminated tailings site are considered in this assessment.

9.2.2 Transportation of the Materials

Railroad transportation was not considered feasible for tailings transport since there are no rail facilities in the vicinity of the tailings or the open pit mine, and the length of haul would be too short to make rail transportation economically feasible.

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

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

(a) The longer the life of the project, the more attractive the use of conveyors becomes.

(b) The greater the mass to be moved, the more attractive the use of conveyors becomes.

(c) Conveyors can be more attractive in difficult terrain.

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

With all of the factors considered, the quantity of material to be moved at Maybell may warrant the use of conveyors. However, for this project, truck transportation is assumed to be the means of hauling the tailings. If the decision is made to move the tailings, a detailed evaluation would disclose whether conveyors would be economically attractive.

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

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

9.2.3 Disposal at an Alternative Site

A discussion of the proposed disposal site is given in Chapter 8. The disposal site has unique physical, geological, and hydrological characteristics. Because the Federal Government, with input from the State, is ultimately responsible for the selection of a disposal site, there is no assurance that the disposal site considered in this report will be selected.

Nevertheless, an effort was made to assess the characteristics of the disposal site based on what limited data were available and to show the costs that would result if the contaminated materials were actually disposed of in an open pit mine within 2 mi of the tailings site.

Vegetation covers 20% or less of the area near Maybell, and the average annual rainfall is about 14 in. The open pit mine is accessible from gravel-based roads that are adequate for hauling the heavy loads of tailings.

Disposal of the tailings in the open pit mine will conform to the preferred method of disposal, i.e., below grade. The bottom and sides of the pit may need to be lined before emplacement of the tailings, to prevent contamination of ground water beneath the site. However, the cost of lining the disposal pit was not included in the cost estimate.

Disposal site costs consist of preparation of the site, placement of tailings and cover material, and necessary reclamation of surface areas. The costs for the disposal option are summarized in Table 9-1. As shown, the total cost for this option (Option II) is $22,700,000.

Costs for health physics and radiological monitoring are included in individual component costs (lines 1 through 5, Table 9-1).

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

9.3 ANALYSES OF COSTS AND BENEFITS

9.3.1 Health Benefits

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

In this evaluation, the health benefit of each option is calculated from the reduction in radon exhalation that is expected for that option. In accordance with proposed requirements for stabilization of uranium mill tailings, radon fluxes were assumed to be reduced from their predicted values under present conditions (as conservatively calculated in Paragraph 3.6.2) to less than 2 pCi/m^2-s for Option I. In Option II, radon flux was assumed to be reduced to zero by the removal of the tailings. Since health effects are proportional to radon flux, the present health effects rate was estimated to be reduced by more than 99% with stabilization in-place and by 100% with tailings removal.

The potential cancer cases avoided (health benefits) for both options are given as a function of time in part A of Table 9-2. The cost per potential cancer case avoided for both options is included as part B in Table 9-2. As an alternative to the presentation in Table 9-2, the number of potential cancer cases avoided per million dollars expended was calculated and plotted in Figure 9-2. Option I yields the larger health benefit per unit cost, and Option II yields the smaller benefit per unit cost.

9.3.2 Land Value Benefits

The land surrounding the Maybell site is either under Bureau of Land Management control or is privately owned by one of 12 constituents.

The presence of the tailings pile affects land usage and values only slightly. The remedial actions of either option would have little effect, if any, on the values of the site or on the area surrounding the site.

Disposal of the tailings in the open pit mine (Option II) would offer two advantages over stabilization of the tailings in place (Option I). First, the problem of possible erosion and contamination of surrounding land would be eliminated, and secondly, approximately 90 acres on the site would be freed for other uses.

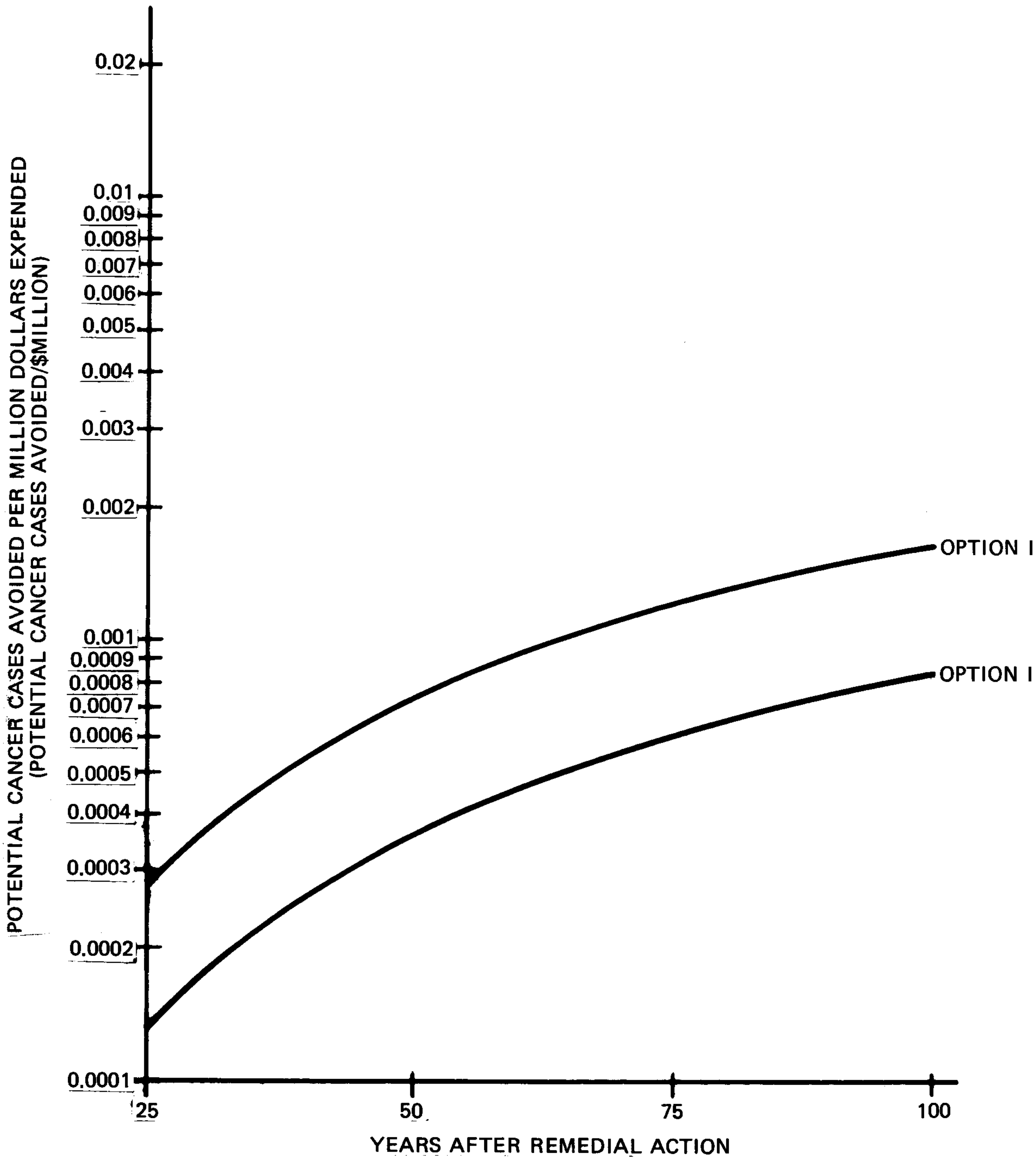


FIGURE 9-2. POTENTIAL CANCER CASES AVOIDED PER MILLION DOLLARS EXPENDED

360-11 REV 5/81

TABLE 9-1

SUMMARY OF STABILIZATION AND DISPOSAL COSTS[a]

		Options	
		I	II
1.	Tailings Site Costs	6.2	5.2
2.	Off-Site Other than Windblown	0.1	0.1
3.	Off-Site Windblown	0.7	0.7
4.	Transportation		
	a. Capital Costs	--	1.7
	b. Haul Costs	--	4.1
5.	Disposal Site	--	3.0
6.	Total Cleanup[b] (sum of lines 1 through 5)	6.9	14.8
7.	Engineering Design and Construction Management (30% of the difference between lines 6 and 4b)	2.1	2.7
8.	Total[b] (sum of lines 6 and 7)	9.0	17.5
9.	Contingency (30% of line 8)	2.7	5.2
10.	GRAND TOTAL[b] (sum of lines 8 and 9)	11.7	22.7

[a]Costs are presented in millions of year 1980 dollars.

[b]Totals may differ from the sum of component costs because of round-off.

360-11 3/81

TABLE 9-2

POTENTIAL CANCER CASES AVOIDED
AND COST PER POTENTIAL CASE AVOIDED

A. Number of Potential Cancer Cases Avoided

Options:	I	II
Option Cost (million $)	11.7	22.7
Years After Remedial Action		
25	<0.0033	0.0033
50	<0.0083	0.0083
75	<0.013	0.013
100	<0.019	0.019

B. Cost Per Potential Cancer Case Avoided (Million $)

Options:	I	II
Option Cost (million $)	11.7	22.7
Years After Remedial Action		
25	>3,500	6,900
50	>1,400	2,700
75	> 900	1,700
100	> 600	1,200

360-11 Rev 5/81

GLOSSARY

GLOSSARY

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

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

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

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

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

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

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

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

	emission of 1.3 x 10^5 MeV of potential alpha energy. This level is equivalent to the energy produced in the decay of the daughter products RaA, RaB, RaC, and RaC' that are present under equilibrium conditions in a liter of air containing 100 pCi of Rn-222. It does not include decay of RaD (22-yr half-life) and subsequent daughter products.
working level month (WLM)	One WLM is equal to the exposure received from 170 WL-hours.