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**ENGINEERING ASSESSMENT  
OF INACTIVE URANIUM MILL TAILINGS**

**SLICK ROCK SITES  
SLICK ROCK, COLORADO**

September 1981

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

Contract No. DE-ACO4-76GJO1658

By

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NOTICE

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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, Slick Rock Sites, Slick Rock, 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 Slick Rock sites 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 Roger Jones of 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 Slick Rock sites in order to revise the October 1977 engineering assessment of the problems resulting from the existence of radioactive uranium mill tailings at Slick Rock, 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 387,000 tons of tailings at the Slick Rock sites constitutes the most significant environmental impact, although windblown tailings and external gamma radiation also are factors. The five alternative actions presented in this engineering assessment include millsite decontamination with the addition of 3 m of stabilization cover material (Option IA), consolidation of the piles (Options IB and IC), and removal of the tailings to remote disposal sites and decontamination of the tailings sites (Options II and III). Cost estimates for the five options range from about \$6,800,000 for stabilization in-place, to about \$11,000,000 for disposal at a distance of about 6.5 mi.

Three principal alternatives for the reprocessing of the Slick Rock 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 over \$800/lb of U<sub>3</sub>O<sub>8</sub> whether by conventional or heap leach plant processes. 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, nor for the foreseeable future.

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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 mill sites in eight western states and in Pennsylvania. In 1980, the U.S. Department of Energy (DOE) contracted with FB&DU to produce revised reports of the sites designated in the Uranium Mill Tailings Remedial Action (UMTRA) program in order to reflect the current conditions, new criteria and options, and to estimate current remedial action costs.

A preliminary survey (Phase I) was carried out in 1974 by the U.S. Atomic Energy Commission (AEC) in cooperation with the U.S. Environmental Protection Agency (EPA) and the affected states. In a summary report,<sup>(1)</sup> 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 update 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 Slick Rock sites:

- (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 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 revised as follows:

- (a) Option IA - Stabilization of tailings with a 3-m cover at their present locations
  - Option IB - Consolidation and stabilization of tailings with a 3-m cover at the Union Carbide site
  - Option IC - Relocation and stabilization of tailings with a 3-m cover at the southwest corner of the Union Carbide property
- (b) Option II - Disposal at site 1, southeast Cougar Canyon area, 1.5 mi northwest of Union Carbide tailings pile
- (c) Option III - Disposal at site 2, Disappointment Valley, 6.5 mi east of Union Carbide tailings 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.

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,

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\*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 Slick Rock sites appears as Appendix I to Reference 5.

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 Slick Rock was performed in April 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 July 14, 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 Slick Rock sites.

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 Slick Rock sites.

## 1.2 SITE DESCRIPTIONS

### 1.2.1 Location and Topography

There are two sites at Slick Rock: the Union Carbide Corporation site and the North Continent site. (Throughout the remainder of the report the Union Carbide site may be referred to as the UC site and the North Continent site may be referred to as the NC site.) The two sites are about 0.9 mi apart. They are located approximately 9 mi east of the Utah-Colorado border, 25 mi north of Dove Creek, Colorado, and 3 mi northwest of the post office at Slick Rock, Colorado. The sites lie in the Dolores River Valley at an elevation of approximately 5,450 ft above sea level. The locale is arid and includes canyons, mesas, steep cliffs, and valleys typical of the western slope of the Rocky Mountains. The sites and their 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<sup>(3)</sup>

### 1.2.2.A Union Carbide Site

Union Carbide Corporation has been the owner and operator of the site since its inception in 1956. The upgrader became operational in 1957. Ore was delivered to the upgrader from mines in the Slick Rock area and the resultant upgraded material was trucked to Union Carbide's Rifle, Colorado, mill for further processing. Approximately 350,000 tons of sand tailings remain on the site. These tailings contain only a small portion of the original level of radioactivity as a result of the sand-slime separation process.

### 1.2.2.B North Continent Site

The original owner of the site was Shattuck Chemical Company (1931). North Continent Mines, Inc. acquired the interests of Shattuck in 1934. Union Mines Development Corporation, a Federal Government-established corporation, acquired the site in 1945 for the specific purpose of supplying uranium and vanadium for the Manhattan Project of World War II. The Federal Government took title to the site in 1949, and in 1957 Union Carbide Corporation acquired the property and is still the owner.

Ore averaging 0.28%  $U_3O_8$  and 3.00%  $V_2O_5$  was delivered to the mill from company-controlled mines within a 10-mi radius. From 1931 until 1942 a method of acid leaching was used on the ore. The initial mill capacity was 10 to 15 tons/day. In 1942 a rotary kiln roaster was installed, and the mill was converted to a salt roast process along with the acid leach for the recovery of  $V_2O_5$ ,  $U_3O_8$ , and a radium concentrate. At that time mill capacity was increased to 30 tons/day. Approximately 37,000 tons of ore were fed to process during the lifetime of the mill, producing approximately the same amount of tailings, which still remain.<sup>(3)</sup>

## 1.2.3 Present Condition of the Sites

### 1.2.3.A Union Carbide Site

Figure 2-4A is a descriptive map of a portion of the 355-acre UC site as it now exists. The tailings pile is convex-shaped and covers about 19 acres. Figure 2-5A shows a typical cross-section of the pile.

The former mill buildings have been removed except for some concrete foundations. The tailings were stabilized with approximately 6 in. of earth cover obtained from areas adjacent to the pile, and at present about 20% of the surface is covered with vegetation. Approximately 25% of this cover shows erosion. There is a small earthen dike between the

pile and the river. The tailings pile is posted and enclosed with a barbed-wire fence. The owner provides maintenance and security.

A warehouse, housing, and a trailer park located west of the former mill area are in use. The Rocky Mountain Gas Company has constructed a gas sweetener plant on 5 acres of the site.

#### 1.2.3.B North Continent Site

Figure 2-4B is a descriptive map of a portion of the 168-acre NC site as it now exists. The tailings pile covers about 6 acres on the southeast bank of the Dolores River. Figure 2-5B shows a typical cross-section of the pile.

All of the former mill structures and foundations have been removed. The tailings were stabilized with 6 in. of earth cover, and about 10% of the pile is covered with native vegetation. The tailings area is fenced, and maintenance and security are provided by the owner.

#### 1.2.4 Tailings and Soil Characteristics

The UC tailings are coarse-grained sand, while the NC tailings are finer-grained with a clay content. Bulk densities run between 88 and 97 lb/ft<sup>3</sup>. There are approximately 350,000 tons of tailings covering 19 acres on the UC site, and 37,000 tons covering 6 acres on the NC site. The weights and volumes of tailings materials at both sites are given in Table 2-1.

Alluvial deposits from the Dolores River form the soil beneath both piles. The soil rests on underlying bedrock of sandstone and siltstone strata.

#### 1.2.5 Geology, Hydrology, and Meteorology

The Slick Rock tailings piles are located on the flood plain of the Dolores River. Bedrock at the piles consists of sedimentary strata: Navajo Sandstone at the UC site and the Salt Wash Member of the Morrison Formation at the NC site. The bedrock strata dip gently to the northeast. A simplified stratigraphic column is shown in Figure 2-6.

The flowing surface waters near the sites consist of the Dolores River and three of its tributaries. The tailings are protected by rock, soil material, and vegetative cover. Nevertheless, an intermediate regional flood (100-yr flood) or larger flood would inundate the base of the piles and could erode part of the UC dike earth cover and possibly the tailings themselves. The flow of flood waters across the base of the NC site would not be as swift.

Contamination of surface waters other than by floods is unlikely by overland runoff or by seepage of precipitation through the piles. The potential for water erosion has been reduced by the construction of diversion ditches and the location of dirt roads. Overland flow across the piles is limited almost entirely to the precipitation that falls on the piles. Flow of water through the piles is not evident from any seepage along the river bank; however, contamination of unconfined water in the alluvium due to flood waters rising within the tailings is possible.

Contamination of confined water systems theoretically is possible because the bedrock strata are permeable and waters of the Dolores River recharge the aquifers. The quantity of recharge from the Dolores River would dilute any leaching from the tailings piles.

Meteorology records from Cortez show that thunderstorm activity and precipitation in the area are greatest during August and September. Average annual precipitation at Slick Rock has been estimated to be 7 in. The strongest winds at the sites are those that are channeled up and down the valley in a north-south direction, based upon observation by local residents in the absence of recorded weather data at Slick Rock.

### 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  $^{230}\text{Th}$ ,  $^{226}\text{Ra}$ ,  $^{222}\text{Rn}$ , and  $^{222}\text{Rn}$  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  $^{226}\text{Ra}$  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  $^{222}\text{Rn}$  and its daughter products, resulting from the continuous radioactive decay of  $^{226}\text{Ra}$  in the tailings. Radon is a gas which diffuses from the piles. The principal exposure results from inhalation of  $^{222}\text{Rn}$  daughters. This exposure affects the lungs. For this assessment, no criteria have been established for radon concentrations in air. However, the pathway for radon and radon daughters accounts

for the major portion of the exposure to the population.

- (b) External whole-body gamma exposure directly from radionuclides in the piles.
- (c) Inhalation and ingestion of windblown tailings. The primary health effect relates to the alpha emitters  $^{230}\text{Th}$  and  $^{226}\text{Ra}$ , each of which causes exposure to the bones and lungs.
- (d) Ingestion of ground and surface water contaminated with radioactive elements (primarily  $^{226}\text{Ra}$ ) 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<sup>(4)</sup> ranged from 6 to 24 pCi/m<sup>2</sup>-s on the stabilized cover of the UC tailings pile and from 4 to 246 pCi/m<sup>2</sup>-s on the NC tailings pile. Measurements of the radon exhalation flux made in 1980 ranged from less than 1 to about 130 pCi/m<sup>2</sup>-s on the UC tailings pile and from about 1 to 700 pCi/m<sup>2</sup>-s on the NC tailings pile. The two sets of measurements were made under similar weather conditions, namely, warm and dry. 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 including background were performed by FB&DU in 1976 with continuous radon monitors supplied by ERDA at six locations in the vicinity of the Slick Rock tailings piles. The locations and gross values of the radon measurements are shown in Figure 3-4. The highest outdoor radon concentration was measured 0.2 mi north of the UC site, where the Dolores River Valley narrows. The radon concentration at this location averaged 3.8 pCi/l for a 24-hr period. Indoor radon concentration averaged 4.2 pCi/l in a closed vacant trailer in the trailer park where tailings have been used.

Three 24-hr measurements of atmospheric radon indicated an average background concentration of 1.5 pCi/l for the Slick Rock area. The valley has many uranium mines, both active and inactive, which may contribute to naturally occurring radon levels.

#### 1.3.1.2 Direct Gamma Radiation

The range of natural background values in the Slick Rock area was between 6 and 13  $\mu\text{R/hr}$ , averaging 10  $\mu\text{R/hr}$  as measured 3 ft above ground with an energy-compensated Geiger Mueller detector.<sup>(5)</sup> Above the surface of the tailings piles and millsites, gross gamma radiation rates were below 150  $\mu\text{R/hr}$  at the UC site with one isolated exception of 180  $\mu\text{R/hr}$ . At the NC site, gamma radiation reached a maximum of 3,000  $\mu\text{R/hr}$  in an area west of the millsite. Gamma radiation rates in the remainder of the fenced area were also relatively high. Gamma radiation rates to 730  $\mu\text{R/hr}$  were measured in a contaminated area about 100 yd southwest of the south fence of the NC site.

#### 1.3.1.3 Windblown Contaminants

Prevailing winds in the area follow the Dolores River Valley and therefore tend to be north and south winds. Concentrations of  $^{226}\text{Ra}$  found in surface soil samples along with results of the EPA gamma survey and the delta survey (described in Paragraph 3.4.3) were used to determine the extent of windblown tailings. Recent surveys indicate that windblown tailings extend about 500 ft to the north of the UC tailings pile, but are confined to a relatively small area around the NC tailings pile. The extent of windblown contamination is presented in Figures 3-12A and 3-12B.

#### 1.3.1.4 Ground and Surface Water Contamination

Twelve water samples taken from the Dolores River during this assessment contained  $^{226}\text{Ra}$  concentrations ranging from 1.0 to 2.4 pCi/l.<sup>(5)</sup> These values are less than the 5-pCi/l limit for combined  $^{226}\text{Ra}$  and  $^{228}\text{Ra}$  in the EPA Interim Primary Drinking Water Regulations for radionuclides.<sup>(6)</sup>

#### 1.3.1.5 Soil Contamination

The leaching of radium from the tailings into the subsoil generally extends about 2 ft before reaching the average soil background radium concentration of 1.5 pCi/g. In the mill areas, contamination 4 ft deep has been found in isolated locations. A high level of soil contamination, averaging 75 pCi/g, was measured southwest of the NC pile. The high concentration extended to a depth of 7.5 ft, where cobbles and water prevented further evaluation.

#### 1.3.2 Remedial Action Criteria

For the purpose of conducting the original engineering assessment,<sup>(2)</sup> provisional criteria provided by the EPA were used. The criteria were in two categories, and applied either to structures with tailings present or to land areas to be decontaminated. For structures, the indoor radiation level below which no remedial action was indicated was considered to

be an external gamma radiation level of less than 0.05 mR/hr above background and a radon daughter concentration of less than 0.01 WL above background. Land could be released for unrestricted use if the external gamma radiation levels were less than 10  $\mu$ R/hr above background. When cleanup was necessary, residual radium content of the soil after remedial action should not exceed twice background in the area.

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

For open land, remedial action must provide reasonable assurance that the average concentration of  $^{226}\text{Ra}$  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  $^{222}\text{Rn}$  from the disposal site to the atmosphere by residual radioactive materials will not exceed 2 pCi/m<sup>2</sup>-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

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\*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.

those substances prior to remedial action exceed the levels specified below for causes other than residual radioactive materials.\*

<u>Substance</u>	<u>mg/l</u>
Arsenic . . . . .	0.05
Barium . . . . .	1.0
Cadmium . . . . .	0.01
Chromium . . . . .	0.05
Lead . . . . .	0.05
Mercury . . . . .	0.002
Molybdenum . . . . .	0.05
Nitrogen (in nitrate) . . . . .	10.0
Selenium . . . . .	0.01
Silver . . . . .	0.05
	<u>pCi/l</u>
Combined $^{226}\text{Ra}$ and $^{228}\text{Ra}$ . . . . .	5.0
Gross alpha particle activity (including $^{226}\text{Ra}$ 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<sup>2</sup>-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.

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\*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.

### 1.3.3 Potential Health Impact

Radon gas exhalation from the piles and the subsequent inhalation of radon daughters account for most of the total dose to the population from the Slick Rock sites under present conditions. The gamma radiation exposure from the piles is very small since there are very few people who live or work within 0.2 mi of the piles, 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<sup>(7)</sup> earlier indicated that 13 ft of earth cover would be required to reduce the radon diffusion from the Slick Rock tailings by 95%. Later experimental work<sup>(8)</sup> has demonstrated that 2 to 3 ft of compacted clay may be sufficient to reduce radon flux to less than 2 pCi/m<sup>2</sup>-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).<sup>(9)</sup> 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<sup>(10)</sup> 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 vicinity within 1.5 mi of the UC site is  $2.8 \times 10^{-6}$  per person per year, or less than 2% of the average lung cancer risk due to all causes for Colorado residents ( $1.8 \times 10^{-4}$ ).<sup>(11)</sup>

The 25-yr health effects were calculated for three population projections using the present population of 100 persons in the 0- to 1.5-mi area. The results for pile-induced radon and background radon for this area were as follows:

25-Year Cumulative Health Effects within 1.5 Miles  
of Edge of UC Pile

<u>Projected Population Growth</u>	<u>Pile-Induced RDC</u>	<u>Background RDC</u>
Zero growth	0.009	0.14
0.8% constant growth rate	0.010	0.16
5% declining growth rate*	0.013	0.22

Health effects attributable to radon released from the Slick Rock piles are approximately 6% of those attributable to background radon concentrations for the area within 1.5 mi of the UC site. The exposure and consequent risk will continue as long as the radiation sources remain in their present locations and conditions.

1.3.4 Nonradioactive Pollutants

There are other potentially toxic materials in the tailings. Chemical analyses of tailings samples from drill holes on the Slick Rock tailings piles showed selenium at about 1 ppm, lead and barium between 10 and 530 ppm. The arsenic concentration measured ranged as high as 67 ppm on the NC pile. Three samples of surface waters in the area surrounding the Slick Rock tailings piles contained selenium in concentrations above the limit of the EPA Interim Primary Drinking Water Regulations.<sup>(6)</sup> However, there was no consistent degradation of the surface waters as they flowed by the tailings piles. The Dolores River contained about 6 times the maximum acceptable level of selenium upstream from the tailings and 3 to 9 times below. The Dolores River samples also contained above-maximum levels of lead and arsenic both upstream and downstream of the tailings piles. Consequently, the Slick Rock tailings should not appreciably downgrade the nonradioactive environmental pollutant quality of the Dolores River.

1.4 SOCIOECONOMIC AND LAND USE IMPACTS

Based on site inspection and San Miguel County Planning Department estimates, 100 persons were estimated to live within 1.5 mi of the UC pile in 1980. Calculation of a population projection could be misleading because of the area's small population base and its extreme dependence on mining. The water, sewage, and commercial facilities now in the area are sufficient to serve almost a doubling of the present population in the event of a uranium/mineral boom. However, an adverse market quickly could reduce the population to 10 to 20 people. Presently, there are no good prospects for long-term, sustained population growth.

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

The only residential concentration near Slick Rock is located on flat land southwest of the UC tailings. It consists of two frame houses and a trailer park with 20 mobile homes. Industrial and commercial activities in the vicinity are extremely limited.

The area near the Slick Rock tailings is characterized as agricultural land primarily used for low density grazing. Although 93% of the land in the area is put to agricultural use, mining activities sustain the area's economy. The amount of land devoted to mineral exploration, extraction, and milling fluctuates with market conditions.

The market value of dry grazing land in the area generally is about \$30/acre, while irrigable cropland is valued at \$530/acre. The Union Carbide property has an assessed value of less than \$10/acre; however, some of this land has not been reclassified for mining usage. If the tailings were not present, there would be virtually no change in land values in the surrounding areas.

The presence of the tailings at the two Slick Rock sites restricts use of the tailings areas themselves. Both sites are fenced and not available for use as cropland. There are no apparent future uses of the land at the two sites, although the availability of the mobile home facilities would be attractive should mineral activity expand.

#### 1.5 RECOVERY OF RESIDUAL VALUES

Samples of tailings obtained during this study were composited and analyzed. Samples from the UC and NC piles contain 0.005% and 0.008% of  $U_3O_8$ , respectively. Because of the small tonnage of tailings in the NC pile, the two piles were assumed to be combined in the reprocessing evaluation.

There are five factors that can be employed to evaluate whether reprocessing Slick Rock 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 Slick Rock 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 over \$800/lb of  $U_3O_8$  whether by heap leach or conventional plant processes. The spot market price for uranium was \$25/lb early in 1981. Therefore, reprocessing the Slick Rock tailings for uranium recovery is not economical under present or foreseeable 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

A mobile scanning unit operated by the AEC performed a gamma radiation survey of the Slick Rock, Colorado, area in 1971. A subsequent field survey identified only three off-site locations where tailings use was suspected or confirmed. The cost of remedial action for these locations has been estimated to be \$41,000. Cleanup of the windblown tailings surrounding the two piles has been estimated to cost a total of \$275,000. The total remedial action cost for off-site structures and decontamination of off-site windblown lands has been estimated at \$316,000, exclusive of engineering and contingency allowances.

### 1.8 DISPOSAL SITE SELECTION

In this report, two of the alternative remedial action options include moving the Slick Rock tailings to a disposal site. Each site was evaluated 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 sites evaluated in this work must be considered only as tentative.

The relative locations of the disposal sites listed in Table 1-2 as Options II and III are shown in Figure 8-1. In each of these options, surface material would be removed, as appropriate, from the disposal area and stockpiled. A retaining dike and diversion ditches would be constructed if necessary. The tailings would be emplaced, contoured, and covered with 3 m of soil. The surface would be covered with 0.3 m of riprap or vegetation established for erosion control, and the entire site 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 piles in their present locations and configurations, 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 3 m of cover material and the removal of tailings to two possible locations. The options are summarized in Table 1-2.

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

Option IA represents remedial action activities to stabilize the piles more completely in their present locations with the addition of 3 m of cover. Erosion of the tailings would be controlled more completely and radon exhalation would be reduced to not more than 2 pCi/m<sup>2</sup>-s above background. The site would have limited future use.

### 1.9.2 Cost-Benefit Analyses

As summarized in Table 9-1, the total estimated costs for the three remedial action options vary from about \$6,800,000 to about \$11,000,000. Each of these options would have both 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 9-4. The curves in Figure 9-4 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 <sup>a</sup>	Condition of Structures On Site <sup>b</sup>	Mill Housing <sup>c</sup>	Adequate Fencing, Posting, Security	Property Close to River or Stream	Houses or Industry within 0.5 Mi	Evidence of Wind or Water Erosion	Possible Water Contam- ination	Tailings Removed for Private Use	Other Hazards On Site
<u>ARIZONA</u>										
Monument Valley	U	R	N	No	No	Yes	Yes	No	Yes	No
Tuba City	U	PR-UO	E-P	No	No	Yes	Yes	No	No	Yes
<u>COLORADO</u>										
Durango	P	PR-UO	N	Yes	Yes	Yes	Yes	No	Yes	Yes
Grand Junction	S	PR-O	N	Yes	Yes	Yes	Yes	Yes	Yes	No
Gunnison	S	B-O	N	No	Yes	Yes	No	Yes	No	No
Maybell	S	R	N	Yes	No	No	Yes	No	No	No
Naturita	RMS	PR-O	N	Yes	Yes	Yes	Yes	Yes	No	No
New Rifle	P	M-O	N	Yes	Yes	Yes	Yes	Yes	No	No
Old Rifle	S	PR-UO	N	Yes	Yes	Yes	No	Yes	Yes	No
Slick Rock (NC)	S	R	N	Yes	Yes	Yes	Yes	Yes	No	No
Slick Rock (UCC)	S	R	E-P	Yes	Yes	Yes	No	Yes	No	No
<u>IDAHO</u>										
Lowman	U	R	N	No	Yes	Yes	Yes	Yes	Yes	No
<u>NEW MEXICO</u>										
Ambrosia Lake	U	PR-O	N	No	No	No	Yes	No	No	No
Shiprock	S	PR-O	N	Yes	Yes	Yes	No	Yes	Yes	No
<u>NORTH DAKOTA</u>										
Belfield	R	PR-O	N	No	No	Yes	No	No	No	No
Bowman	R	R	N	No	No	No	No	No	No	No
<u>OREGON</u>										
Lakeview	S	B-O	N	Yes	No	Yes	Yes	No	No	No

TABLE 1-1 (Cont)

	Condition of Tailings <sup>a</sup>	Condition of Structures On Site <sup>b</sup>	Mill Housing <sup>c</sup>	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
<u>PENNSYLVANIA</u>										
Canonsburg	P	B-O	N	Yes	Yes	Yes	No	Yes	Yes	Yes
<u>TEXAS</u>										
Falls City	P	B-O	N	Yes	No	No	Yes	No	No	No
<u>UTAH</u>										
Green River	S	B-Y	N	Yes	Yes	Yes	Yes	Yes	No	No
Mexican Hat	U	PR-UO	E-O	No	No	Yes	Yes	Yes	No	No
Salt Lake City	U	R	N	No	Yes	Yes	Yes	Yes	Yes	Yes
<u>WYOMING</u>										
Converse County	U	R	N	Yes	No	No	No	No	No	No
Riverton	S	PR-O	N	No	No	Yes	No	No	No	No

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<sup>a</sup>S - Stabilized but requires improvement  
P - Partially stabilized  
U - Unstabilized  
RMS - Reprocessed, moved and stabilized - contamination remaining  
R - Removed - contamination remaining

<sup>b</sup>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

<sup>c</sup>N - None  
E - Existing  
O - Occupied  
P - Partially occupied

TABLE 1-2

## SUMMARY OF REMEDIAL ACTION OPTIONS AND EFFECTS

<u>Option Number</u>	<u>Site Specific Cost (\$000)</u>	<u>Description of Remedial Action</u>	<u>Benefits</u>	<u>Adverse Effects</u>
IA	6,800	The piles 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-C,E, H,I	Y,Z
IB	9,200	The NC pile would be moved to the UC site where the two piles would be consolidated and stabilized 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-C,E, F,H,I	Z
IC	9,100	The two piles and all contaminated materials would be relocated and stabilized with 3 m of local earth cover on the southwest corner of the Union Carbide property. 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-C,E, F-I	--

TABLE 1-2 (Cont)

Option Number	Site Specific Cost (\$000)	<u>Description of Remedial Action</u>	<u>Benefits</u>	<u>Adverse Effects</u>
II	9,600	The tailings, contaminated soil, and rubble would be removed by truck to site 1, south-east Cougar Canyon area, located about 1.5 mi from the UC tailings site. The tailings sites would be decontaminated and released for unlimited use.	A-I	--
III	11,000	Same as Option II, except tailings removed to site 2, Disappointment Valley, located about 6.5 mi from the UC tailings site.	A-I	--

1-24

Notes

1. All options include on- and off-site remedial action.
2. For Options II and III, costs include removal of contaminated earth to varying depths in different areas (see Figures 9-1A and 9-1B).

TABLE 1-2 (Cont)

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Definition of Benefits

- A. Better security, decontamination at populated areas
- B. On-site windblown and water-eroded tailings cleaned up
- C. Wind and water erosion controlled with 3 m of cover material
- D. Pile protected from river flooding
- E. Gamma radiation reduced to near-background levels
- F. NC site released for unlimited use
- G. UC site released for unlimited use
- H. Minimum maintenance required
- I. Rate of radon release reduced to at least 2 pCi/m<sup>2</sup>-s

Definition of Adverse Effects

- Y. No further development of NC site recommended
- Z. No further development of UC site recommended

## 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, Slick Rock Sites, Slick Rock, Colorado"; Ford, Bacon & Davis Utah Inc.; GJT-7; Oct 1977.
3. "Phase I Report on Conditions of Uranium Millsites and Tailings (Union Carbide and North Continent Sites) at Slick Rock, Colorado"; AEC; Grand Junction, Colorado; 1974; (See Appendix I to Reference 5 below).
4. R.J. Countess; " $^{222}\text{Rn}$  Flux Measurement with a Charcoal Canister"; Health Physics; Vol 31, p. 455; 1976.
5. F.F. Haywood, et al.; "Radiological Survey of the Inactive Uranium-Mill Tailings Piles at Slick Rock, Colorado"; ORNL-5452; Oak Ridge National Laboratory; Oak Ridge, Tennessee; June 1980.
6. Federal Register, Part II; EPA Interim Primary Drinking Water Regulations; EPA; July 9, 1976.
7. 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.
8. 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.
9. "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.
10. 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.
11. Vital Statistics of the U.S.; Vol II; Mortality; National Center for Health Statistics; HEW; 1968.

CHAPTER 2  
SITE DESCRIPTIONS

## CHAPTER 2

### SITE DESCRIPTIONS

The purpose of this chapter is to describe the UC and NC sites at Slick Rock, Colorado, their surroundings, and the characteristics of the tailings materials present on the sites.

#### 2.1 LOCATION

An aerial photograph showing the locations of both sites is included as Figure 2-1. The UC millsite is approximately 3 mi northwest of the Slick Rock, Colorado, Post Office. It is approximately 9 mi east of the Utah-Colorado border and 25 mi north of Dove Creek, Colorado. The Dolores River borders the site on the north and east. The site is in Section 25, Township 44 north, Range 19 west, New Mexico Principal Meridian, at 38 deg 02 min 43 sec north latitude and 108 deg 54 min 30 sec west longitude.

The NC millsite is about 2 mi northwest of the Slick Rock Post Office and about 0.9 mi east of the UC site. The site is on the south side of the Dolores River in Section 30, Township 44 north, Range 18 west, New Mexico Principal Meridian, at 30 deg 02 min 30 sec north latitude and 108 deg 53 min 30 sec west longitude.

#### 2.2 TOPOGRAPHY

The topography of the two sites is similar. They are located in the valley of the Dolores River. The elevation of the river in this area is approximately 5,428 ft above sea level with the valley floor varying in elevation from 5,460 to 5,600 ft above sea level. The area includes canyons, mesas, steep cliffs, and mountainous terrain typical of the western slope of the Rocky Mountains. The surrounding peaks of Horse Range Mesa rise to elevations of 7,200 ft. Vegetation is sparse, consisting mainly of juniper, sagebrush, and some piñon pine.

The UC site, of approximately 355 acres, contains one 19-acre tailings pile. The base of the pile is about 10 ft above the Dolores River; the top of the pile is about 60 ft above the river. Because of the horseshoe bend in the river at the UC site, the distance from the pile to the river varies from 35 to 300 ft.

The millsite and ore storage areas were adjacent to the south edge of the UC tailings and occupied about 13 acres. Figure 2-2A is a topographic map of the UC tailings and former millsite area.

The total area of the NC site is approximately 160 acres, of which the tailings pile occupies 6 acres. The base of the pile is about 8 ft above the Dolores River; the top is approximately 50 ft above the river. The distance from the tailings to the edge of the river varies from 15 to 75 ft. The NC pile is situated against a bluff. The pile contour has a uniform 3-to-1 slope.

The adjacent millsite and ore storage areas occupied about 20 acres on top of the bluff (including land upon which some residences and office buildings were located). Figure 2-2B is a topographic map of the NC tailings and former millsite area.

### 2.3 OWNERSHIP

The Union Carbide Corporation has been the owner and operator of the UC site since its inception in 1956. Five acres of the original 360 acres were sold to the Rocky Mountain Gas Company.

The NC mill was built in 1921 by the Shattuck Chemical Company of Denver, Colorado. In 1934, North Continent Mines, Inc., acquired the interests of the Shattuck Chemical Company. In 1945, North Continent Mines deeded the property to the Union Mines Development Corporation, a corporation established by the Federal Government to produce uranium and vanadium for the Manhattan Project during World War II. In February 1949, the Union Mines Development Corporation deeded the property to the Federal Government; in November 1957, the Union Carbide Corporation acquired title to the site and still remains the owner.

Current ownership of the UC and NC sites is shown in Figures 2-3A and 2-3B, which have been adapted from the site description and ownership maps prepared for DOE and published in the Federal Register.<sup>(1)</sup>

### 2.4 HISTORY OF MILLING OPERATIONS AND PROCESSING

#### 2.4.A Union Carbide Site<sup>(2)</sup>

The UC upgrader at Slick Rock became operational in September 1957 with a design capacity of 350 tons/day of ore, later expanded to 500 tons/day. Ore averaging 0.245% U<sub>3</sub>O<sub>8</sub> and 1.35% V<sub>2</sub>O<sub>5</sub> was delivered to the upgrader from the Deremo mine and other mines in the Slick Rock area. All of the ore was trucked to the upgrader, and the resultant upgraded material was trucked to the UC mill at Rifle, Colorado, for further processing.

Dry-grinding and air-sizing were used to produce a minus-14 mesh product and recover a large portion of the fine fraction. The fine fraction constituted the first concentrate. The

coarse-ore fraction was combined with recirculated acid solution; a sand-slime separation then was made on the slurry. The sand product was further acid-leached, washed, and discharged to tailings. The slimes were dewatered and dried as a second concentrate. A third product resulted from ammonia neutralization of part of the pregnant solution. All three products were shipped to Union Carbide's Rifle mill for further processing. About 60% of the uranium was contained in the initial dry-fine product and an additional 30 to 35% in the other two products.(3)

The plant was closed in December 1961. Approximately 350,000 tons of tailings, containing only a small portion of the residual radioactivity, remain on the site.

#### 2.4.B North Continent Site<sup>(2)</sup>

From 1931 until 1942 a method of acid leaching was used on ore averaging 0.28%  $U_3O_8$  and 3%  $V_2O_5$ . The initial mill capacity was 10 to 15 tons/day. In 1942 a rotary kiln roaster was installed and the mill converted to a salt roast process along with the acid leach for the recovery of  $V_2O_5$ ,  $U_3O_8$ , and a radium concentrate. Mill capacity was increased to 30 tons/day. Approximately 37,000 tons of ore were fed to process during the mill lifetime, producing the same amount of tailings. Ore was delivered by trucks and mule teams to the NC mill from their company-controlled mines within a 10-mi radius.

### 2.5 PRESENT CONDITION OF THE SITES

#### 2.5.A Union Carbide Site

Figure 2-4A is a descriptive map of a portion of the 355-acre UC site as it now exists. Except for some concrete foundations, the mill buildings have been removed from the site. The tailings are surrounded by a five-strand barbed-wire fence. Radiation warning signs are displayed on the fence, and locked gates are in place. The pile is maintained by the owner. The Rocky Mountain Gas Company has constructed a gas sweetener plant on the site.

West of the mill area there are two structures used as warehouses. In the same area are a trailer park and housing units used by employees of the Union Carbide Corporation and the Rocky Mountain Gas Company.

The UC tailings pile is convex-shaped with an average side slope of about 5-to-1. Figure 2-5A shows a typical cross-section of the UC tailings pile. The pile was stabilized in accordance with State of Colorado regulations. This stabilization consisted of the addition of approximately 6 in. of soil, which was seeded for vegetation. Vegetation has been established on only about 20% of the surface of the pile.

A small earthen dike has been constructed between the UC pile and the river. Grading around the pile has isolated it from surrounding runoff. However, water erosion has occurred on about 25% of the pile, and the soil cover has completely eroded from small areas.

#### 2.5.B North Continent Site

Figure 2-4B is a descriptive map of a portion of the 160-acre NC site as it now exists. The site once included a small town with housing, water systems, and office buildings, but all traces of these man-made structures have been removed. The property is fenced and posted; however, livestock can get onto the site near the Dolores River. The bridge over the river, formerly providing access at the northeast corner of the site from the paved county road, has been washed out. However, the site is accessible from a dirt road that originates at Colorado State Highway 141 directly west of the Slick Rock Post Office.

The radium slimes and the 37,000 tons of uranium-vanadium tailings were placed in the area shown in Figure 2-4B. Approximately 350 to 400 tons of tailings were removed from the NC pile for reprocessing at the Slick Rock (UC) upgrader and the Uravan mill. When the mill was dismantled, bricks removed from the roaster were buried in the NC tailings pile. Figure 2-5B shows a typical cross-section of the NC tailings pile.

The pile was stabilized in accordance with State of Colorado Regulations in effect at that time. It was contoured, covered with 6 in. of topsoil, seeded, and fertilized. Approximately 10% of this cover shows erosion, and the growth is sparse as a result of the semiarid climate.

#### 2.6 TAILINGS AND SOIL CHARACTERISTICS

The types, volumes, and weights of contaminated materials at both Slick Rock sites are summarized in Table 2-1. The major portion of materials is uranium and vanadium tailings, with a small amount of radium slimes. The UC tailings generally are coarse sand, while the NC tailings generally are finely-ground sand with a slight clay content. Bulk densities and the pH of the tailings are given in Table 2-2. The pH of the tailings is in the neutral range. Assay results of composite tailings samples are shown in Tables 5-1A and 5-1B.

The tailings at the UC site are predominantly a sand product since the slime fraction of the ore was shipped to other mills for processing.

The tailings piles at both sites are located on alluvial deposits of the Dolores River and on underlying bedrock of sandstone and siltstone strata. The alluvium of the Dolores

River area consists of silt, sand, gravel, and cobbles. Gravel terraces are present in dissected remnants along the Dolores River in the vicinity of Slick Rock. The UC and NC tailings piles are topographically below the lowermost ancestral terrace, but upon the uppermost terraces of the modern flood plain. These surficial deposits could be as thick as 20 ft under sections of the tailings sites.

## 2.7 GEOLOGY, HYDROLOGY, AND METEOROLOGY

### 2.7.1 Geology

The two Slick Rock tailings piles are located on the south and west bank of the flood plain of the Dolores River. The bedrock at Slick Rock is of sedimentary origin ranging in age from Permian to Late Cretaceous. The NC tailings rest upon alluvium underlain by bedrock of the Salt Wash Member of the Morrison Formation. The UC tailings rest on alluvium and bedrock of the Navajo Sandstone. The Slick Rock Member of the Entrada Sandstone received its name from Slick Rock exposures such as that on the bank opposite the UC tailings. The entire sedimentary sequence dips gently (2 to 8 deg) toward the axis of the Disappointment Syncline to the northeast. 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. Apparently no further hydrologic characterization of the Slick Rock tailings sites is contemplated at this time.

As shown in Figure 2-7, the flowing surface waters near the sites consist of the Dolores River and three of its tributary drainages. The Dolores River is a perennial stream except during long periods of drought. Its tributaries are intermittent drainages and carry water only during spring runoff or after a canyon cloudburst.

The UC tailings are located on the modern flood plain of the Dolores River. An earthen dike acts as a barrier against the river; however, an intermediate regional flood (100-yr flood) or greater would inundate the base of the pile.

The channel of Corral Draw, a tributary of the Dolores River, crossed Poverty Flats before the UC tailings were placed there. The channel has been redirected to the south of the tailings pile. Diversion ditches and the dirt road divert runoff from the pile, so surface runoff is confined to the

precipitation that falls directly on the site. Coarse rock material has been used to protect areas subject to erosion.

Because the NC tailings are located on the modern flood plain of the Dolores River, they also are subject to flooding. Should the foot of the pile be flooded, however, the resulting erosion would be minimal because the river channel widens downstream from the tailings, thus decreasing the flow velocity of the river. A thick stand of shrubs along the foot of the pile also reduces flow velocity.

Surface runoff at the NC site is limited to the precipitation that falls directly on the site. Drainage ditches and the dirt road above the site direct water away from the tailings. There is no evidence of erosion of the tailings, although small rivulets show in the cover material.

### 2.7.3 Ground Water Hydrology

Ground water conditions in the Slick Rock area are highly dependent on local structural, stratigraphic, and topographic features because canyon cutting and tectonic fracturing have drained many potential aquifers. In the Slick Rock area, both bedrock and alluvial aquifers have supplied water from the wells depicted in Figure 2-8.

Unconfined ground water at the Slick Rock sites is found in the alluvium and in the immediate underlying bedrock. Percolation of precipitation through the tailings into the ground water system is highly unlikely because surface runoff is limited to the precipitation that falls on the site, annual precipitation is less than 7 in., and evaporation rates are high. The unconfined ground water level under the tailings piles is approximately at the level of the Dolores River. These waters generally are well below the tailings; however, during times of high water flow, water rises into sections of the piles.

The UC tailings lie on alluvial material and on bedrock of the Navajo Sandstone, which underlies the Entrada Sandstone in the Slick Rock area. The Entrada Sandstone is tapped at isolated locations and is one of the potentially productive aquifers in the area. The Navajo Sandstone is not as productive an aquifer as the Entrada, although the two formations are sufficiently connected hydraulically to transmit water between their respective strata. The NC tailings lie on alluvial material underlain by bedrock strata of the Salt Wash Member of the Morrison Formation. Water in the Salt Wash Member is confined by overlying mudstones and by the lowermost mudstone strata of the member itself.

Water confined in these three potential aquifers (the Entrada, Navajo, and Morrison) is recharged in part along the Dolores River and flows northeastward toward the core of the

Disappointment Syncline. Unconfined ground waters and surface waters near the site contribute to this recharge; should these waters be contaminated by the tailings, the contamination could enter the confined ground water system. The extent of such contamination would be reduced by dilution by the Dolores River and would be hard to distinguish from the effects of natural sources of radionuclides. Even if waters from the NC site could infiltrate the Salt Wash Member, the change in water quality would be minimal because this member is the host rock for much of the uranium and vanadium deposits in the area. Farther downstream, in Paradox Valley, the Dolores River flows across salt exposures of the Paradox Basin evaporites, and the water quality of the river and its associated unconfined and confined ground water system deteriorates significantly.

Recent<sup>(4,5)</sup> 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 environments of the piles. The principal investigator<sup>(4)</sup> 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 tailings piles are near the Dolores River, there may be a large source of water to migrate by capillary action to the surface.

#### 2.7.4 Meteorology<sup>(6)</sup>

Winds and intense rainfall can result in erosion of the tailings. There is little information regarding the frequency, duration, and intensity of winds at Slick Rock because the nearest airport weather stations are too far away to be of any but regional significance. Based on regional information and local topography, however, it is probable that the strongest winds at the sites are those that sweep up and down the valley as shown in Figure 2-9. The average wind speed in the Slick Rock area is estimated to be 3.4 mi/hr.

High-intensity rainfalls, such as thunderstorms, are events that have caused and will continue to cause some erosion on the tailings piles. Annual average precipitation at Slick Rock has been estimated at approximately 7 in. Thunderstorm activity and precipitation are greatest during August and September. Rock, soil material, and partial vegetative cover protect most sections of the piles from all but the most severe conditions. Much of the gully erosion in the past has been repaired, and ongoing maintenance is performed on the UC site.

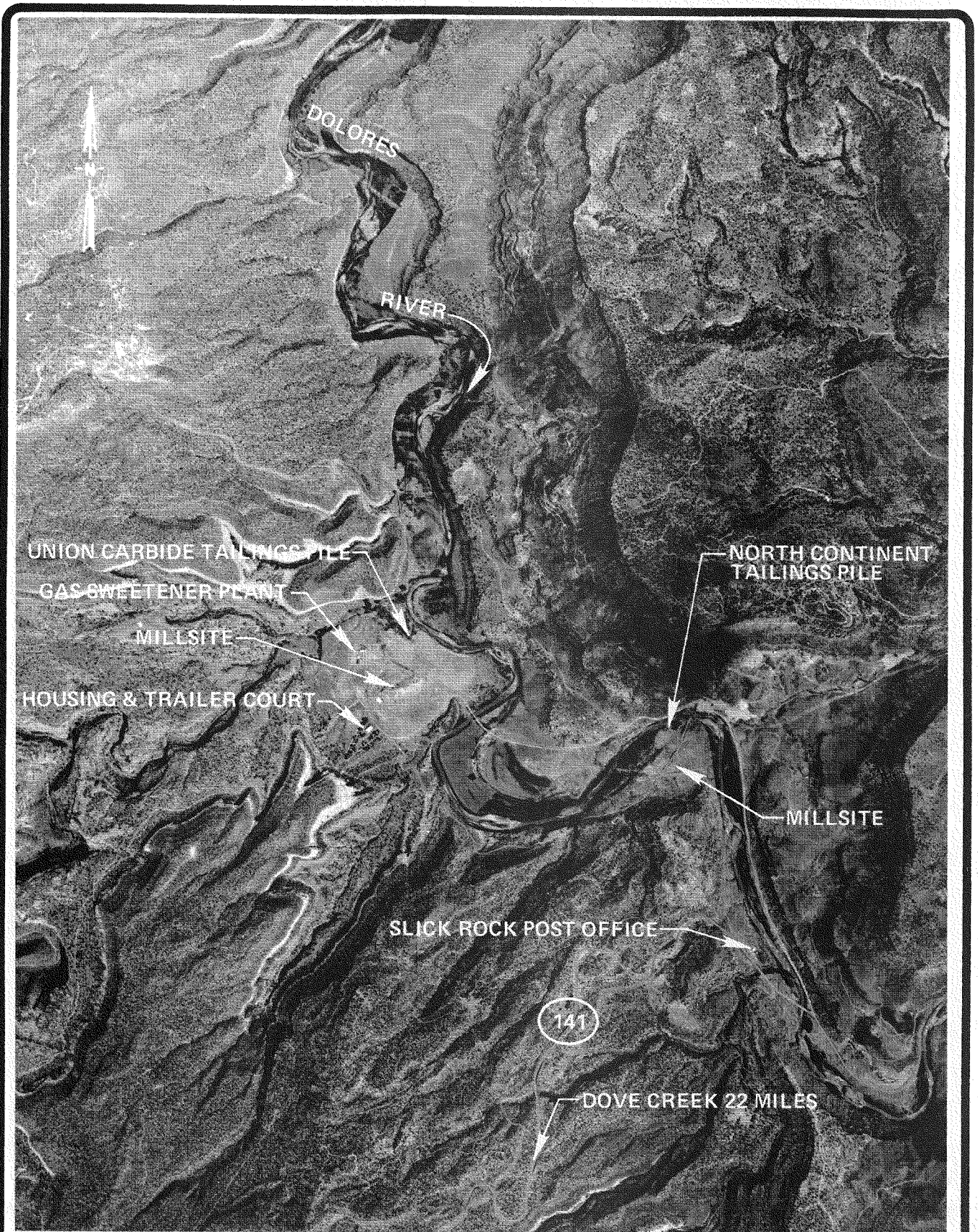
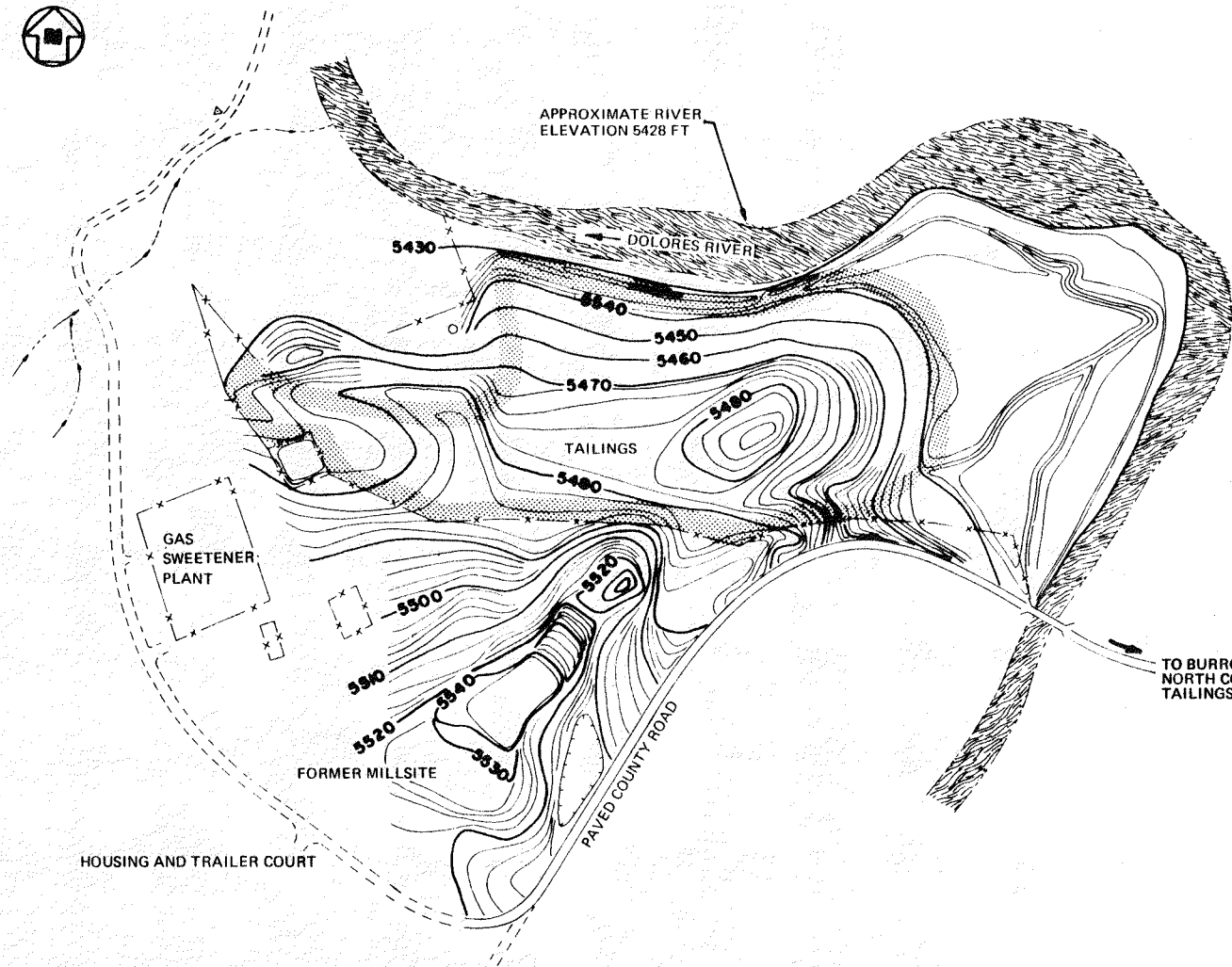



FIGURE 2-1. AERIAL PHOTOGRAPH OF SITE

360-07 10/77



NOTE:  
MAP DEVELOPED FROM FB&DU SURVEY DATA  
LOGGED APRIL 9, 1976

LEGEND

 EDGE OF TAILINGS

TO BURRO MINE AND  
NORTH CONTINENT  
TAILINGS PILE 0.9 MI

0 100 200 300 400 500 600 FT  
CONTOUR INTERVAL 2 FT

FIGURE 2-2A. TOPOGRAPHIC MAP OF UNION CARBIDE TAILINGS AREA

360-07 10/77

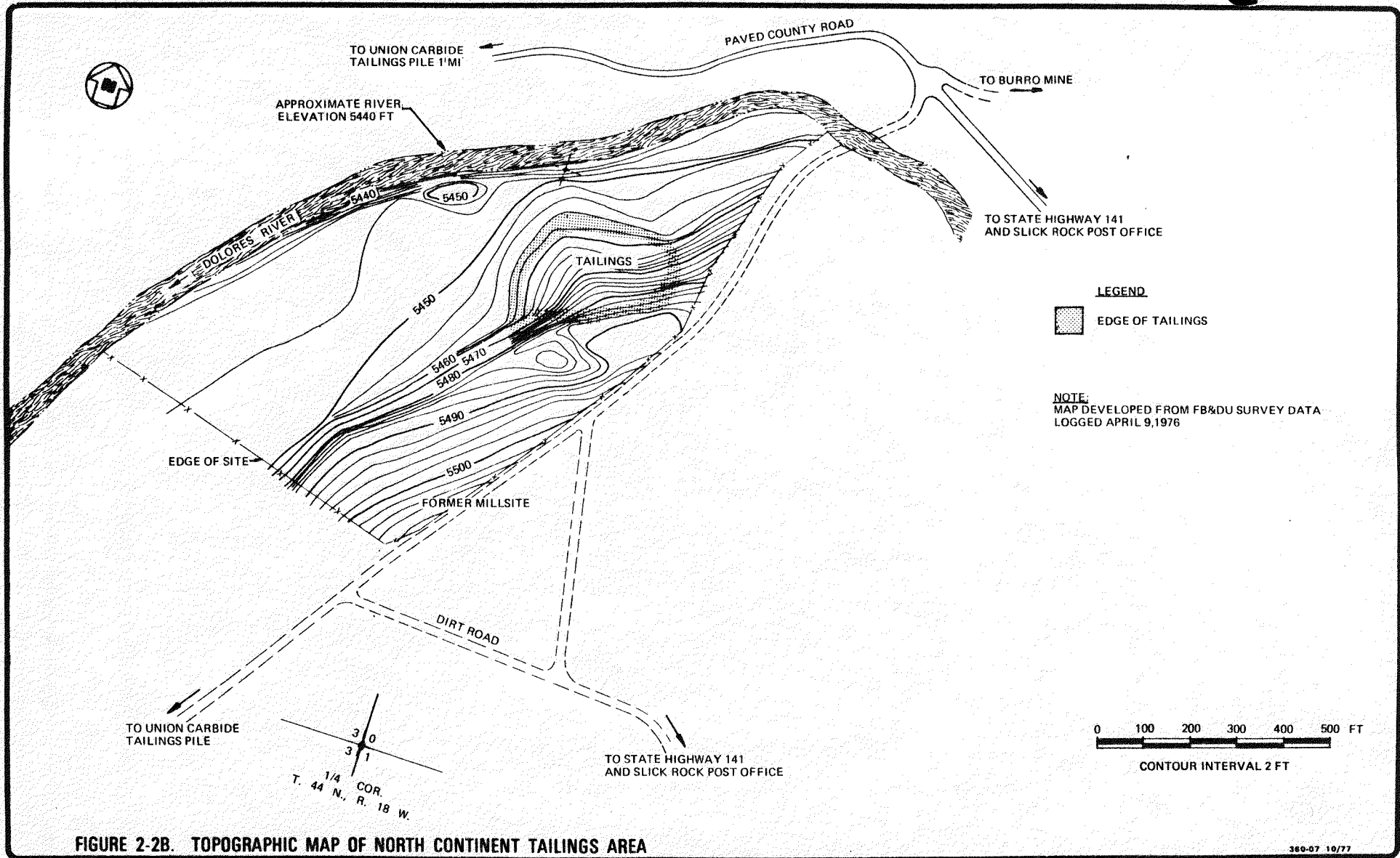
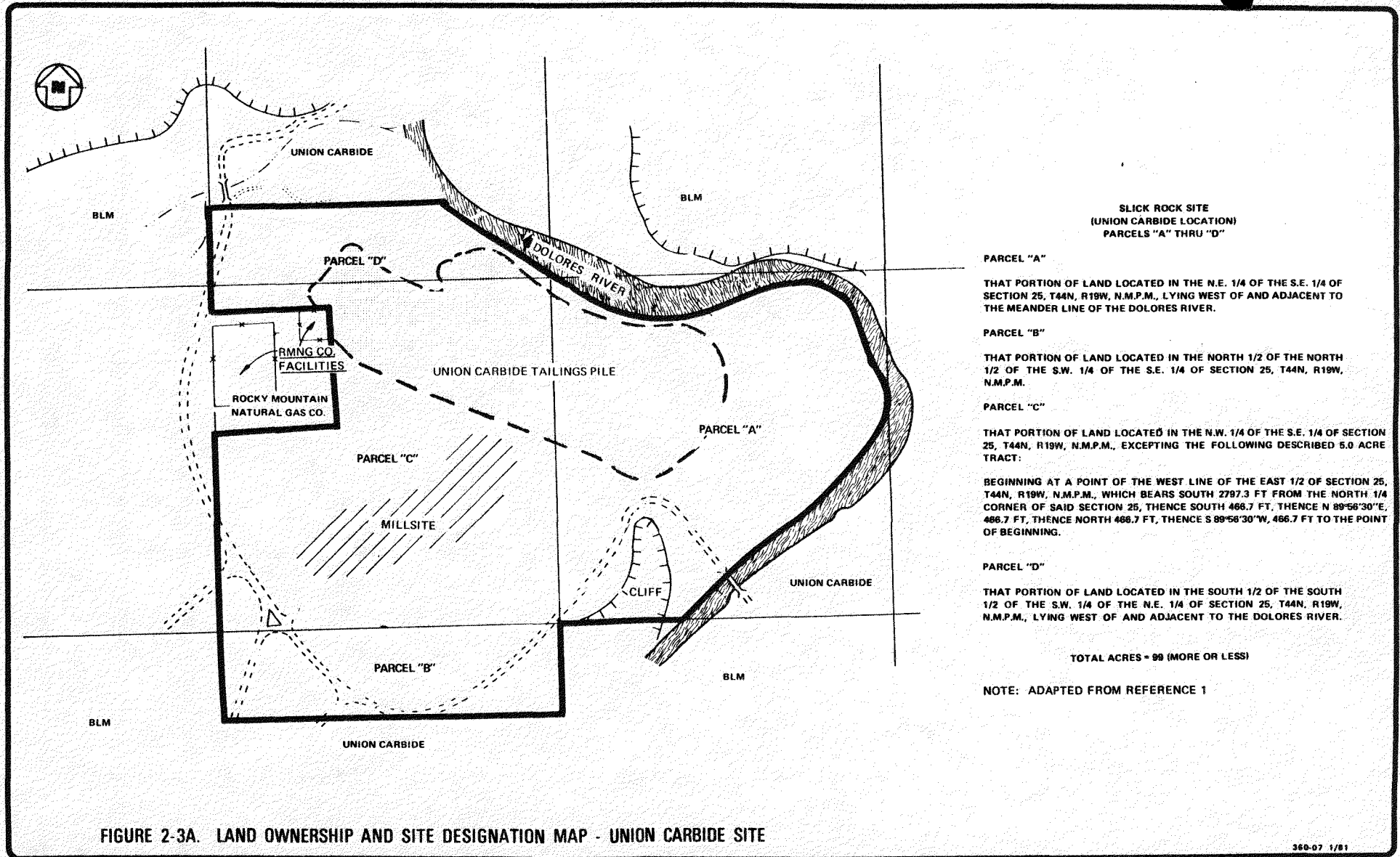


FIGURE 2-2B. TOPOGRAPHIC MAP OF NORTH CONTINENT TAILINGS AREA

360-07 10/77



**SLICK ROCK SITE  
(UNION CARBIDE LOCATION)  
PARCELS "A" THRU "D"**

**PARCEL "A"**

THAT PORTION OF LAND LOCATED IN THE N.E. 1/4 OF THE S.E. 1/4 OF SECTION 25, T44N, R19W, N.M.P.M., LYING WEST OF AND ADJACENT TO THE MEANDER LINE OF THE DOLORES RIVER.

**PARCEL "B"**

THAT PORTION OF LAND LOCATED IN THE NORTH 1/2 OF THE NORTH 1/2 OF THE S.W. 1/4 OF THE S.E. 1/4 OF SECTION 25, T44N, R19W, N.M.P.M.

**PARCEL "C"**

THAT PORTION OF LAND LOCATED IN THE N.W. 1/4 OF THE S.E. 1/4 OF SECTION 25, T44N, R19W, N.M.P.M., EXCEPTING THE FOLLOWING DESCRIBED 5.0 ACRE TRACT:

BEGINNING AT A POINT OF THE WEST LINE OF THE EAST 1/2 OF SECTION 25, T44N, R19W, N.M.P.M., WHICH BEARS SOUTH 2797.3 FT FROM THE NORTH 1/4 CORNER OF SAID SECTION 25, THENCE SOUTH 466.7 FT, THENCE N 89°58'30"E, 466.7 FT, THENCE NORTH 466.7 FT, THENCE S 89°58'30"W, 466.7 FT TO THE POINT OF BEGINNING.

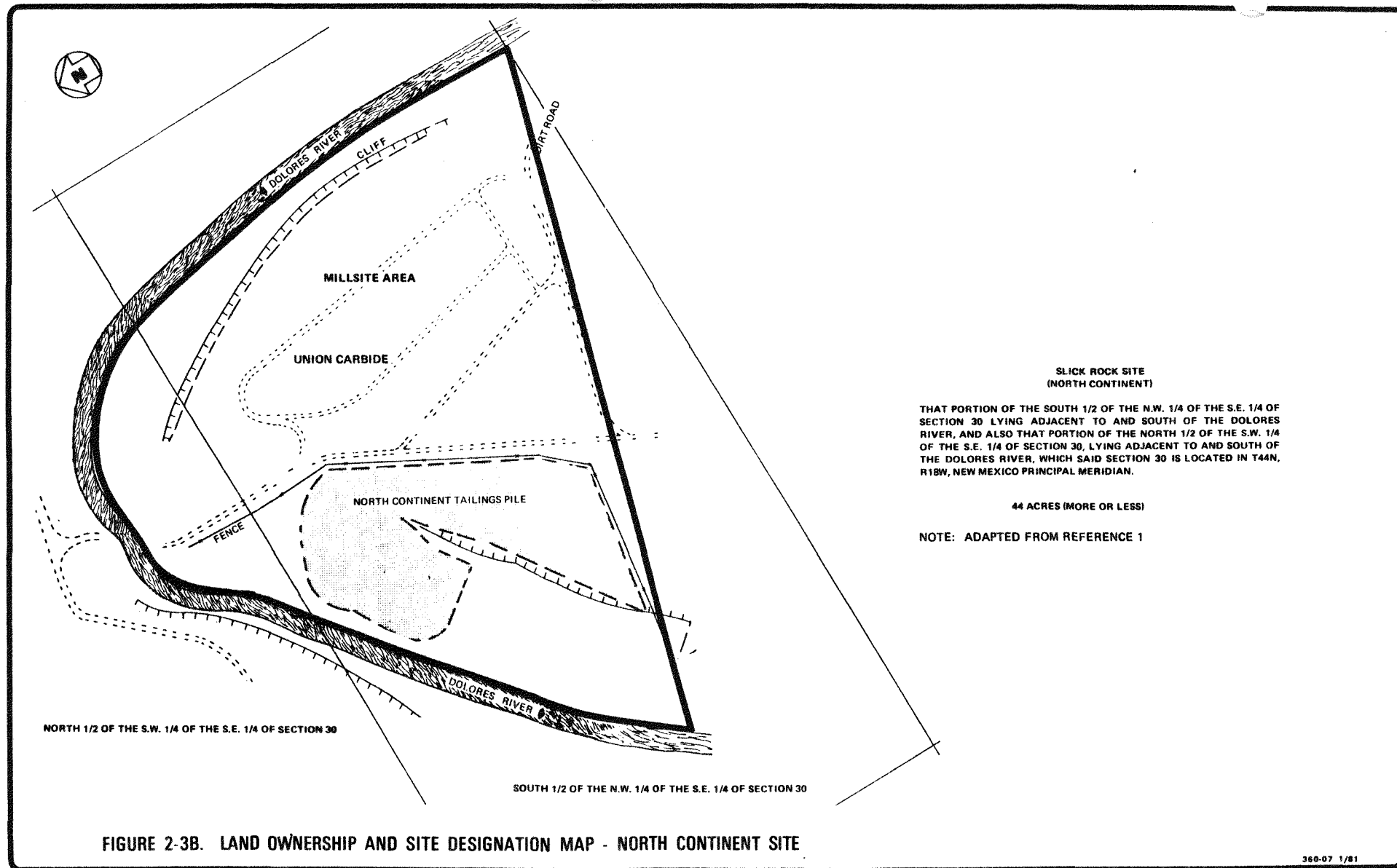
**PARCEL "D"**

THAT PORTION OF LAND LOCATED IN THE SOUTH 1/2 OF THE SOUTH 1/2 OF THE S.W. 1/4 OF THE N.E. 1/4 OF SECTION 25, T44N, R19W, N.M.P.M., LYING WEST OF AND ADJACENT TO THE DOLORES RIVER.

TOTAL ACRES = 99 (MORE OR LESS)

NOTE: ADAPTED FROM REFERENCE 1

**FIGURE 2-3A. LAND OWNERSHIP AND SITE DESIGNATION MAP - UNION CARBIDE SITE**



360-07 1/81

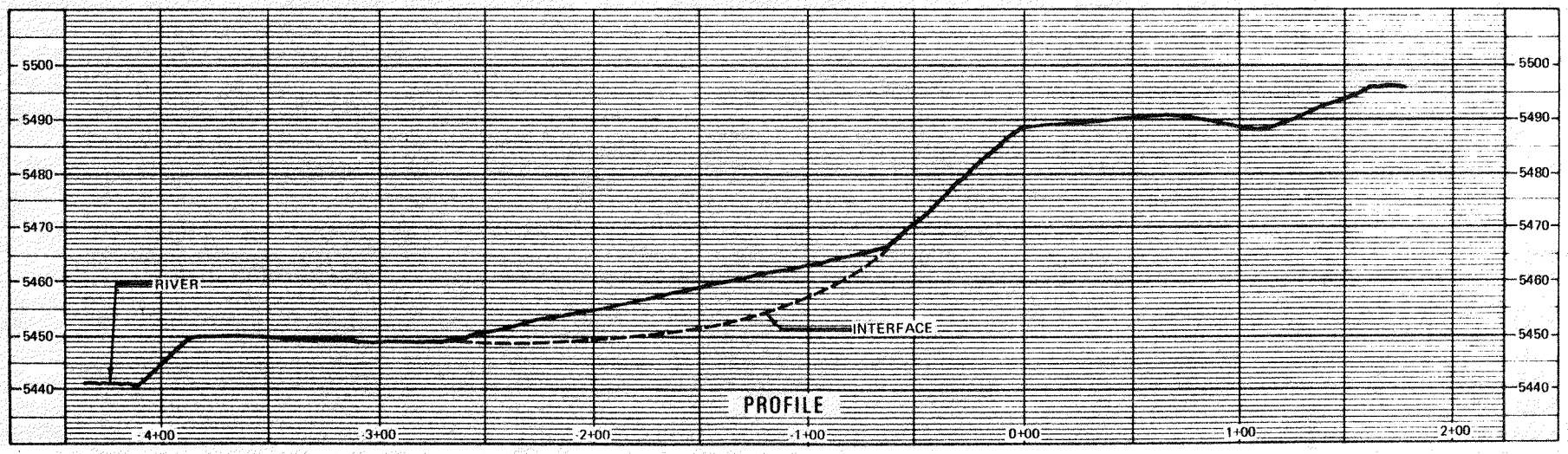
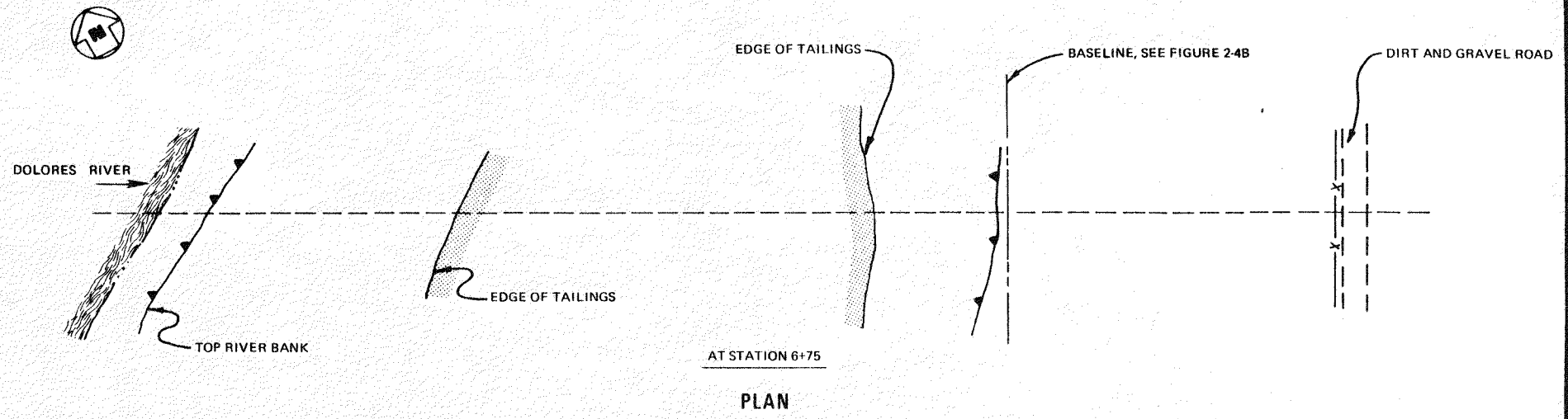


FIGURE 2-5B. CROSS-SECTION AT STATION 6+75, NORTH CONTINENT SITE

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SYSTEM	FORMATION	THICKNESS (FEET)	CHARACTER	POSITION OF THE TAILINGS
CRETACEOUS	MANCOS SHALE	2,000 - 5,000	GRAY SHALE; FORMS VALLEYS AND SLOPES	
	DAKOTA SANDSTONE	0 - 200	GRAY AND BROWN SANDSTONE AND SHALE; CAPS MESAS	
	BURRO CANYON FORMATION	50 - 250	CONGLOMERATIC SANDSTONE AND MAROON AND GREEN MUDSTONE; CAPS AND MESAS	
JURASSIC	MORRISON FORMATION	300 - 500	BRUSHY BASIN MEMBER: VARICOLORED SHALES, SOME SANDSTONE; FORMS SLOPES	NORTH CONTINENT TAILINGS ←
			SALT WASH MEMBER: LIGHT COLORED SANDSTONE AND RED MUDSTONE; FORMS BENCHES	
	SUMMERVILLE FORMATION	0 - 400	RED AND GRAY SHALE, THIN SANDSTONE; FORMS SLOPES	
	ENTRADA SANDSTONE	50 - 1,000	SLICK ROCK MEMBER: LIGHT COLORED MASSIVE SANDSTONE; FORMS CLIFFS	
	NAVAJO SANDSTONE	0 - 2,000	LIGHT COLORED MASSIVE SANDSTONE; FORMS CLIFFS	UNION CARBIDE TAILINGS ←
OLDER SEDIMENTARY ROCKS				

FIGURE 2-6. SIMPLIFIED STRATIGRAPHIC COLUMN

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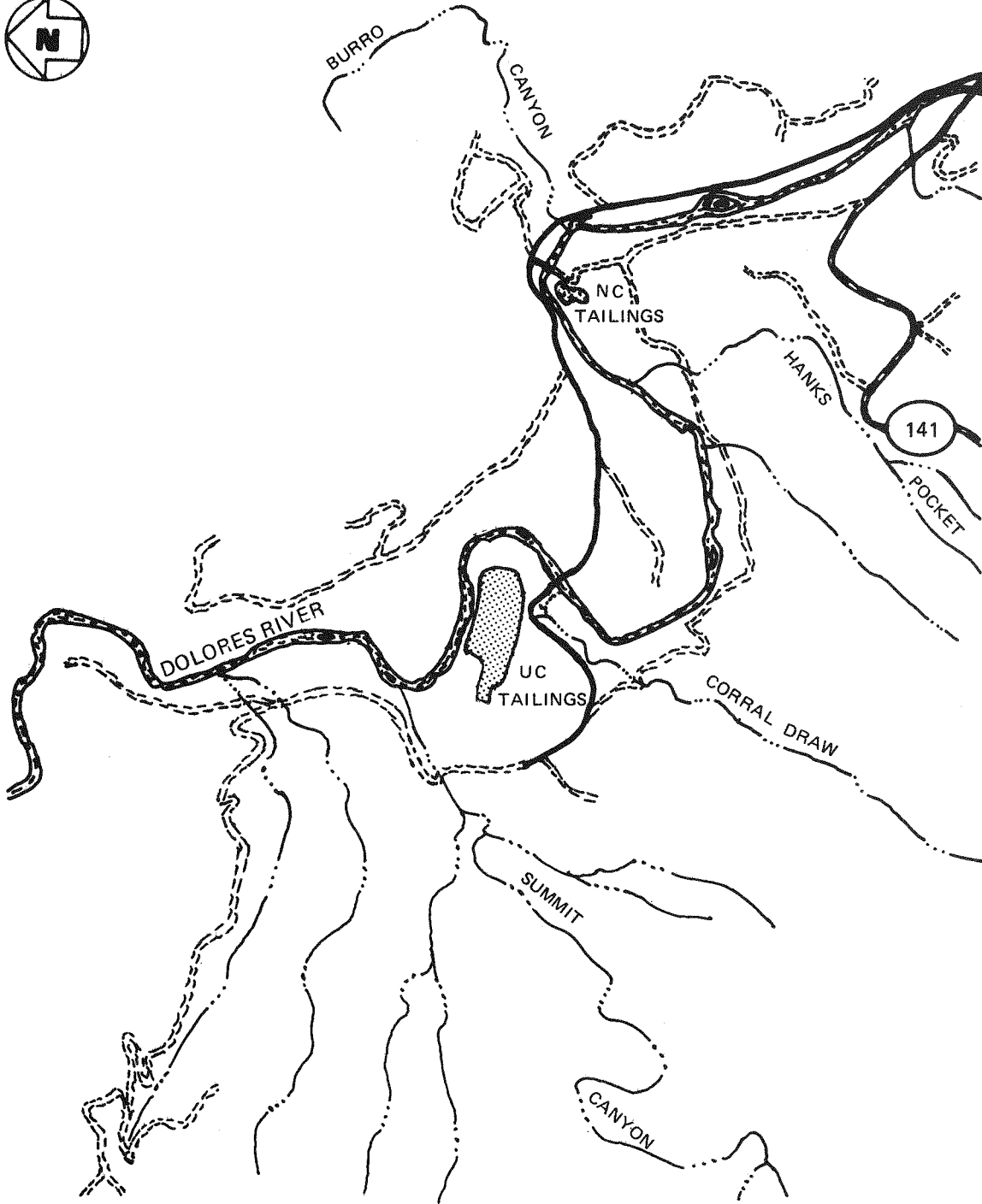
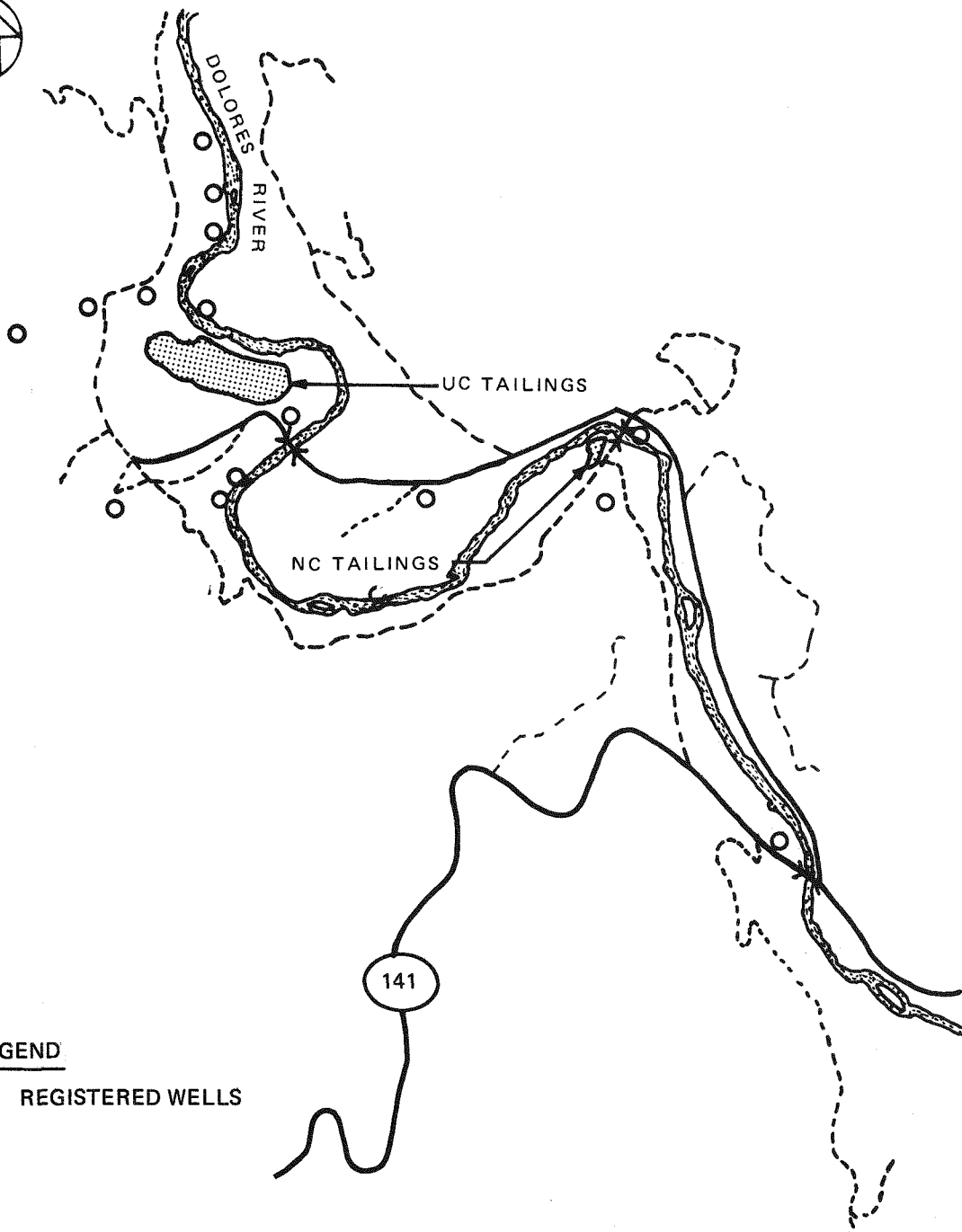


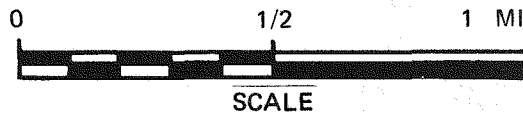
FIGURE 2-7. SURFACE DRAINAGE PATTERNS

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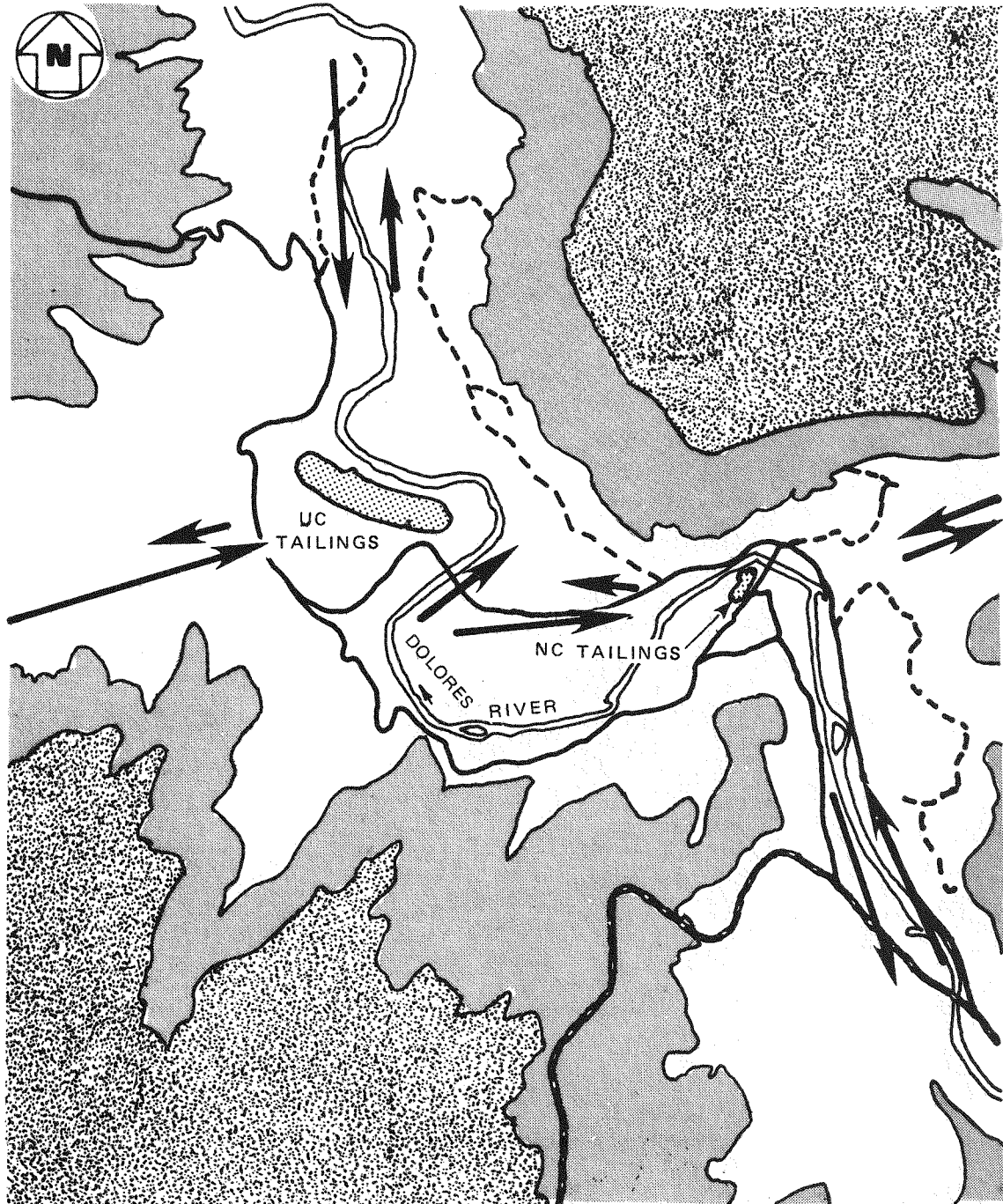
**LEGEND**

○ REGISTERED WELLS





**FIGURE 2-8. REGISTERED WELLS NEAR SLICK ROCK**

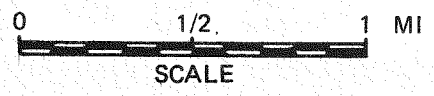
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**LEGEND**

-  500+ FEET ABOVE VALLEY FLOOR
-  200-500 FEET ABOVE VALLEY FLOOR

RELATIVE MAGNITUDE OF WINDS  
DEPICTED BY LENGTH OF ARROWS



**FIGURE 2-9. WIND MAP**

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TABLE 2-1

## CONTAMINATED MATERIALS AT SLICK ROCK SITES

<u>Material</u>	<u>Union Carbide Site</u>		<u>North Continent Site</u>	
	<u>Volume (yd<sup>3</sup>)</u>	<u>Weight (tons)</u>	<u>Volume (yd<sup>3</sup>)</u>	<u>Weight (tons)</u>
Uranium and Vanadium Tailings	278,300	350,000 <sup>a</sup>	28,700	36,600 <sup>a</sup>
Stabilization Cover	15,300	19,600 <sup>a</sup>	4,800	6,200 <sup>a</sup>
Contaminated Subsoil Beneath Tailings	92,000 <sup>b</sup>	124,000 <sup>i</sup>	96,800 <sup>e</sup>	130,700 <sup>i</sup>
Contaminated Soil in Mill and Ore Storage Areas	84,000 <sup>c</sup>	113,400 <sup>i</sup>	43,600 <sup>f</sup>	58,900 <sup>i</sup>
Windblown Contaminated Soil	42,000 <sup>d</sup>	56,700 <sup>i</sup>	2,500 <sup>g</sup>	3,400 <sup>i</sup>
Other Contaminated Soil	--	--	90,400 <sup>h</sup>	122,000 <sup>i</sup>
Total	511,600	663,700	266,800	357,800

<sup>a</sup>Except for tailings, weight is based on average existing field densities, which include moisture.

<sup>b</sup>Volume based on 19 acres contaminated to an average depth of 3 ft beneath tailings interface.

<sup>c</sup>Volume based on 13 acres contaminated to an average depth of 4 ft.

<sup>d</sup>Volume based on 52 acres contaminated to an average depth of 6 in.

<sup>e</sup>Volume based on 6 acres contaminated to an average depth of 10 ft beneath tailings interface.

<sup>f</sup>Volume based on 9 acres contaminated to an average depth of 3 ft.

<sup>g</sup>Volume based on 3 acres contaminated to an average depth of 6 in.

<sup>h</sup>Volume based on 7 acres contaminated to an average depth of 8 ft.

<sup>i</sup>Weight based on 100 lb/ft<sup>3</sup> density.

TABLE 2-2

## PHYSICAL PROPERTIES AND pH OF THE URANIUM TAILINGS

<u>Sample Location*</u>	<u>Percent Moisture</u>	<u>Bulk Density (lb/ft<sup>3</sup>)</u>	<u>pH (5% water by wt)</u>
<u>Union Carbide</u>			
SRUC-5	4.26	98	7.83
SRUC-18	7.25	88	7.40
SRUC-6			7.95
<u>North Continent</u>			
SRNC-9	4.75	91	7.80
SRNC-12	0.65	97	7.25

\*See Figures 2-4A and 2-4B.

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## 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, Vol 44, No. 173, 51894; Sep 5, 1979.
2. "Phase I Report on Conditions of Union Carbide Uranium Upgrader Site and Tailings near Slick Rock, Colorado" and "Phase I Report on Conditions of Uranium Millsite and Tailings at Old North Continent Site, Slick Rock, Colorado"; AEC; Grand Junction, Colorado; 1974; (See Chapter 1, Reference 5).
3. R.C. Merritt; The Extractive Metallurgy of Uranium; Colorado School of Mines Research Institute; Golden, Colorado; 1971.
4. 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.
5. 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.
6. "Meteorology Affecting Uranium Tailings at Slick Rock, Colorado"; unpublished report; URS Company; Denver, Colorado; June 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 Slick Rock uranium tailings piles and the resulting potential exposure to the population residing and working in the vicinity of Slick Rock, 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 Union Carbide and North Continent mill tailings sites at Slick Rock, Colorado, was conducted by Oak Ridge National Laboratory (ORNL)<sup>(1)</sup> 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,  $^{238}\text{U}$ , undergoes radioactive decay, it emits a subatomic particle called an alpha particle; the  $^{238}\text{U}$  after undergoing decay becomes  $^{234}\text{Th}$ , which is also radioactive; and  $^{234}\text{Th}$  subsequently emits a beta particle and becomes  $^{234}\text{Pa}$ . 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  $^{230}\text{Th}$  decays to  $^{226}\text{Ra}$ , which then decays to  $^{222}\text{Rn}$ , an isotope of radon. Radon, a noble gas, does not react chemically. The final product in the chain is  $^{206}\text{Pb}$ , a stable isotope that gradually accumulates in ores containing uranium. Uranium ore contains  $^{226}\text{Ra}$  and the other daughter products of the uranium decay chain. One of the daughters of  $^{226}\text{Ra}$  is the isotope  $^{214}\text{Bi}$ , which emits a significant amount of electromagnetic radiation known as gamma radiation. Gamma rays are very similar to X-rays, only more penetrating. The  $^{214}\text{Bi}$  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  $3.7 \times 10^{-2}$  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  $4.5 \times 10^9$  yr for half the  $^{238}\text{U}$  atoms to decay to  $^{234}\text{Th}$ . Similarly, half of a given number of  $^{222}\text{Rn}$  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,  $^{230}\text{Th}$ , 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 piles. 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  $1.3 \times 10^5$  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 the Glossary at the end of the report.)

### 3.3 NATURAL BACKGROUND RADIATION

Several sources of radiation 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 18 off-site soil samples for each member of the uranium decay chain, assuming equilibrium, was 1.5 pCi/g.<sup>(1)</sup> The sample locations, taken in 1976 within a 150-mi radius of Slick Rock, and the corresponding  $^{226}\text{Ra}$  concentrations are shown in Figure 3-2. Another natural source of radiation in the environment arises from the decay of  $^{232}\text{Th}$ , the predominant thorium isotope. The half-life of  $^{232}\text{Th}$  is  $1.4 \times 10^{10}$  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. Background values of the radium and thorium chains vary with locations by factors of 6 and 14, respectively.

The locations and  $^{226}\text{Ra}$  content of four soil samples taken during the 1980 field work at locations about 0.5 mi from the Slick Rock tailings sites are shown in Figure 3-3. The average  $^{226}\text{Ra}$  concentration in these samples was 2.5 pCi/g.

Background values of radon concentrations in air were measured at three locations 0.75 to 2.5 mi from the tailings piles, as shown in Figure 3-4, using continuous radon monitors supplied by ERDA.<sup>(2)</sup> An average background value of 1.5 pCi/l was obtained from the 24-hr samples. However, the range of the measurements extends from 1.2 to 1.7 pCi/l. Numerous uranium mines in the vicinity contribute to the high radon background in the valley.

Background gamma ray levels, as measured 3 ft above the ground, also were determined at several locations within 1 mi of the site by using a calibrated and energy-compensated Geiger Mueller detector. A value of 10  $\mu\text{R/hr}$  was established as the average background level, but the values ranged from

6 to 13  $\mu\text{R/hr}$ .<sup>(1)</sup> Cosmic rays, generally dependent upon the altitude, are part of the measured background radiation levels. The contribution from cosmic rays is approximately 7  $\mu\text{R/hr}$  in the Slick Rock area,<sup>(3)</sup> 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  $^{238}\text{U}$  decay chain: primarily  $^{230}\text{Th}$ ,  $^{226}\text{Ra}$ ,  $^{222}\text{Rn}$ , and  $^{222}\text{Rn}$  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  $^{222}\text{Rn}$  daughters, from decay of  $^{222}\text{Rn}$  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  $^{214}\text{Bi}$ ) 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  $^{230}\text{Th}$  and  $^{226}\text{Ra}$ , 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  $^{226}\text{Ra}$ ) 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 piles into the environment is discussed in the following paragraphs.

#### 3.4.1 Radon Gas Diffusion and Transport

Results of measurements of the radon exhalation flux from the tailings made in 1976<sup>(4)</sup> and 1980 are shown in Figures 3-5A and 3-5B. On the UC pile, the range of measurements for radon flux was from less than 1 to about 130 pCi/m<sup>2</sup>-s, while on the NC pile the range was from about 1 to more than 700 pCi/m<sup>2</sup>-s. Based on this very limited data base, the average flux from the UC pile was estimated to be 70 pCi/m<sup>2</sup>-s, while from the NC pile it was estimated to be about 240 pCi/m<sup>2</sup>-s. The weather was warm and dry during the measurement periods and the tailings surfaces were uniformly dry. Both sites have been stabilized with a 6-in. covering of dirt and rock. Reported values of radon flux at a sampling location may vary considerably from time to time as a result of such factors as soil moisture content, atmospheric inversion conditions, and barometric pressure.

Radon gas above background, considered to be from the piles, has been detected at a distance of about 0.6 mi from the sites. Measurement locations and corresponding 24-hr average radon concentrations are illustrated in Figure 3-4. The high background values in the area may not be solely ascribed to radon being released from the piles, since there are numerous active uranium mines in the area that also contribute to the radon background concentration. The location of the mines on the hillsides above the river valley in which the tailings sites are located is the cause of some radon buildup in the vicinity of the piles.

The variation of radon concentration at two locations during the measurement period is illustrated in Figures 3-6 and 3-7. The figures also include the nearest available weather data, from Cortez, Colorado, 52 mi south-southeast of Slick Rock. The sample location in Figure 3-6 is the trailer park southwest of the UC site. The relatively low value of outdoor radon concentration at the trailer park is probably due to its location at right angles to the prevailing wind directions up and down the valley.

Figure 3-7 shows measurements made 0.21 mi north of the UC site, where the Dolores River Valley narrows. A diurnal variation of <sup>222</sup>Rn concentration is evident in both figures, indicating the presence of a <sup>222</sup>Rn source greater than background in the general area. All radon measurements performed at Slick Rock showed this effect. The background measurement taken about 2.5 mi southwest of the tailings sites and toward the top of the mesa showed the least amount of buildup. These 24-hr measurements were obtained during atmospheric conditions normal

for that time of year (April and May). Data were not recorded during wind or rainstorms.

The radon concentration measurements generally indicated increased concentrations during the night and reduced values during the day. The increase in concentration at night is probably the result of an inversion condition, changes in wind direction, 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 piles.

The calculated radon concentration is shown as a function of distance from the edge of the piles in Figure 3-8. Model calculations were performed using conservatively predicted meteorology for the Dolores River Valley to provide an estimate of the radon concentration in the vicinity of the piles. The model first determines radon flux and the total radon released from the piles 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<sup>(5)</sup> plus wind conditions. The model curves in Figure 3-8 were used to calculate potential health effects resulting from radon diffusing from the Slick Rock tailings, and the health effects of each pile were summed to get the total Slick Rock health effects.

#### 3.4.2 Direct Gamma Radiation

Background gamma radiation in the Slick Rock area is about 10  $\mu\text{R/hr}$ . This is an average value based upon several measurements taken away from the piles.<sup>(1)</sup>

##### 3.4.2.A Union Carbide Site

The external gamma radiation (EGR) levels measured in 1976 on the UC tailings pile and millsite are shown in Figure 3-9A.<sup>(1)</sup> These measurements were taken with calibrated, energy-compensated Geiger Mueller detectors.<sup>(1)</sup> The highest gross gamma radiation (180  $\mu\text{R/hr}$ ) found at the UC site, probably a result of ore spillage, was an isolated spot measured just off the millsite about 100 ft south of the road to the Burro Mine. All other gamma measurements on this site were below 90  $\mu\text{R/hr}$ .

The EGR levels away from the UC tailings pile were also measured during the 1980 field survey work. These measurements were taken with a calibrated gamma scintillation detector. The highest EGR level, 147  $\mu\text{R/hr}$ , was recorded about 100 ft from the edge of the pile, south of the tailings and east of the gas sweetener plant. Several readings in excess of 50  $\mu\text{R/hr}$  were obtained from areas to the south and southeast of the tailings pile, but EGR levels reached background range within about 500 ft in all directions.

Gamma measurements away from the tailings pile taken at 100-yd intervals reached background levels by about 0.2 mi in all directions except to the north. Toward the north, gamma radiation reached the background range 0.4 mi from the tailings pile. The gamma levels measured in the vicinity of the pile are shown in Figure 3-10. The higher gamma readings in the northerly direction were caused by windblown tailings and other radioactive material away from the tailings piles. This is evident from the high gamma radiation level shown in Figure 3-11A, where gamma radiation versus distance from the tailings pile is plotted.

#### 3.4.2.B North Continent Site

The EGR levels measured on the NC tailings pile and millsite are shown in Figure 3-9B.<sup>(1)</sup> The highest gross gamma radiation found at the NC site (3,000  $\mu\text{R/hr}$ ) was measured southwest of the tailings pile between the toe of the bluff and the Dolores River. This "hot spot" was about 200 ft long, and gamma readings averaged over 2,000  $\mu\text{R/hr}$ . These high gamma readings below the bluff did not appear to result from tailings, but rather from either a continuing seepage from the mill or from a major spill. Along the edge of the bluff and in a small wash at the southwest end of the bluff, opposite the hottest spot, there was evidence of contamination by a liquid. Green stained rock was found along exposed rock strata on the bluff a few feet below the surface of the millsite. In the area where gamma readings were highest, a white surface deposit was present. This area was covered with brush and otherwise appeared undisturbed. Further details of drill hole logging in this area are discussed in Paragraph 3.4.5.B. The next highest reading, 730  $\mu\text{R/hr}$ , was found about 300 ft southwest of the first hot spot on a line parallel to the Dolores River and outside the fence enclosing the southern edge of the tailings. A third hot spot, which measured 680  $\mu\text{R/hr}$ , was found south of the tailings pile in the former millsite.

Except for these localized hot spots, measurements away from the NC pile reached the background range within 0.1 mi in all directions from the pile. The gamma levels measured in the area surrounding the piles are shown in Figure 3-10. A typical reduction of gamma radiation as a function of distance from the pile in the south-southeast direction is shown in Figure 3-11B.

During the 1980 field work it was observed that the EGR measurements away from the NC pile reached background range within 400 ft of the edge of the pile in all directions. The highest readings were obtained along a line running northwest from the pile boundary to the Dolores River.

### 3.4.3 Windblown Contaminants

Another pathway is the result of windblown tailings. The prevailing winds follow the Dolores River Valley in a north-south direction. No air particulate measurements were performed at the Slick Rock sites.

Measurements and data analyses were performed in 1980 to establish the boundary of that region around the site that exceeds 5 pCi/g of  $^{226}\text{Ra}$  concentration in the soil believed to be due to windblown contamination. One end of a lead-shielded scintillometer, NaI(Tl), was unshielded and directed toward the ground, where it was held about 1 in. above the ground surface. An unshielded reading was obtained. A 0.5-in.-thick lead shield was then placed over the unshielded end and a second reading was obtained. The difference between the unshielded and shielded readings, called the "delta", represents the exposure to radioactivity at that location. A delta of about 400 counts/min has been estimated to indicate an area with a soil concentration of about 5 pCi/g of  $^{226}\text{Ra}$  with the meter used. The delta values and the estimated 5-pCi/g boundary lines around the sites are shown in Figures 3-12A and 3-12B.

#### 3.4.3.A Union Carbide Site

Windblown tailings were observed north and east of the UC pile. Figure 3-13A indicates an iso-exposure line due to the windblown tailings as determined by the EPA.<sup>(6)</sup>

If scattered tailings and ore are removed from inside the 10  $\mu\text{R/hr}$  line (toward the pile), and if the pile is covered to provide essentially complete gamma shielding, then the remaining tailings outside the line (away from the pile) would produce a new gamma exposure rate, 3 ft above ground, approximately equal to 10  $\mu\text{R/hr}$ .

Seven traverses with the scintillometer were conducted, starting at the Union Carbide tailings pile fence and proceeding across open land surrounding the pile. The traverses extended to locations where a concentration of 5 pCi/g of  $^{226}\text{Ra}$  in the surface soil was indicated, as explained above. These locations are connected in Figure 3-12A to form a 5-pCi/g boundary around the site. The boundary extends to the Dolores River on the north, 400 ft from the tailings fence on the south, and 100 ft to the east and west of the tailings pile. This survey suggests a smaller contaminated area than resulted from the EPA gamma survey.<sup>(6)</sup> Figure 3-12A represents only windblown contamination, which does not include the millsite, a substantial radiation source. The cleanup work and cost options described in this report are based on the 52 acres of contaminated land included in the EPA gamma survey, only about 16 acres of which are located outside the designated site boundaries.

Surface soil samples were taken in the area surrounding the site.<sup>(1)</sup> The sample locations and  $^{226}\text{Ra}$  concentrations are shown in Figure 3-14A. The data show levels of surface contamination on the former millsite measuring as high as 41 pCi/g. Immediately north of the tailings pile a sample had a  $^{226}\text{Ra}$  concentration of about 52 pCi/g. Away from the millsite, the ore storage area, and the tailings pile, the  $^{226}\text{Ra}$  concentrations drop to background levels within 0.1 mi except to the north. As mentioned in Paragraph 3.4.2.A, the gamma radiation surveys indicate windblown tailings as far as 0.4 mi north of the tailings pile.

#### 3.4.3.B North Continent Site

Little windblown contamination was found around the NC site other than a small area northwest of the pile. The EPA gamma survey results are illustrated in Figure 3-13B. Contamination was found around the previous mill and residential areas.

Six traverses with the scintillometer were conducted around the NC tailings pile in 1980. Again, the traverses were continued until a concentration of 5 pCi/g of  $^{226}\text{Ra}$  in the surface soil was indicated. These locations are connected in Figure 3-12B to form a 5-pCi/g boundary around the site. The boundary extends to the Dolores River on the north of the pile and is reached within 100 ft of the fence on the south, east, and west sides of the pile. This survey is in good agreement with the EPA gamma survey.<sup>(6)</sup> The cleanup work and cost options described in this report are based on the 3 acres of contaminated land included in the EPA gamma survey, 2 acres of which are located outside the designated site boundaries.

The locations and  $^{226}\text{Ra}$  concentrations of surface samples taken from the site are shown in Figure 3-14B. Two spots contained high amounts of radium. The first, which had a  $^{226}\text{Ra}$  concentration of about 30 pCi/g, was at the intersection of two roads about 100 ft south of the tailings pile. The second, which had a  $^{226}\text{Ra}$  concentration of about 19 pCi/g, was at the edge of the bluff overlooking the Dolores River about 200 yd southeast of the tailings pile. Neither of these spots appears to be due to windblown tailings.

#### 3.4.4 Ground and Surface Water Contamination

Twelve water samples were taken from the Dolores River in the vicinity of the two Slick Rock tailings sites. The samples were taken along a 3-mi section of the Dolores River ranging from about 1 mi upstream of the NC site to almost 1 mi downstream of the UC site, as shown in Figure 3-15.

Samples from the Dolores River within 0.2 mi of the tailings piles contained 1.0 to 2.4 pCi/l of  $^{226}\text{Ra}$ , which is below the EPA Interim Primary Drinking Water Regulations limit

of 5 pCi/l of combined  $^{226}\text{Ra}$  and  $^{228}\text{Ra}$ . River water samples taken farther than 0.2 mi from the tailings piles contained only a trace of  $^{226}\text{Ra}$ . The quality of the Dolores River with respect to  $^{226}\text{Ra}$  was closely monitored from 1961 to 1972 at Bedrock, Colorado, downstream from Slick Rock. The average  $^{226}\text{Ra}$  level during this period was 0.48 pCi/l,<sup>(7)</sup> and ranged between 0.28 and 0.85 pCi/l. Union Carbide Corporation has a water monitoring program planned for the Slick Rock area.

#### 3.4.5 Soil Contamination

The amount of  $^{226}\text{Ra}$  activity in the tailings and the extent of leaching of radium from the tailings into the soil were determined by drilling holes through the tailings piles and into the soil beneath them. Also, several holes were drilled in the mill areas at both Slick Rock sites. The radioactivity profile was measured in these holes with a Geiger tube probe with a lead shield that collimates the radiation. Soil samples also were taken from selected holes for radiometric analysis. The locations of the drill holes are shown in Figures 2-4A and 2-4B.

##### 3.4.5.A Union Carbide Site

A typical  $^{226}\text{Ra}$  activity profile of the UC tailings and subsoil is shown in Figure 3-16A-1. Figure 3-16A-1 illustrates the radiometric profile of hole 18 on the southeast edge of the tailings pile. About 2 ft of soil beneath the tailings appear to be contaminated. Radiometric analysis of a sample 2 ft below the tailings-soil interface contained  $^{226}\text{Ra}$  at about twice the average background concentration.<sup>(1)</sup> The tailings are about 2 ft thick and have relatively low radioactivity (120 pCi/g). The radiometric profile for hole 5 is shown in Figure 3-16A-2. It was drilled on the northern edge of the pile where the pile is adjacent to the Dolores River. The profile indicates a sharp drop in radioactivity at the tailings-soil interface. The  $^{226}\text{Ra}$  concentration was reached between 1 and 3 ft beneath the tailings.

Soil contamination to 1.5 ft was found in the area southwest of the mill foundations. Near the foundations in hole 16, 4 ft of soil were found contaminated. This location is in the area where leaching operations were performed, and spills are responsible for the remaining contamination. Hole 20 was drilled in what was apparently the ore stockpile area. Elevated  $^{226}\text{Ra}$  concentrations were measured to a depth of 4.5 ft.

##### 3.4.5.B North Continent Site

The radiometric profile for hole 9 on the southwestern edge of the NC tailings pile is plotted in Figure 3-16B-1. Soil contamination drops rapidly to about 3 times the average background level for  $^{226}\text{Ra}$  1.5 ft below the tailings.

An area about 100 yd southwest of the tailings pile indicated high gamma ray activity as shown in Figure 3-16B-2. Hole 12 drilled in that area showed high average contamination (350 pCi/g) for about 1 ft and an average of 75 pCi/g of  $^{226}\text{Ra}$  for a composite sample extending to a depth of 7.5 ft, where cobbles and water prevented further logging. This area is below a sandstone bluff on which the mill was located.

#### 3.4.6 Off-Site Tailings Use

Some of the uranium tailings have been moved from the site and used around nearby structures. These locations have been identified by a mobile survey and follow-up gamma surveys of individual locations. The locations and survey results are discussed in Chapter 7, where remedial action is considered.

#### 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<sup>(8)</sup> where tailings are present, and (b) the cleanup of open land.

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

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

Title II, Section 206 of PL 95-604 required the EPA to promulgate standards for the protection of the public and the environment from radiological and nonradiological hazards associated with residual radioactivity (as defined in the Act)

at inactive uranium mill tailings and depository sites. The EPA subsequently published both interim cleanup standards (45 FR 27366) and proposed disposal standards (46 FR 2556).

3.5.1 EPA Interim and Proposed Standards

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

- (a) For a period of at least 1,000 yr following disposal:
  - (1) Radon released from the disposal site to the atmosphere would not exceed 2 pCi/m<sup>2</sup>-s;
  - (2) Substances released from the disposal site to underground sources of drinking water would not contaminate the water in excess of limits described in the tabulation below; and,
  - (3) Substances released from the disposal site to surface waters would not contribute to contamination otherwise existing in the water.

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

- (b) The average concentration of  $^{226}\text{Ra}$  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:

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

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

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

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

- (a) Minimization of upstream catchment area
- (b) Topographic features for wind protection
- (c) Relatively flat embankment slopes
- (d) Self-sustaining vegetative or riprap cover
- (e) Earthquake impact avoidance
- (f) Promotion of soil deposition

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

Criterion 6 - Sufficient earth cover, but not less than 3 m, shall be placed over tailings or wastes at the end of milling operations to result in a calculated reduction in surface exhalation of radon from the tailings or wastes to less than 2 pCi/m<sup>2</sup>-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 NRC's 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 piles. 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. (1,9)
- (b) External Gamma Radiation - Gamma radiation above background is measurable to distances of 0.2 mi from the piles, which is an area void of inhabited dwellings; however, persons on site will receive some gamma exposure until the contaminated ground is cleaned and the piles are covered with sufficient material to attenuate the gamma radiation.
- (c) Airborne Activity - The limited spread of significant quantities of windblown tailings, coupled with the distance between the piles and inhabited dwellings, indicates that inhalation or ingestion of tailings particles may be a minor component of the total population dose. This is a general result also reported at other uranium tailings piles. (10,11) Stabilization of the Slick Rock tailings piles against wind erosion will eliminate the gradual accumulation of tailings off site.

- (d) Water Contamination - The low  $^{226}\text{Ra}$  activity in nearby off-site surface water indicates little, if any, contamination from the tailings piles, as confirmed by measurements since 1961.
- (e) Subsoil Contamination - Leaching of radioactive materials into the ground beneath the piles and at the millsite is considerable in some areas. During the mill operations, localized areas were contaminated. A highly contaminated area, from a spill or seepage from the mill, was located 200 ft west of the NC millsite. Water analyses of samples from the river indicate that this pathway results in negligible health risks.
- (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. (For details refer to Chapter 7.)

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.<sup>(9,11)</sup> 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 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  $^{222}\text{Rn}$  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  $^{222}\text{Rn}$  progeny are observed to vary by over an order of magnitude. (12) 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 (13) risk estimator for lung cancer is based only on the absolute model since the relative risk model is not considered valid. (14)

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

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

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

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

The age-dependent excess risks presented in the BEIR-III report must be adjusted, when applied to the population at large, to account for the fact that the breathing rate of miners

on the job is about 1.9 times greater than that of the general population.<sup>(15)</sup> 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.<sup>(16)</sup> For the lifetime plateau to age 75, no cancers were assumed to occur in the years subsequent to age 75. The following cumulative risk estimator for the population at large is obtained using a lifetime plateau to age 75 and weighting by the age distribution of the U.S. population:

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

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

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

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

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

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

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

The risk estimator used for continual exposure to gamma radiation is expressed as:<sup>(17)</sup>

$$72\dot{D} + 0.8\dot{D}^2 \text{ cancers per yr}/10^6 \text{ person rems/yr-continuous}$$

(3-4)

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

### 3.6.2 Health Effects

The health effects due to inhalation of radon released from the Slick Rock piles in their present conditions were calculated using a flux of 150 pCi/m<sup>2</sup>-s for the UC tailings pile and 250 pCi/m<sup>2</sup>-s for the NC pile. These values were calculated using diffusion theory and the tailings physical properties. Even though the calculated value for radon flux appears 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 effect calculations.

The transport of radon from the tailings piles was modeled using a Gaussian plume model, meteorology characteristics of the Slick Rock area, and the population distribution surrounding the tailings piles as a function of the radius and direction from the edge of the sites. The piles were modeled as vertical cylinders with areas and volumes equivalent to those of the piles.

Total predicted outdoor <sup>222</sup>Rn concentration is shown in Figure 3-8 as a function of distance from the edge of the piles, in the southerly direction for the UC pile and in the north-northwesterly direction for the NC pile. The predicted <sup>222</sup>Rn concentration at 0.25 mi from the edge of the piles is almost 20% higher than background level of about 1.5 pCi/l.

Figure 3-17 shows the lung cancer risk per year from continuous exposure to radon as a function of distance from the edge of either of the Slick Rock tailings piles. The curve shows that the risk of developing lung cancer from radon released from the piles is about 10% higher than the natural occurrence from all causes<sup>(18)</sup> at a distance of 0.25 mi from the edge of either pile, but declines to near the natural occurrence within 0.5 mi.

The population distribution within 1.5 mi of the edge of the piles was developed using the best local statistics and other population information for the past decade. This distribution includes virtually all residents close enough to

either pile to be exposed to any noticeable degree to radon emanating from the piles, as described in Chapter 4.

The three population projections used to estimate the cumulative health impacts attributable to the tailings piles are the 0.8% constant growth rate, the 5% declining growth rate, and zero growth, as discussed in Chapter 4. The growth projections assume that the population is distributed around the UC site in the same proportions as those reflected in Table 4-2.

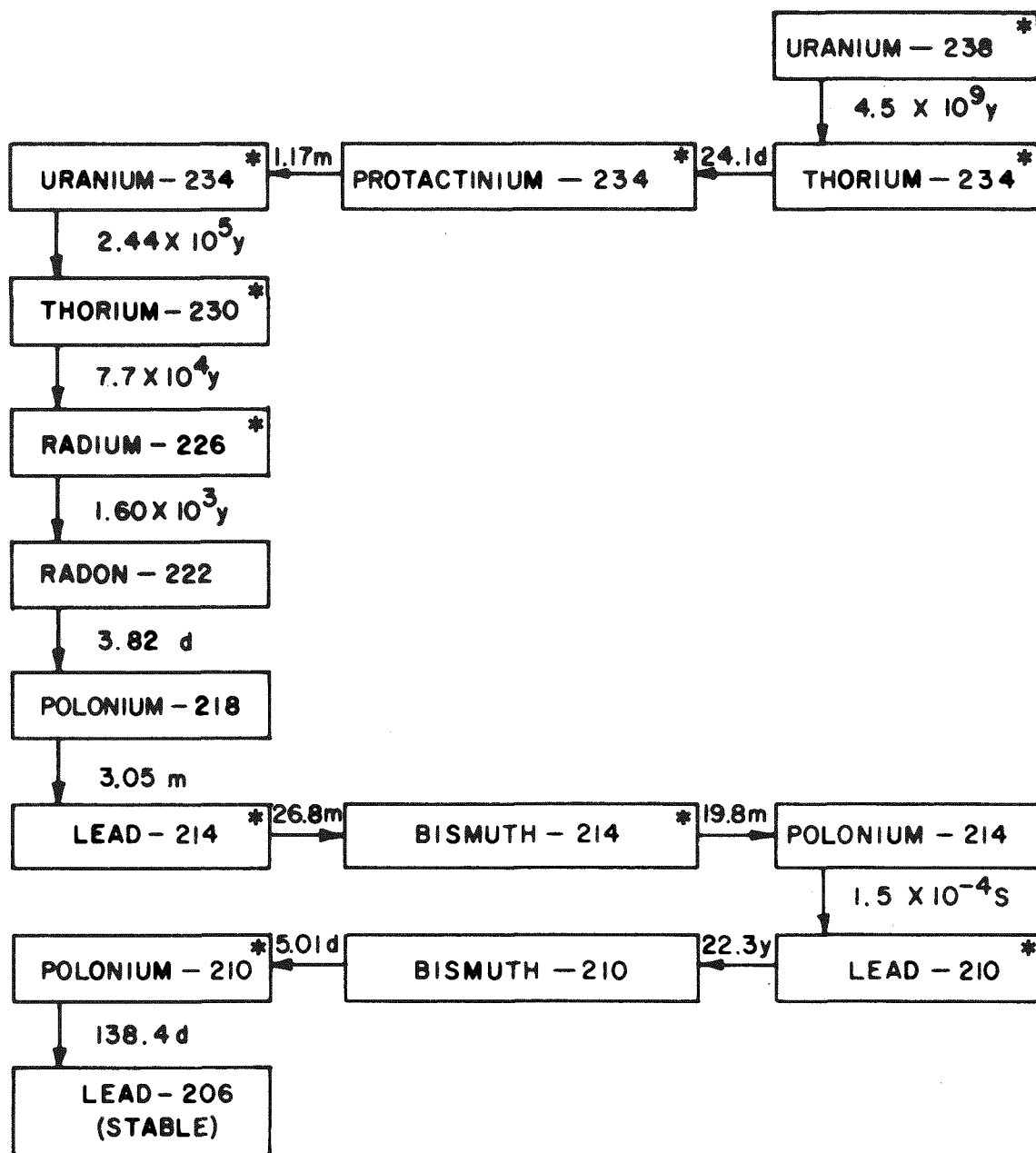
Table 3-3 presents the estimated health impacts from the tailings piles within 1.5 mi of the edge of the UC pile, based on the estimated 1980 population distribution presented in Table 4-2. The cumulative health effects for the three growth scenarios considered for Slick Rock are also included. In Table 3-3, the health effects from the pile radon are shown to be about 6% of those caused by background radon for the vicinity within 1.5 mi of the edge of the UC pile.

### 3.7 NONRADIOACTIVE POLLUTANTS

The tailings piles contain other potentially toxic materials. Chemical analyses of samples from drill holes in the Slick Rock tailings piles showed barium and lead in concentrations between 10 and 530 ppm. The highest selenium concentration measured was 1 ppm for both piles. The arsenic concentration measured ranged as high as 67 ppm on the NC pile.

Three water samples were taken from the Dolores River in the vicinity of the Slick Rock piles and chemically analyzed. The locations of these samples are shown in Figure 3-15. Samples A and B were taken downstream and Sample C was taken upstream of the two piles. Both Samples B and C were analyzed at two separate laboratories as a check on the original results.

All of the analyses of the water samples indicated selenium was above the EPA Interim Primary Drinking Water Regulations<sup>(19)</sup> limit, as shown in Table 3-4. These concentrations are presented as averages of the analyses from both laboratories. The lead content also was above the EPA limit in Samples B and C and the arsenic in Sample C. High concentrations of selenium, arsenic, and lead were found upstream as well as downstream at the Slick Rock tailings piles. There is no evidence that the tailings have contributed to the contamination. All of the samples also contained more iron than the U.S. Public Health Service recommended limit.



NOTE:

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

\* ALSO GAMMA EMITTERS

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

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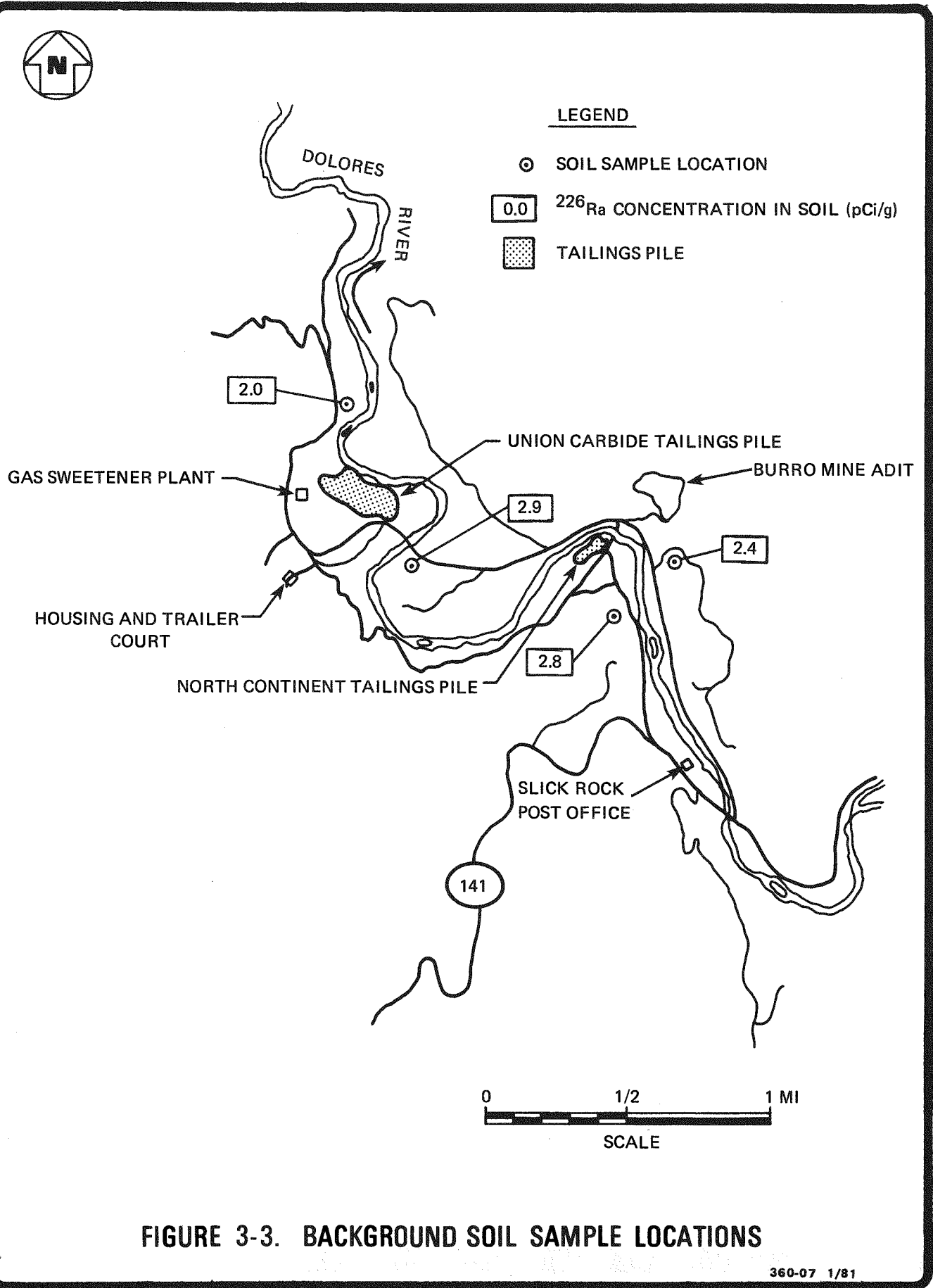
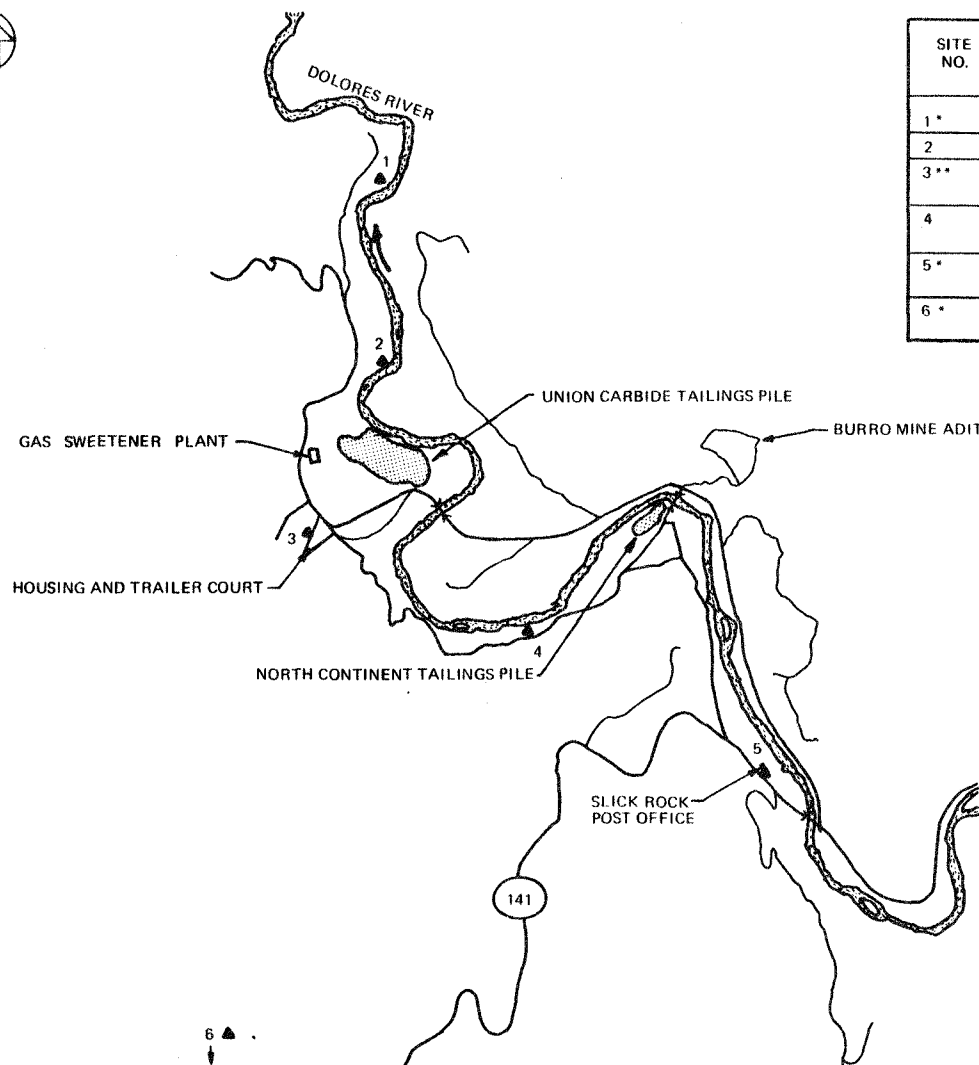


FIGURE 3-3. BACKGROUND SOIL SAMPLE LOCATIONS

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SITE NO.	24 HR OUTDOOR (pCi/l)	24 HR INDOOR (pCi/l)	AVG WIND SPEED (KNOTS)	AVG WIND DIRECTION	LOCATION
1*	1.6	—	8	SE	0.75 MI N OF UC SITE
2	3.8	—	6	N	0.21 MI N OF UC SITE
3**	1.4	4.2	6	N	TRAILER PARK UC SITE 0.27 MI SW OF UC SITE
4	2.0	—	5	—	0.55 MI SE OF UC SITE 0.53 MI SW OF NC SITE
5*	1.7	—	4	—	SLICK ROCK POST OFFICE 0.83 MI SE OF NC SITE
6*	1.2	—	2	NW	2.44 MI SSW OF UC SITE 2.55 MI SW OF NC SITE

\* BACKGROUND MEASUREMENTS

\*\*TAILINGS LOCATION

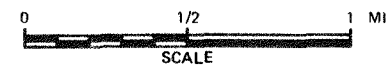
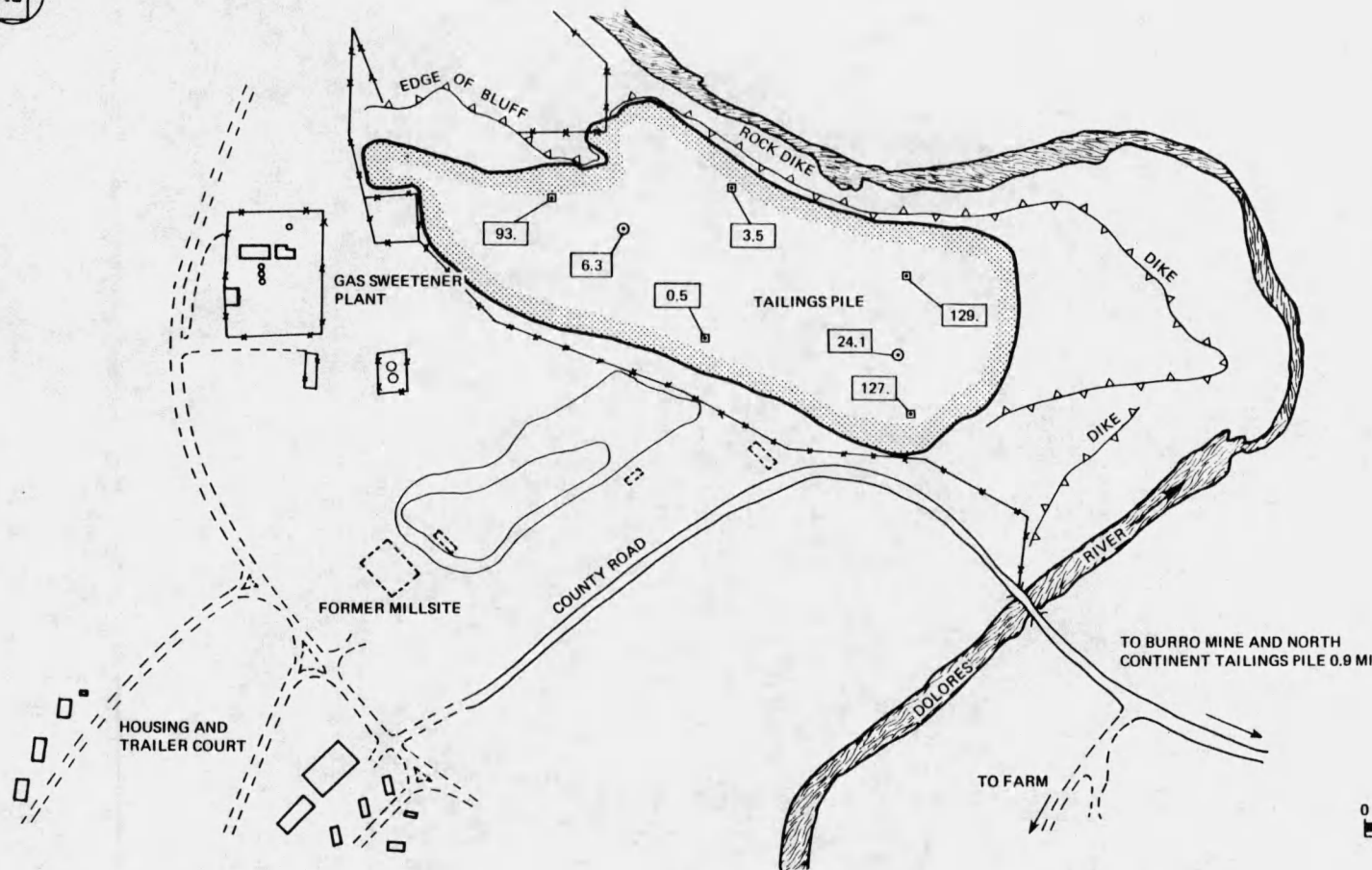


FIGURE 3-4. RADON CONCENTRATION IN VICINITY OF PILES

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- LEGEND**
- RADON CANISTER LOCATION (1980)
  - RADON CANISTER LOCATION (1976)
  - 0.0 RADON FLUX, pCi/m<sup>2</sup> · s
  - \*—\*— FENCE
  - ▨ EDGE OF TAILINGS PILE
  - - - - DIRT ROAD
  - ▲ SUDDEN CHANGE IN SLOPE (DOWNWARD)

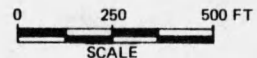
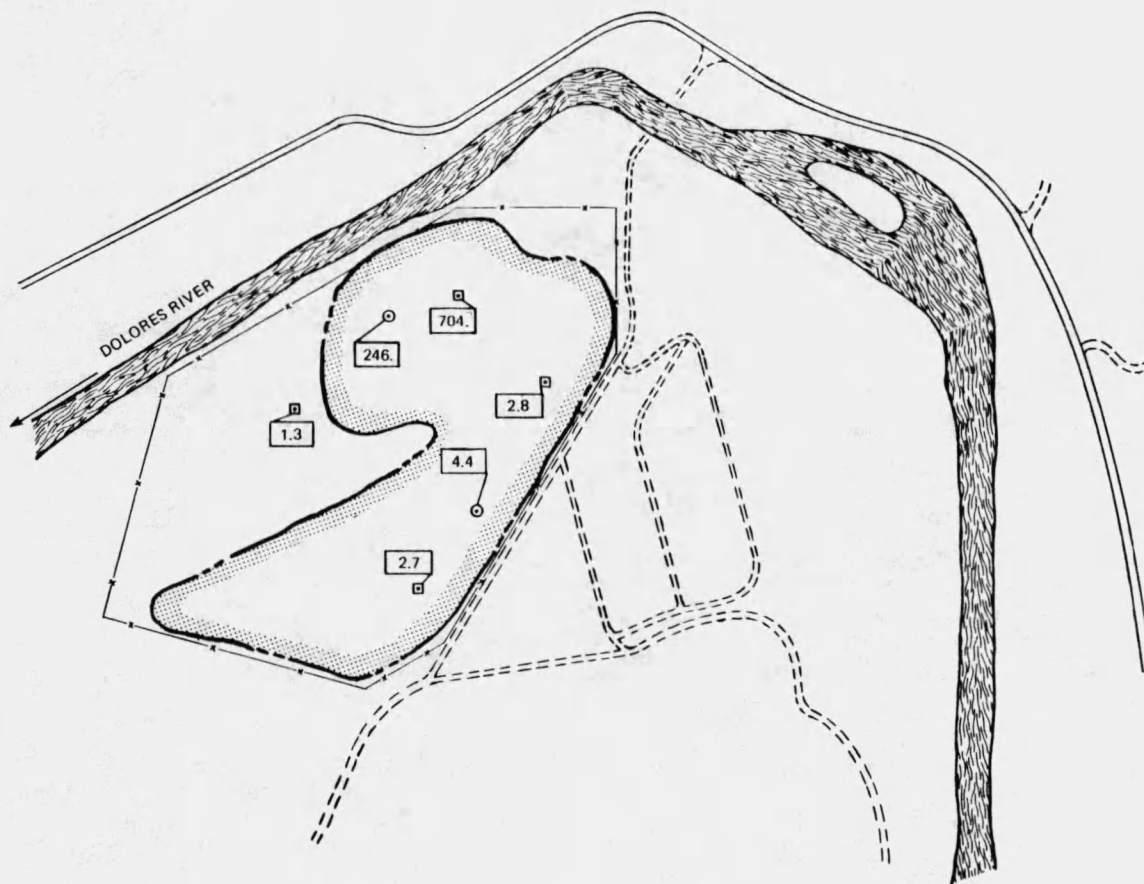


FIGURE 3-5A. RADON CANISTER LOCATIONS AND FLUX VALUES - UNION CARBIDE SITE

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**LEGEND**

- ▣ RADON CANISTER LOCATION (1980)
- RADON CANISTER LOCATION (1976)
- 0.0 RADON FLUX, pCi/m<sup>2</sup>-s
- +— FENCE
- ▨ EDGE OF TAILINGS PILE
- - - - DIRT ROAD

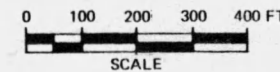
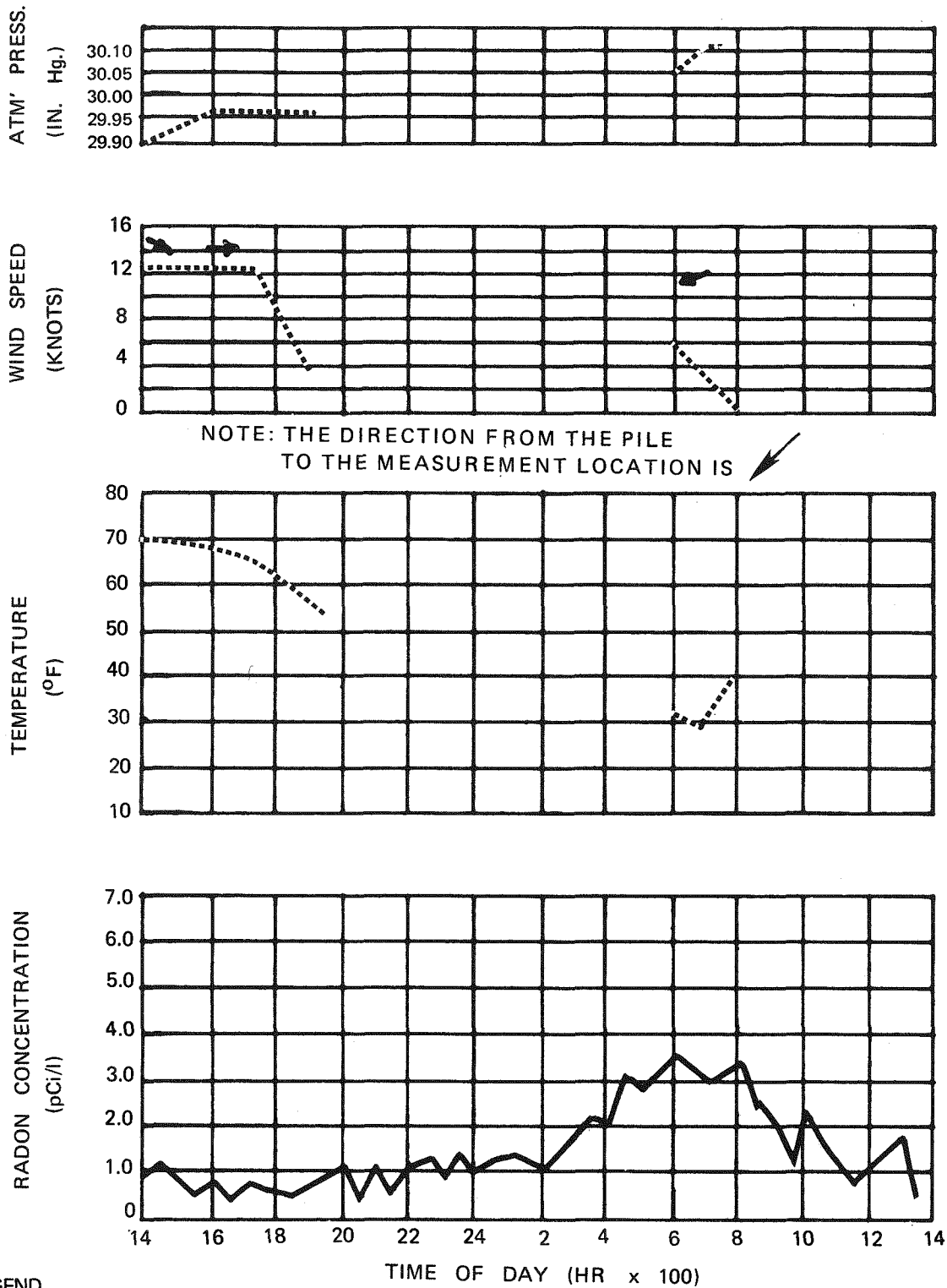


FIGURE 3-5B. RADON CANISTER LOCATIONS AND FLUX VALUES - NORTH CONTINENT SITE

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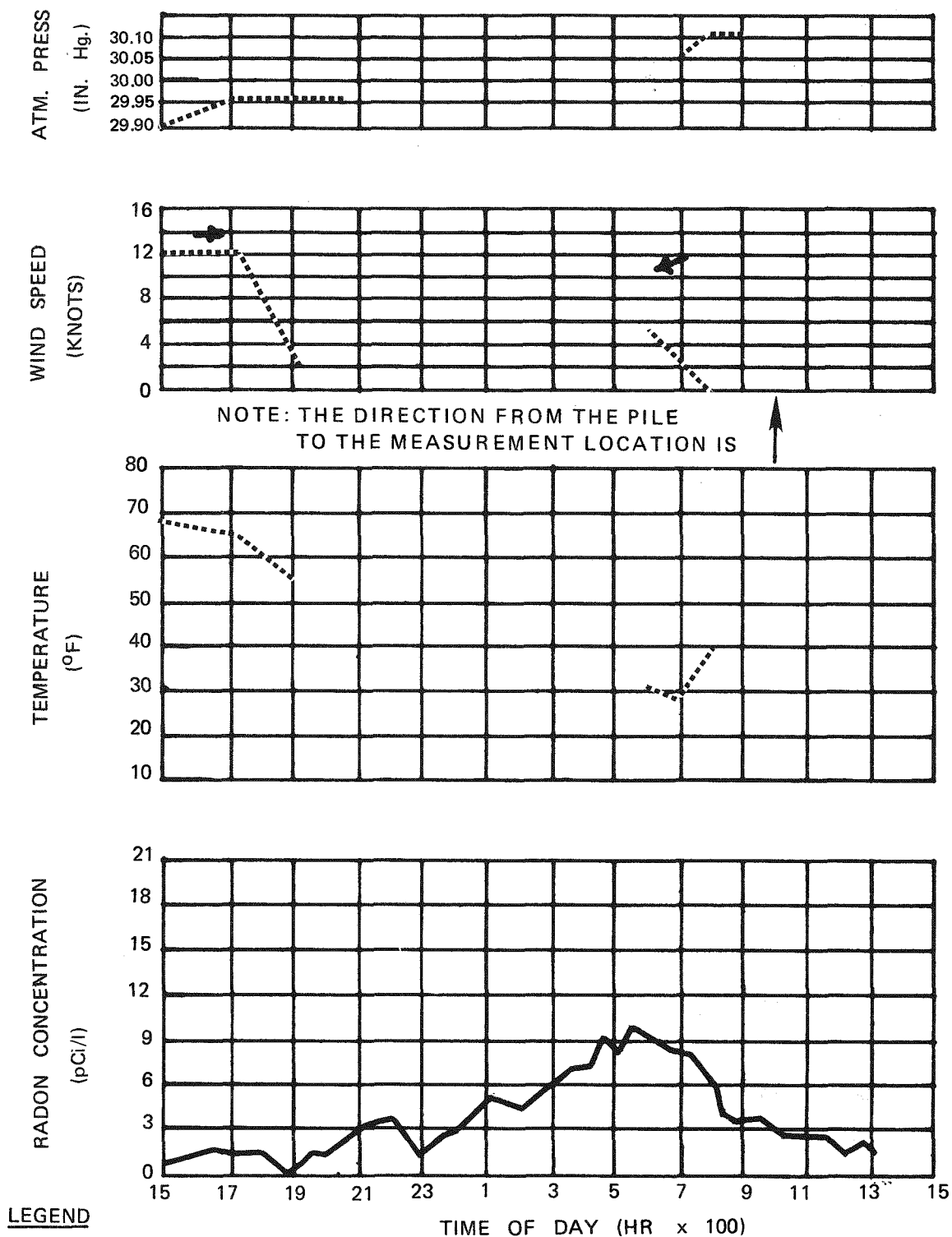


**LEGEND**

- ..... CORTEZ COLO. WEATHER DATA
- ↙ WIND DIRECTION (UP=NORTH, DOWN=SOUTH)

**FIGURE 3-6.  $^{222}\text{Rn}$  AND ATMOSPHERIC TRANSIENTS AT SLICK ROCK TRAILER PARK ON APRIL 9, 1976**

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LEGEND

- ..... CORTEZ CO. WEATHER DATA
- ↑ WIND DIRECTION (UP=NORTH, DOWN=SOUTH)

FIGURE 3-7. <sup>222</sup>Rn AND ATMOSPHERIC TRANSIENTS AT SLICK ROCK  
0.21 MI N OF UNION CARBIDE SITE ON APRIL 9, 1976

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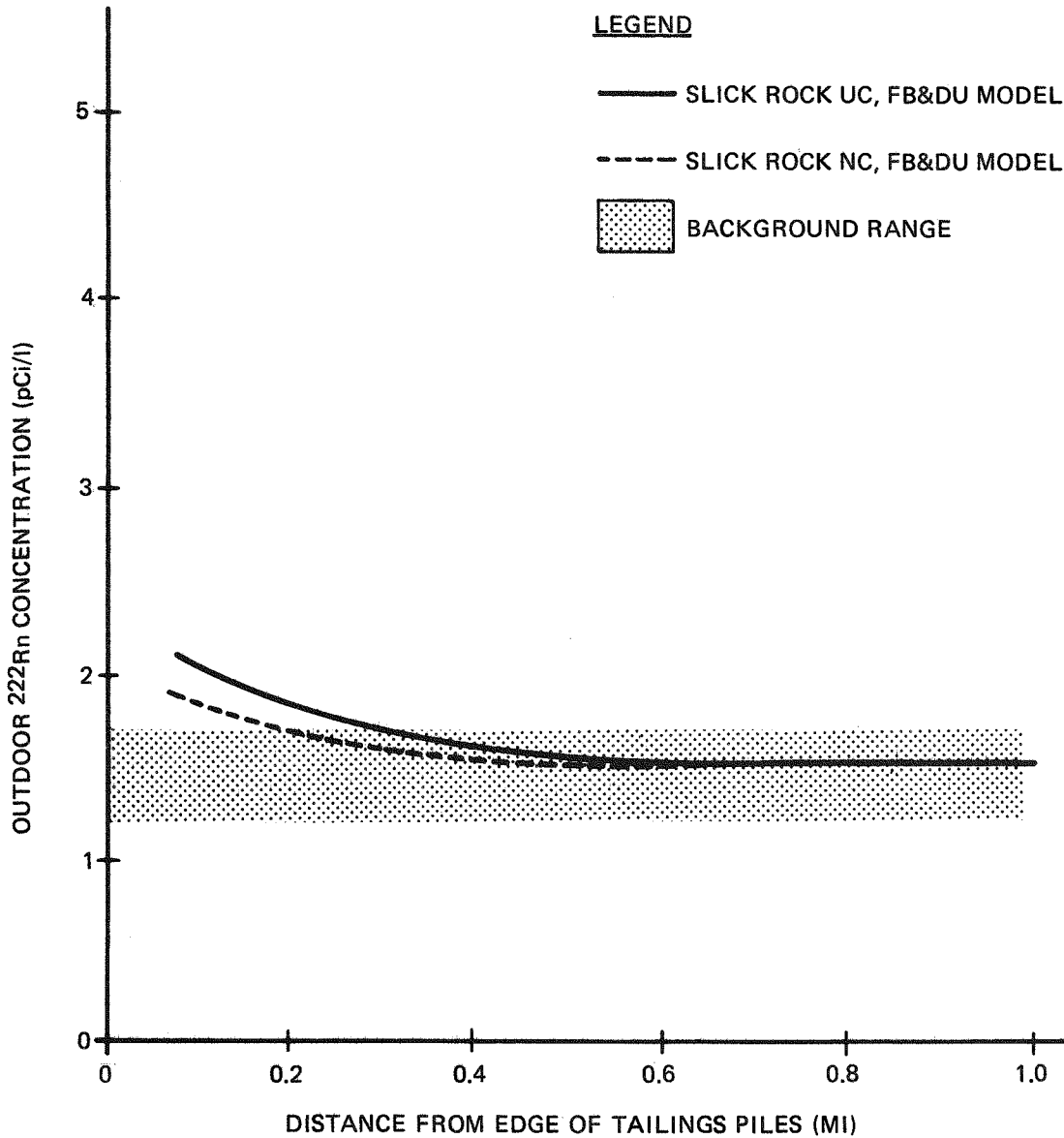


FIGURE 3-8. REDUCTION OF OUTDOOR <sup>222</sup>Rn CONCENTRATION WITH DISTANCE FROM THE TAILINGS PILES

360-07 REV 1/81



NOTE:  
ALL NUMBERS SHOWN  
ARE GROSS GAMMA  
LEVELS IN  $\mu\text{R/hr.}(1)$

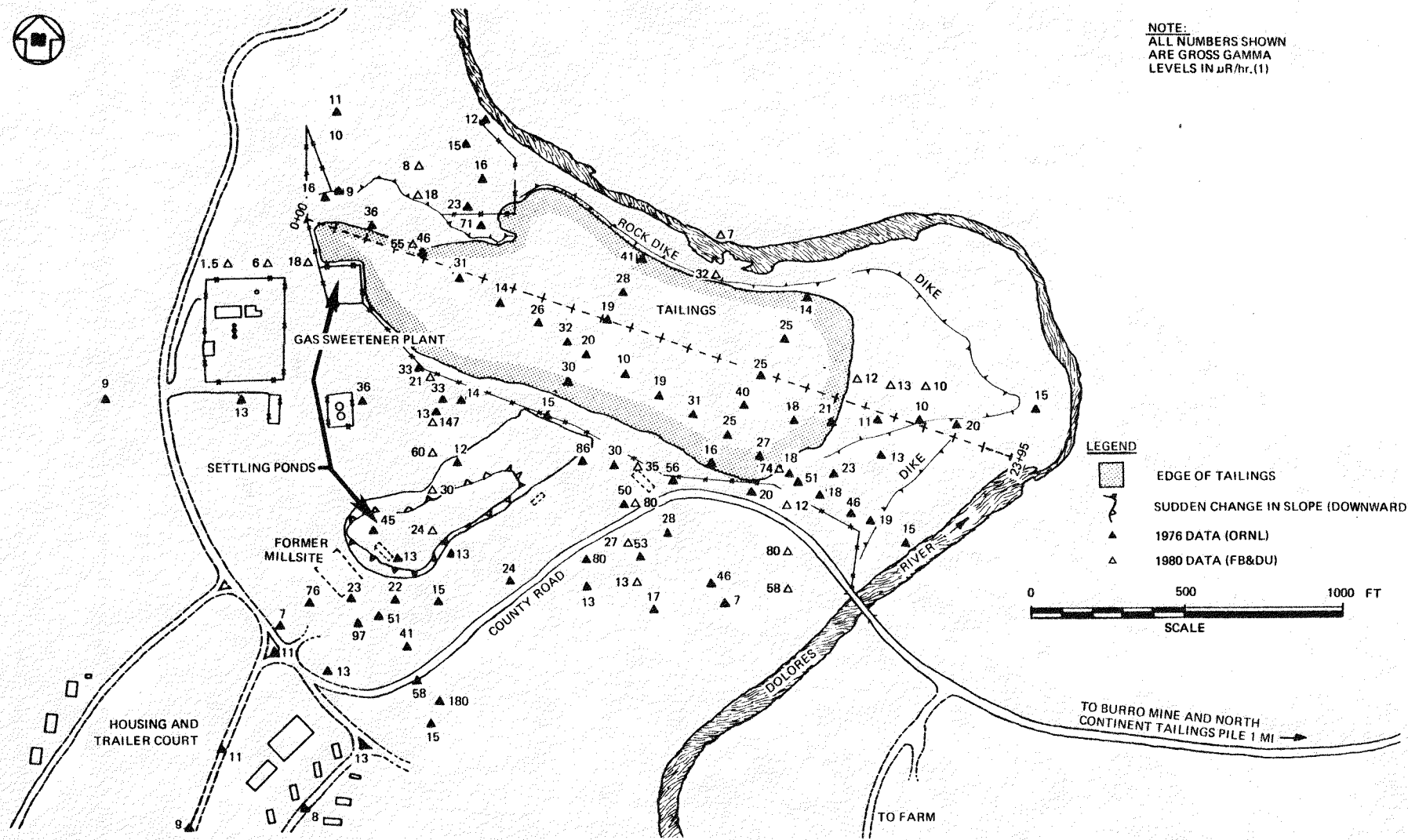
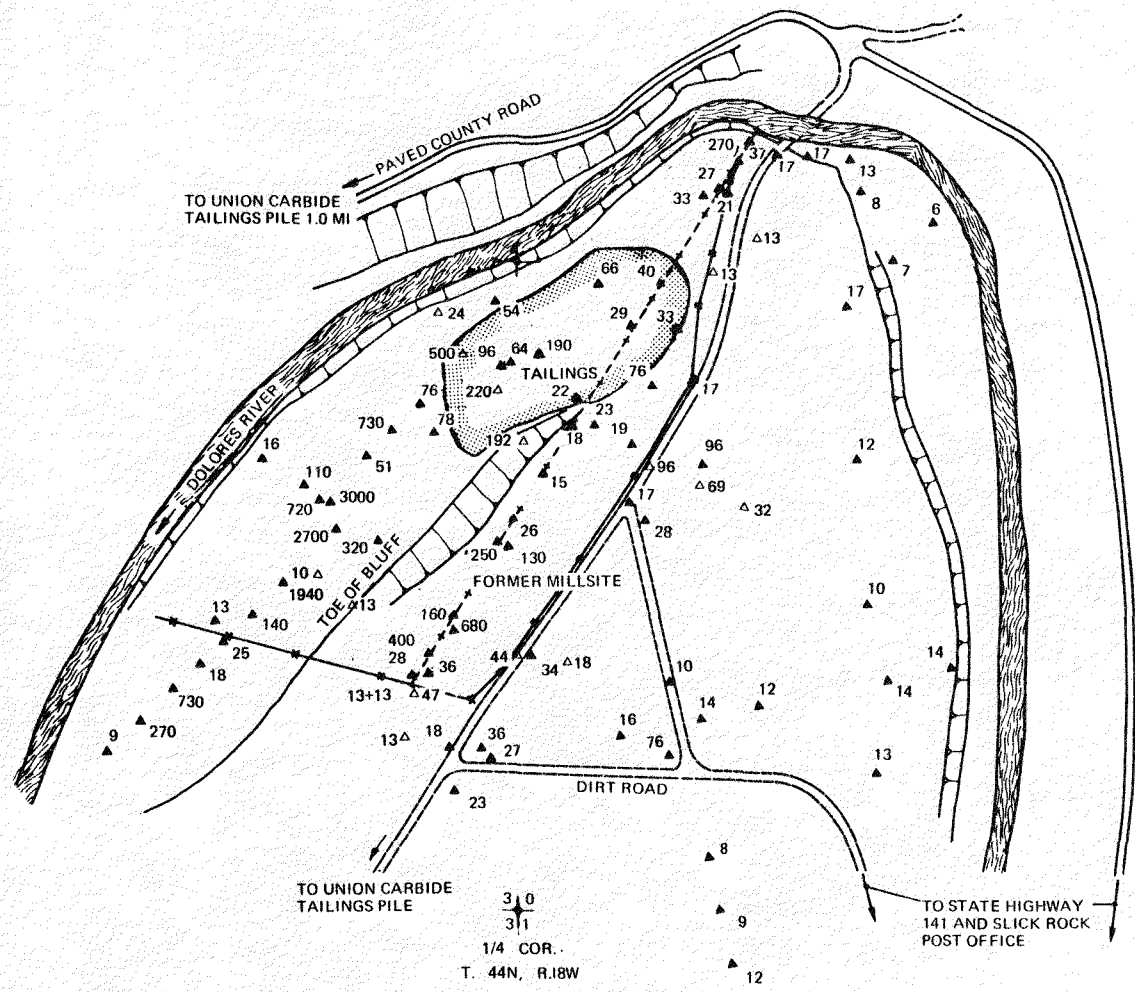


FIGURE 3-9A. GAMMA LEVELS AT UNION CARBIDE MILLSITE 3 FT ABOVE GROUND

360-07 REV 6/81



NOTE:  
ALL NUMBERS SHOWN ARE  
GROSS GAMMA LEVELS  
IN  $\mu\text{R/hr. (1)}$

LEGEND

- EDGE OF TAILINGS
- 1976 DATA (ORNL)
- 1980 DATA (FB&DU)

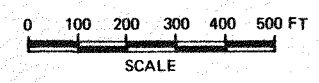


FIGURE 3-9B. GAMMA LEVELS AT NORTH CONTINENT MILLSITE 3 FT ABOVE GROUND

360-07 REV 8/81



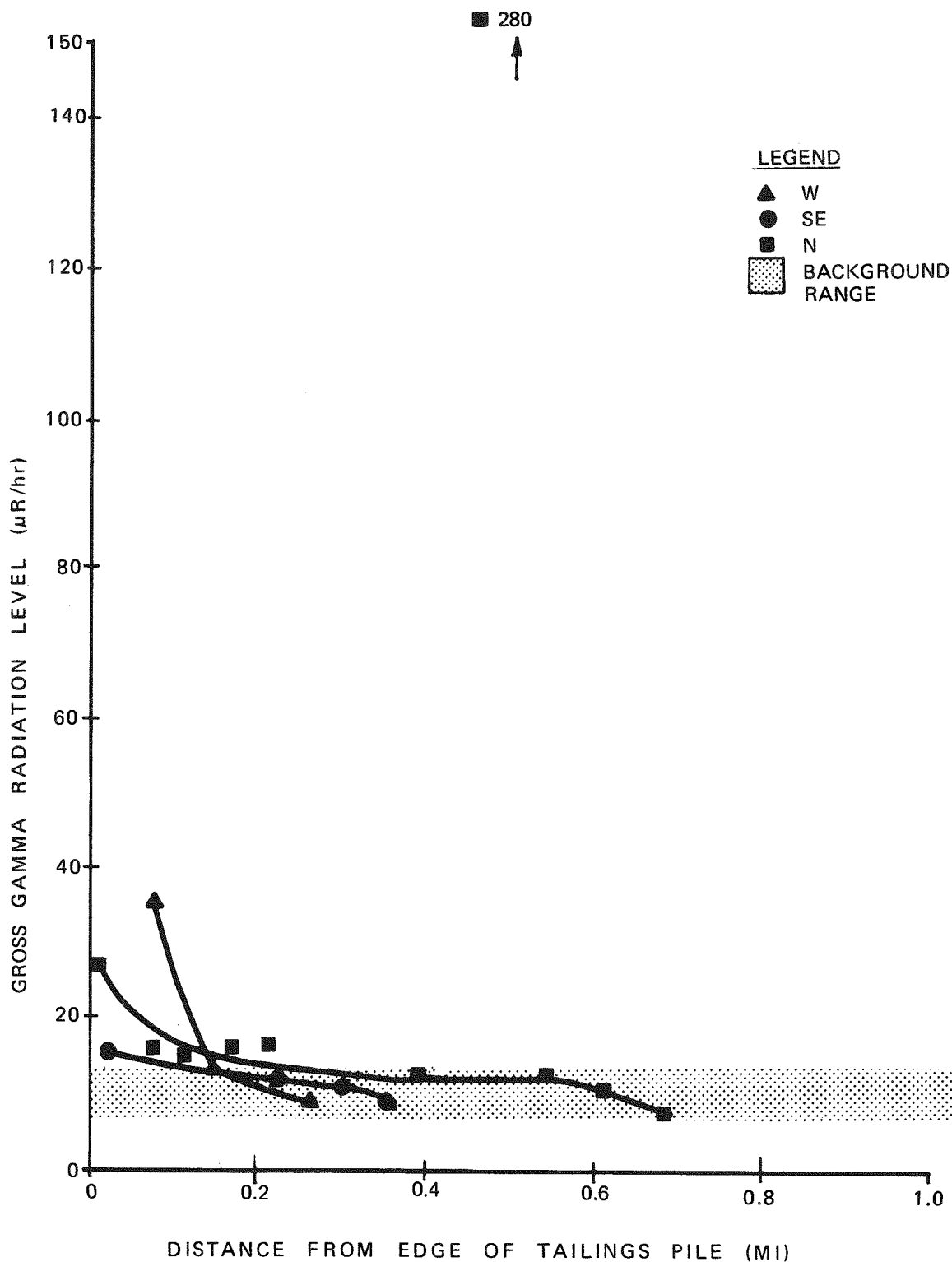


FIGURE 3-11A. REDUCTION OF EXTERNAL GAMMA RADIATION LEVELS WITH DISTANCE FROM THE UNION CARBIDE TAILINGS PILE

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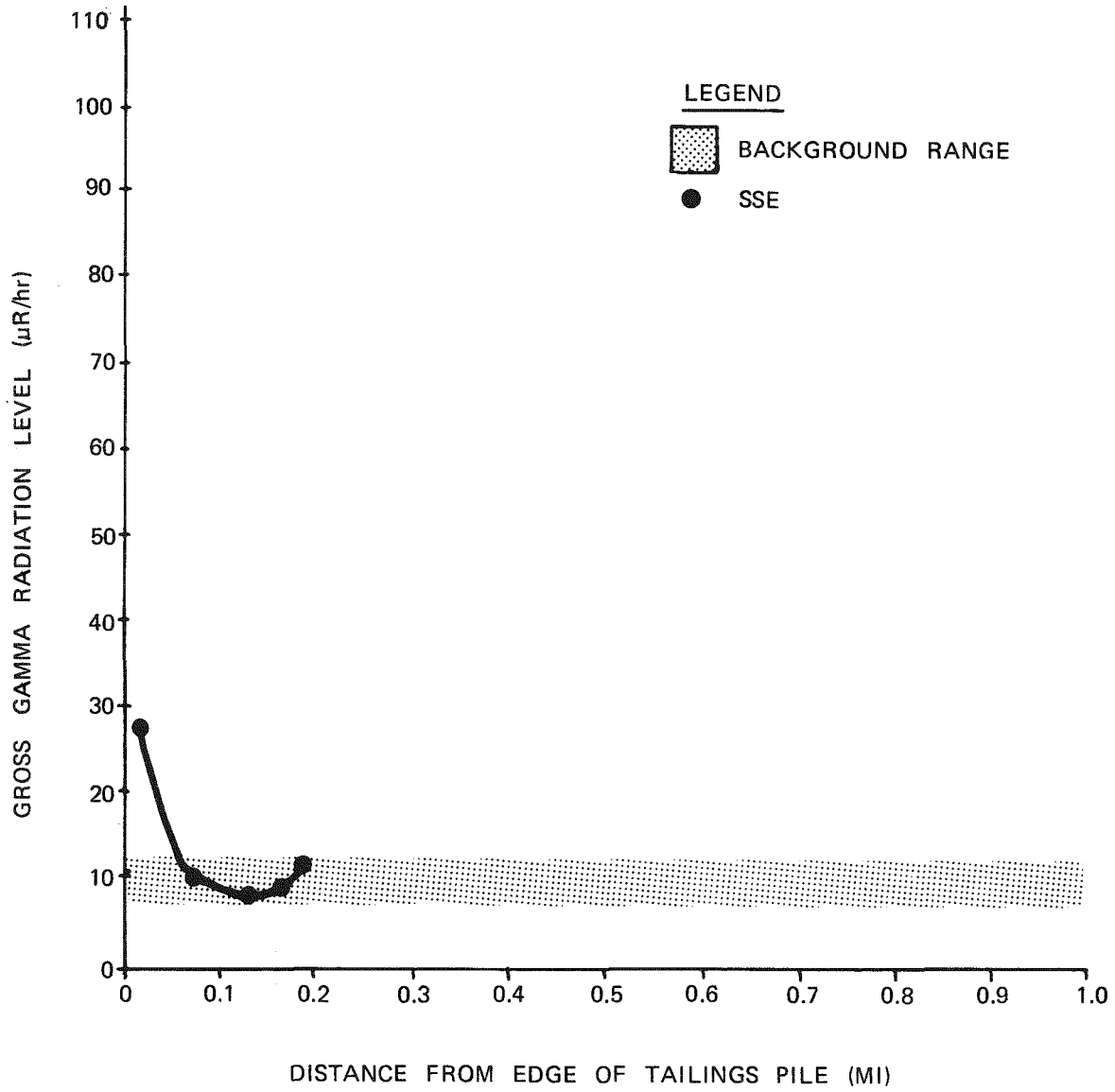
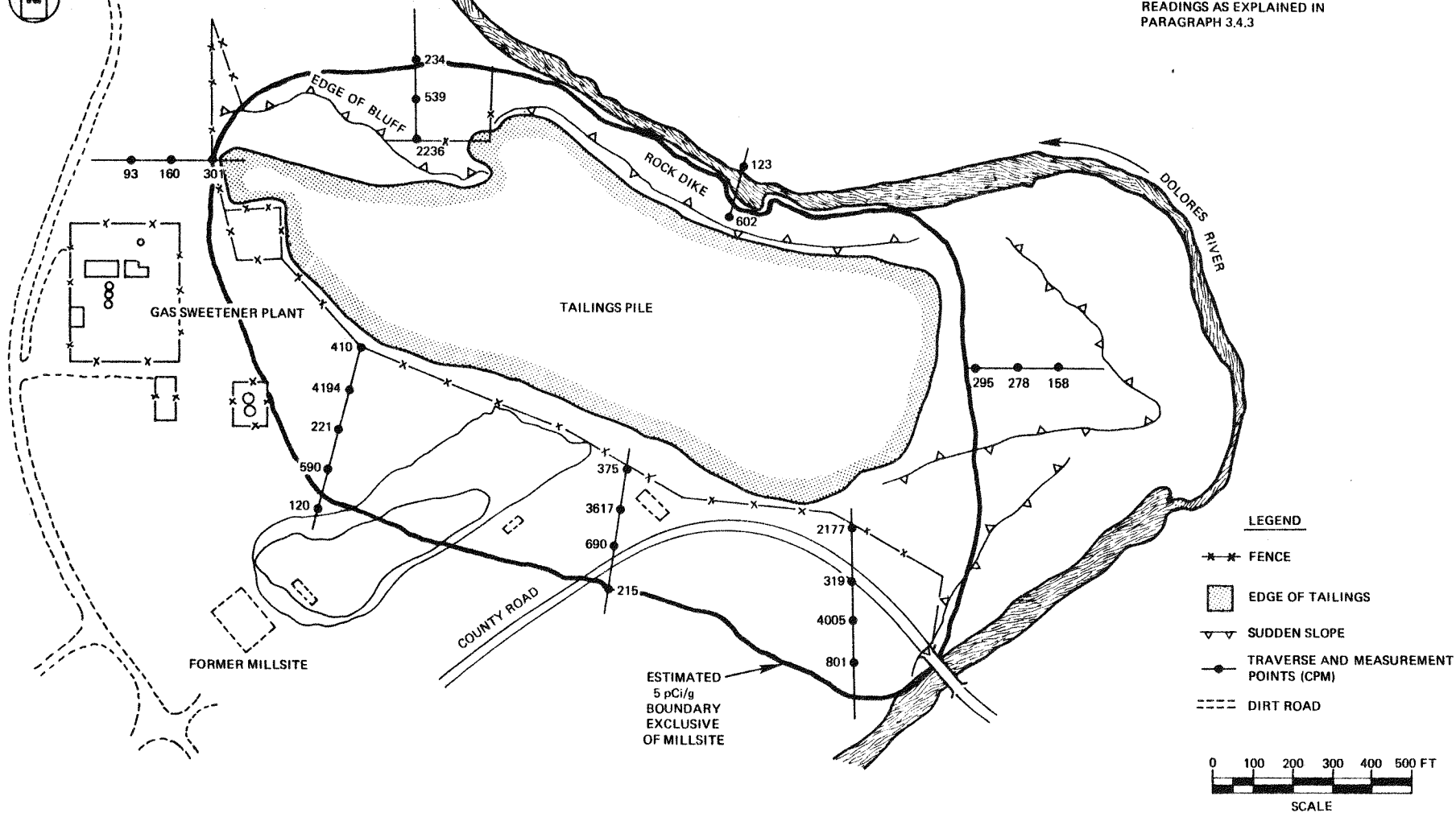


FIGURE 3-11B. REDUCTION OF EXTERNAL GAMMA RADIATION LEVELS WITH DISTANCE FROM THE NORTH CONTINENT TAILINGS PILE

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**NOTE:**  
 NUMBERS SHOWN ARE "DELTA"  
 READINGS AS EXPLAINED IN  
 PARAGRAPH 3.4.3



**FIGURE 3-12A. WINDBLOWN CONTAMINATION SURVEY - UNION CARBIDE SITE**

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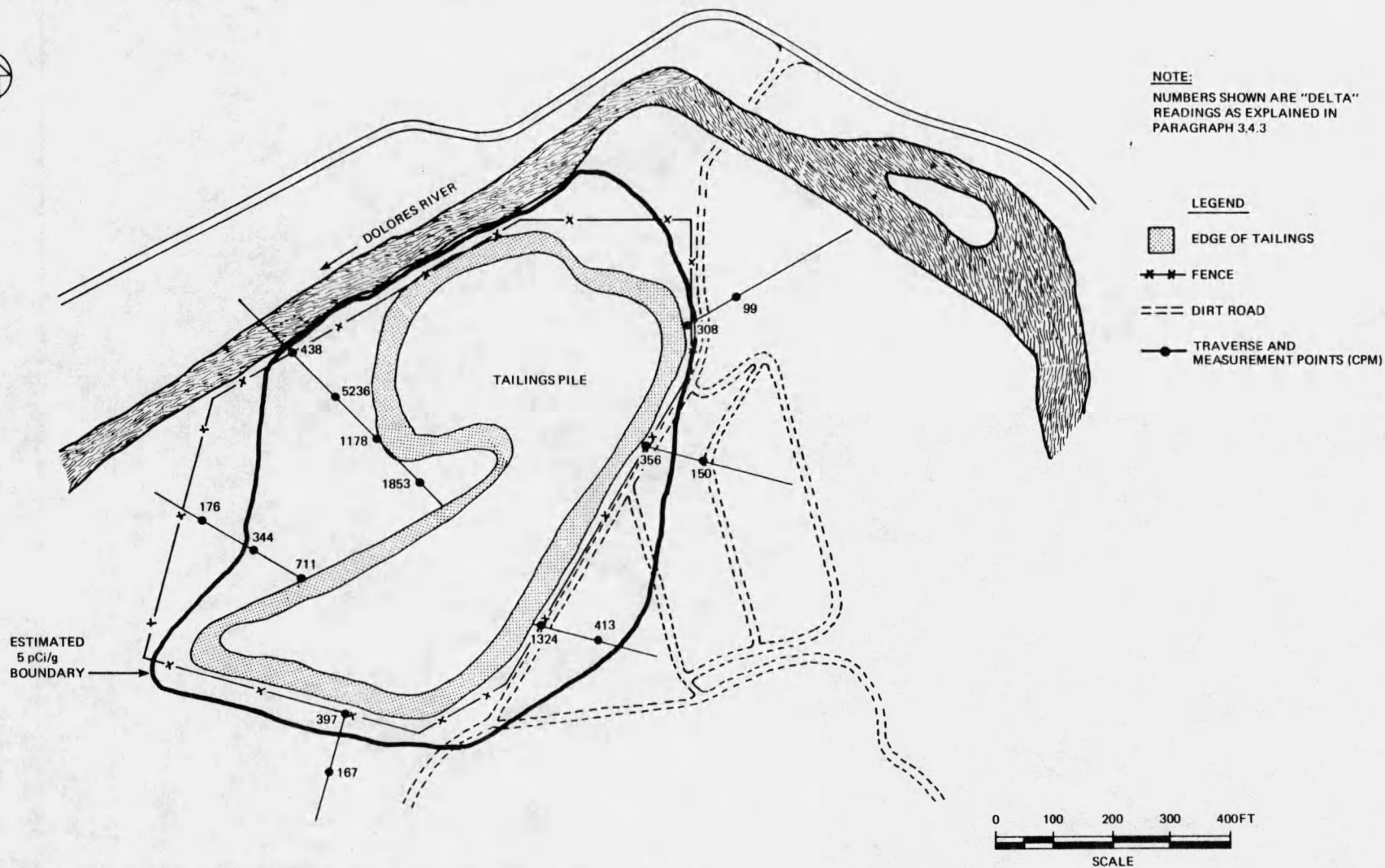


FIGURE 3-12B. WINDBLOWN CONTAMINATION SURVEY - NORTH CONTINENT SITE

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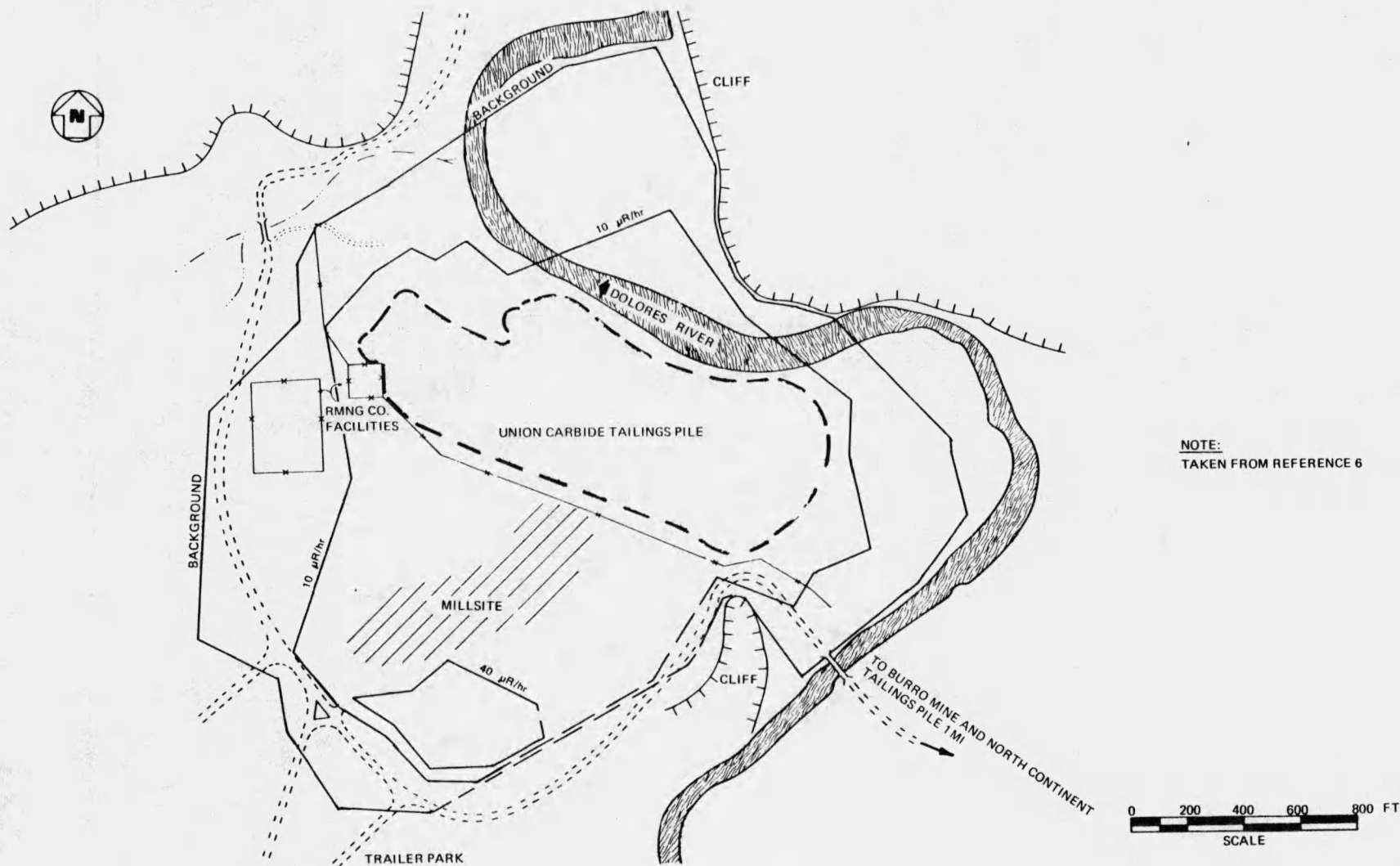
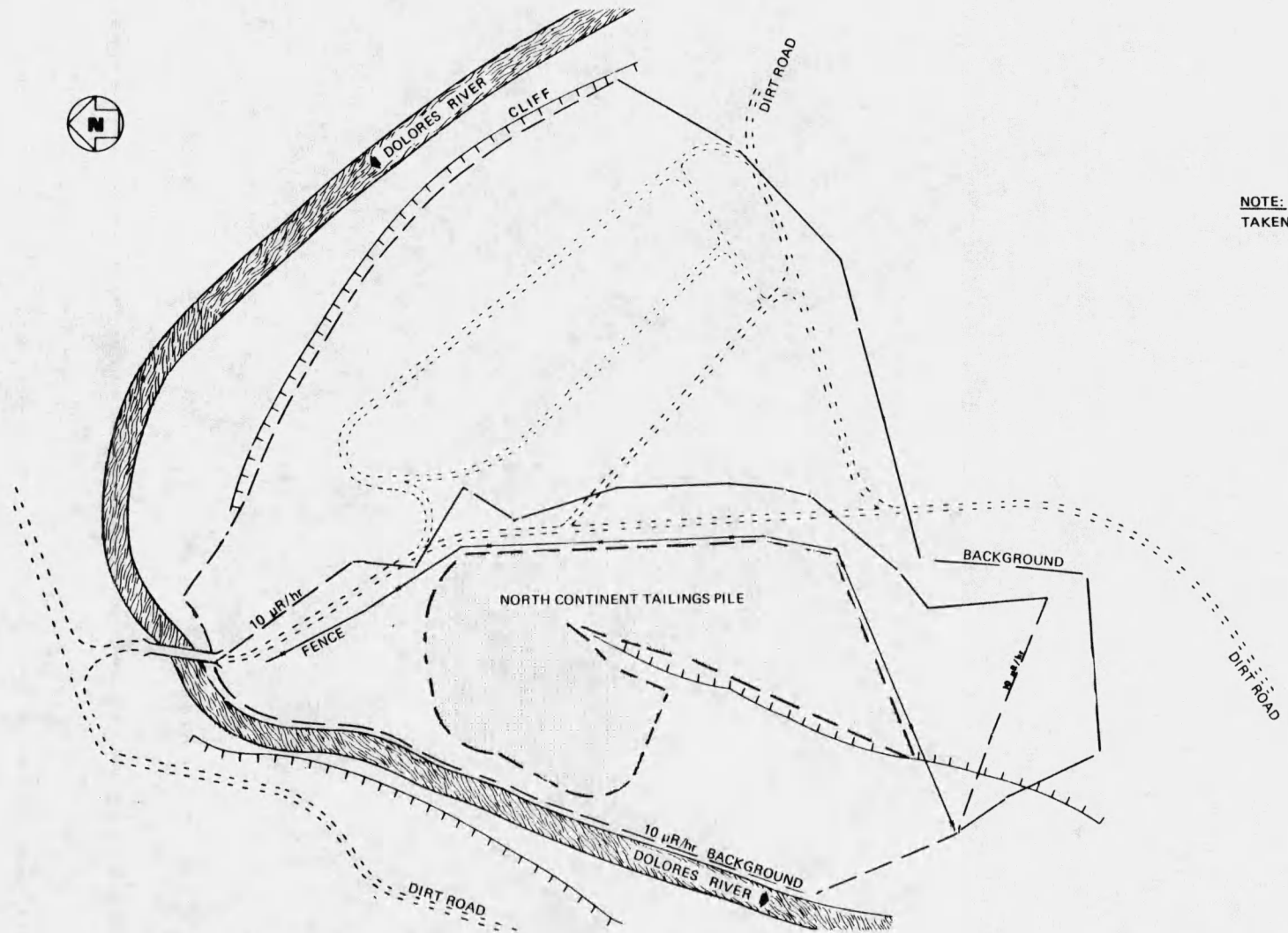


FIGURE 3-13A. EPA GAMMA SURVEY SURROUNDING UNION CARBIDE MILLSITE

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**NOTE:**  
TAKEN FROM REFERENCE 6

**FIGURE 3-13B. EPA GAMMA SURVEY SURROUNDING NORTH CONTINENT MILLSITE**

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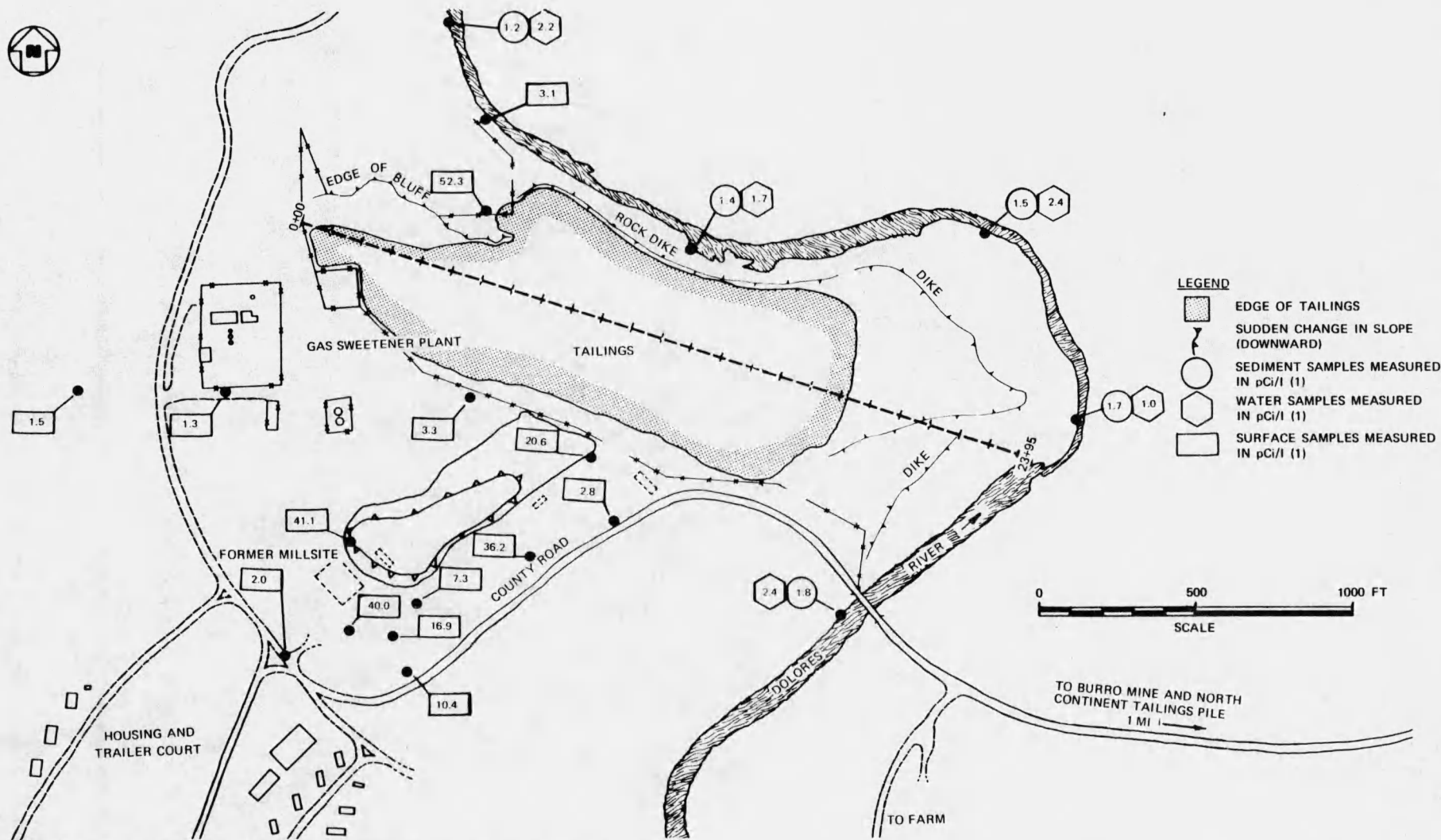
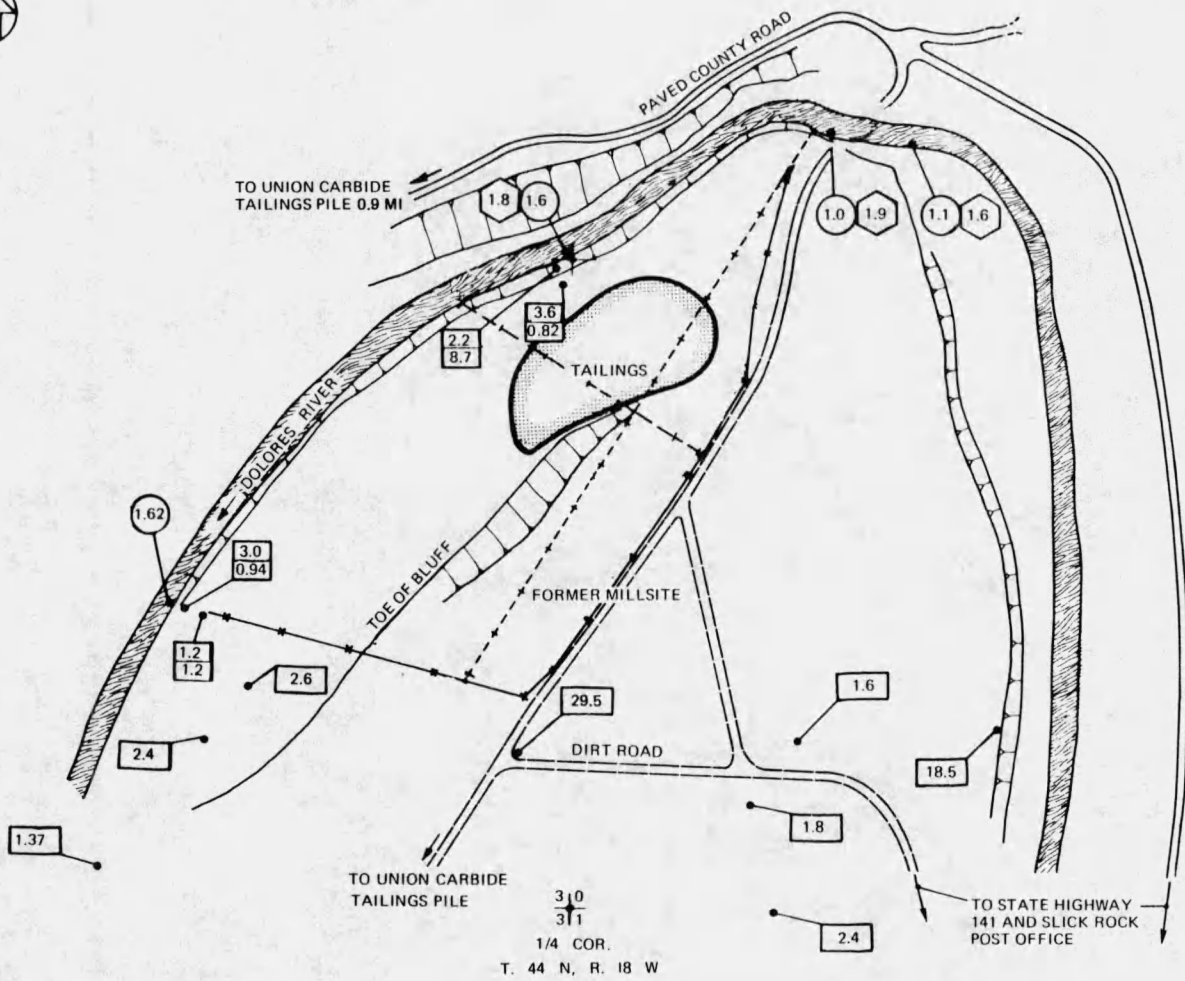






FIGURE 3-14A. SURFACE RADIUM CONCENTRATIONS AT UNION CARBIDE SITE

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**LEGEND**

-  SEDIMENT SAMPLES MEASURED IN pCi/g
-  WATER SAMPLES MEASURED IN pCi/l
-  SURFACE SAMPLES MEASURED IN pCi/g  
SAMPLES TAKEN 6" DEEP IN pCi/g
-  DATA FROM REFERENCE 1

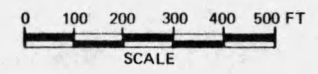
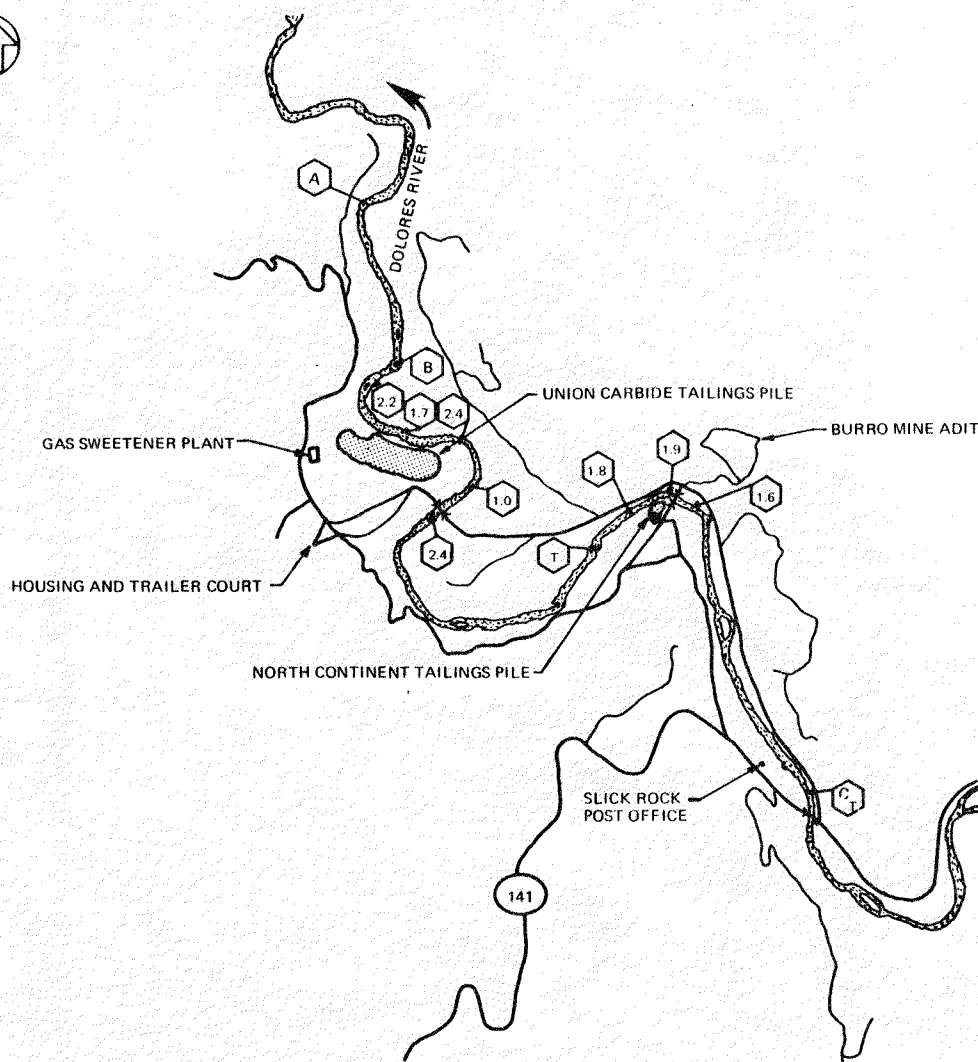



FIGURE 3-14B. SURFACE AND SUBSURFACE RADIUM CONCENTRATIONS AT NORTH CONTINENT SITE

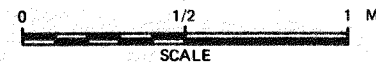
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**NOTE:**  
FOR CHEMICAL ANALYSES  
OF SAMPLES A, B, AND C  
SEE TABLE 3-4.

**LEGEND**

  $^{226}\text{Ra}$  CONCENTRATION (pCi/l) (1)  
 T = TRACE < 0.1 pCi/l



**FIGURE 3-15. SURFACE WATER SAMPLES - RADIUM CONCENTRATIONS**

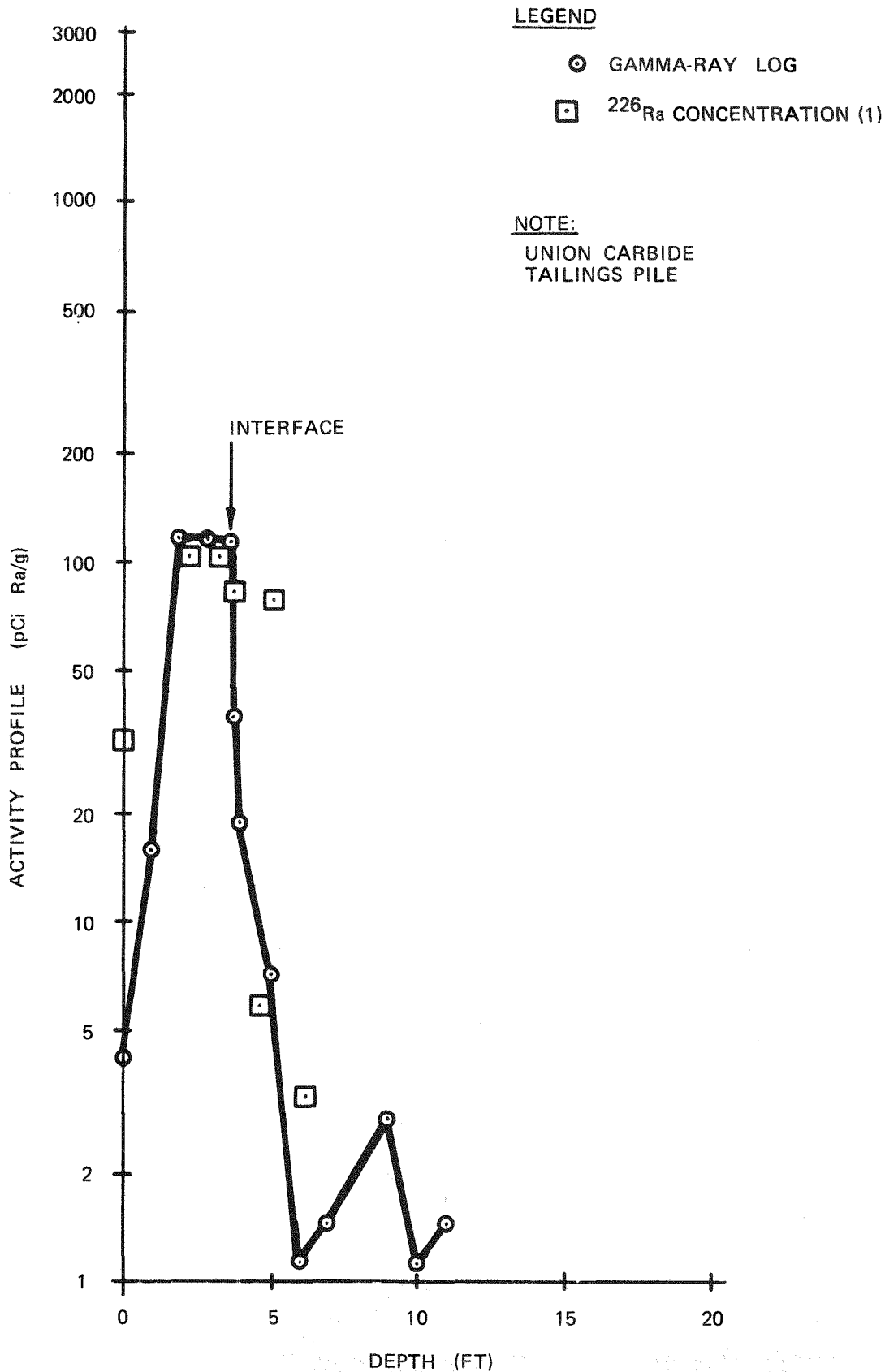


FIGURE 3-16A-1. RADIOMETRIC PROFILE AT DRILL HOLE SRUC-18

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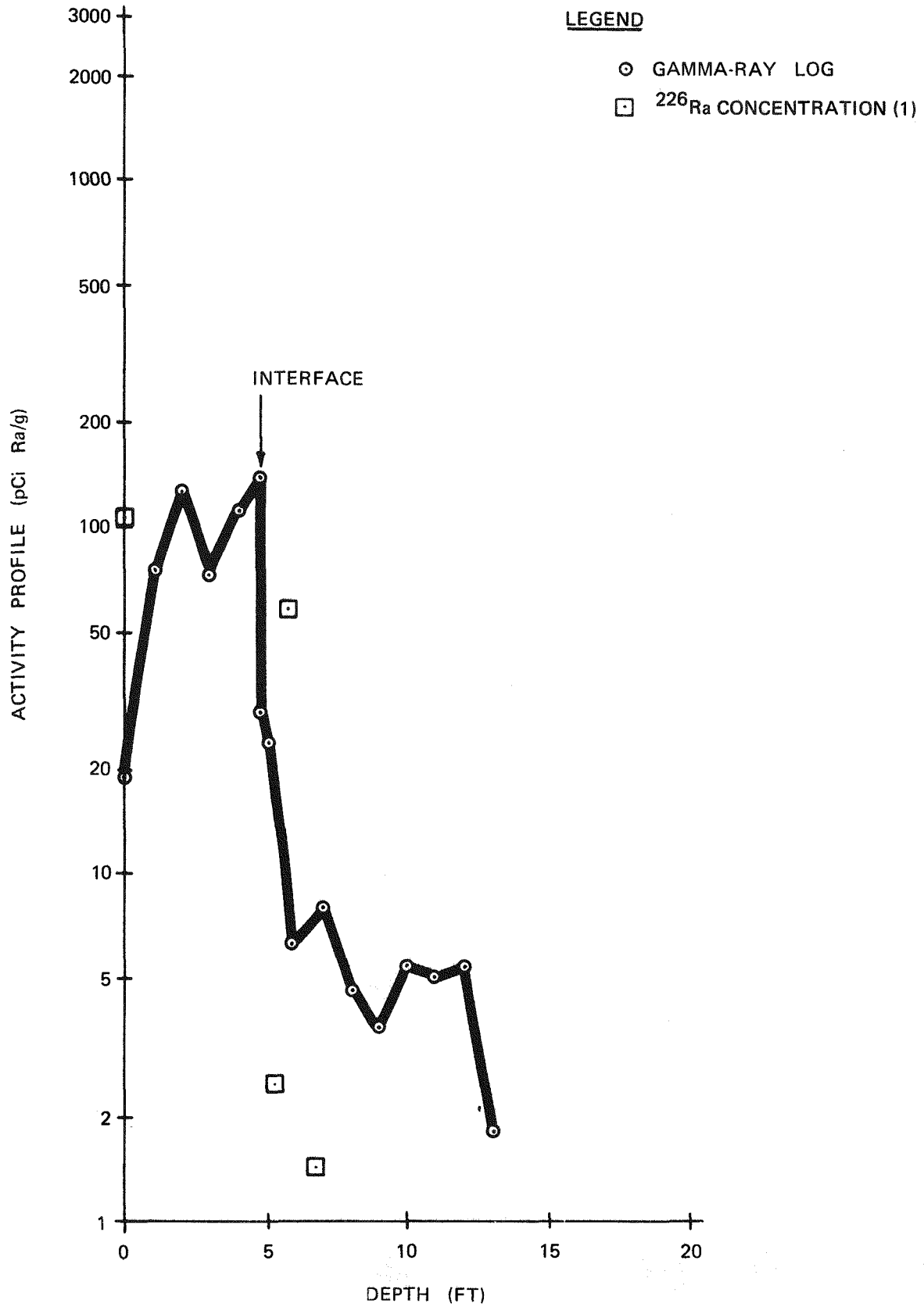


FIGURE 3-16A-2. RADIOMETRIC PROFILE AT DRILL HOLE SRUC-5

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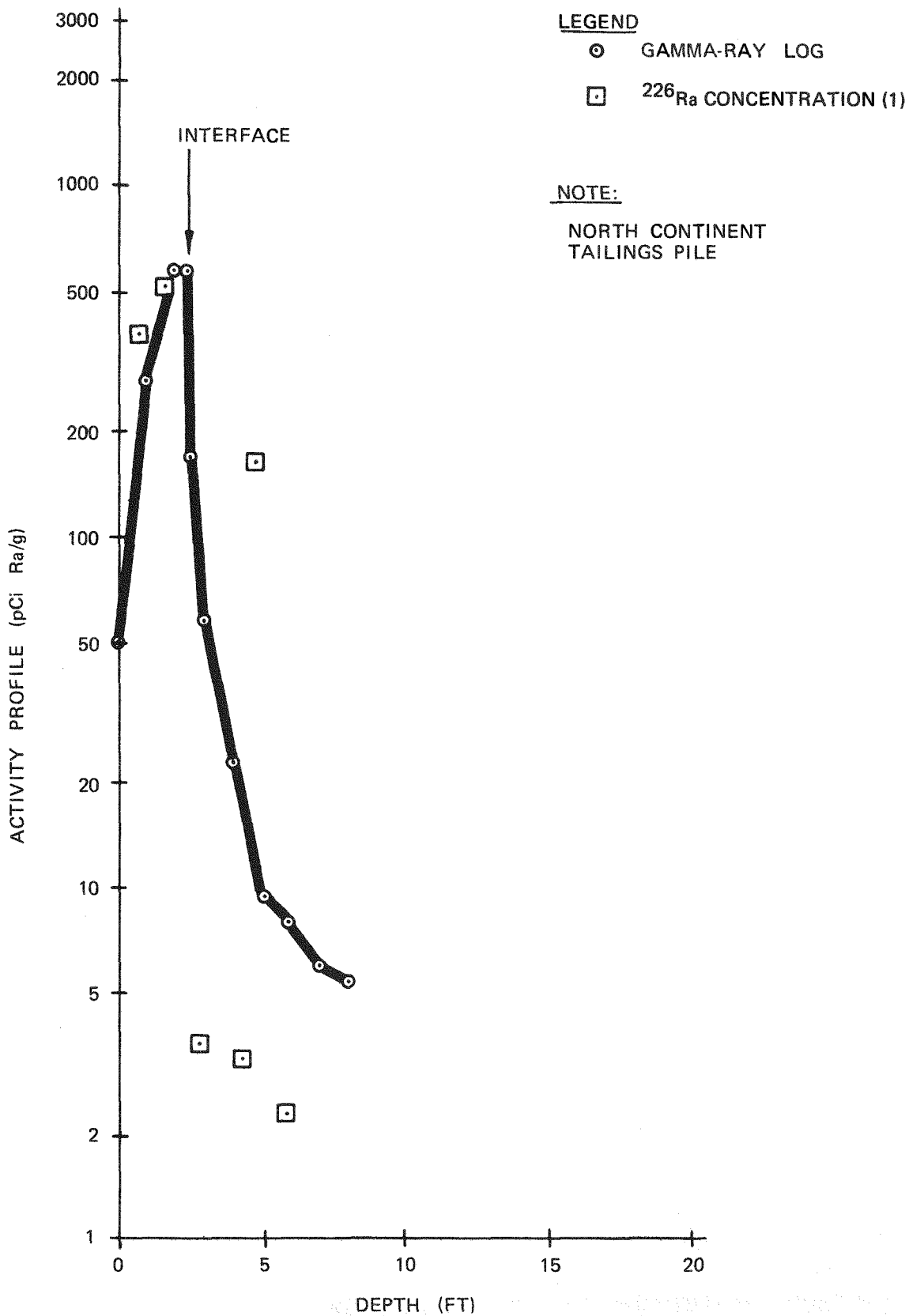


FIGURE 3-16B-1. RADIOMETRIC PROFILE AT DRILL HOLE SRNC-9

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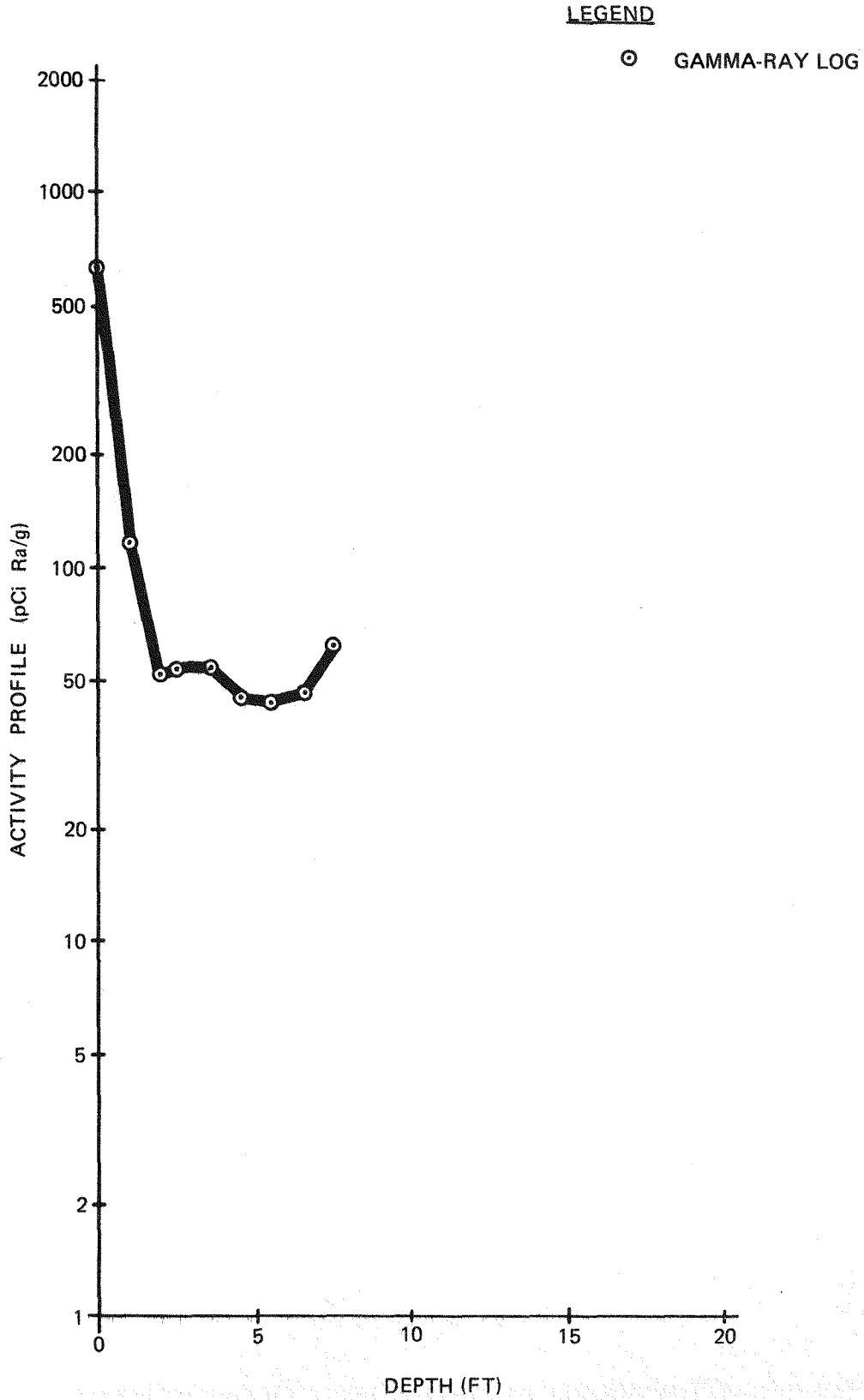
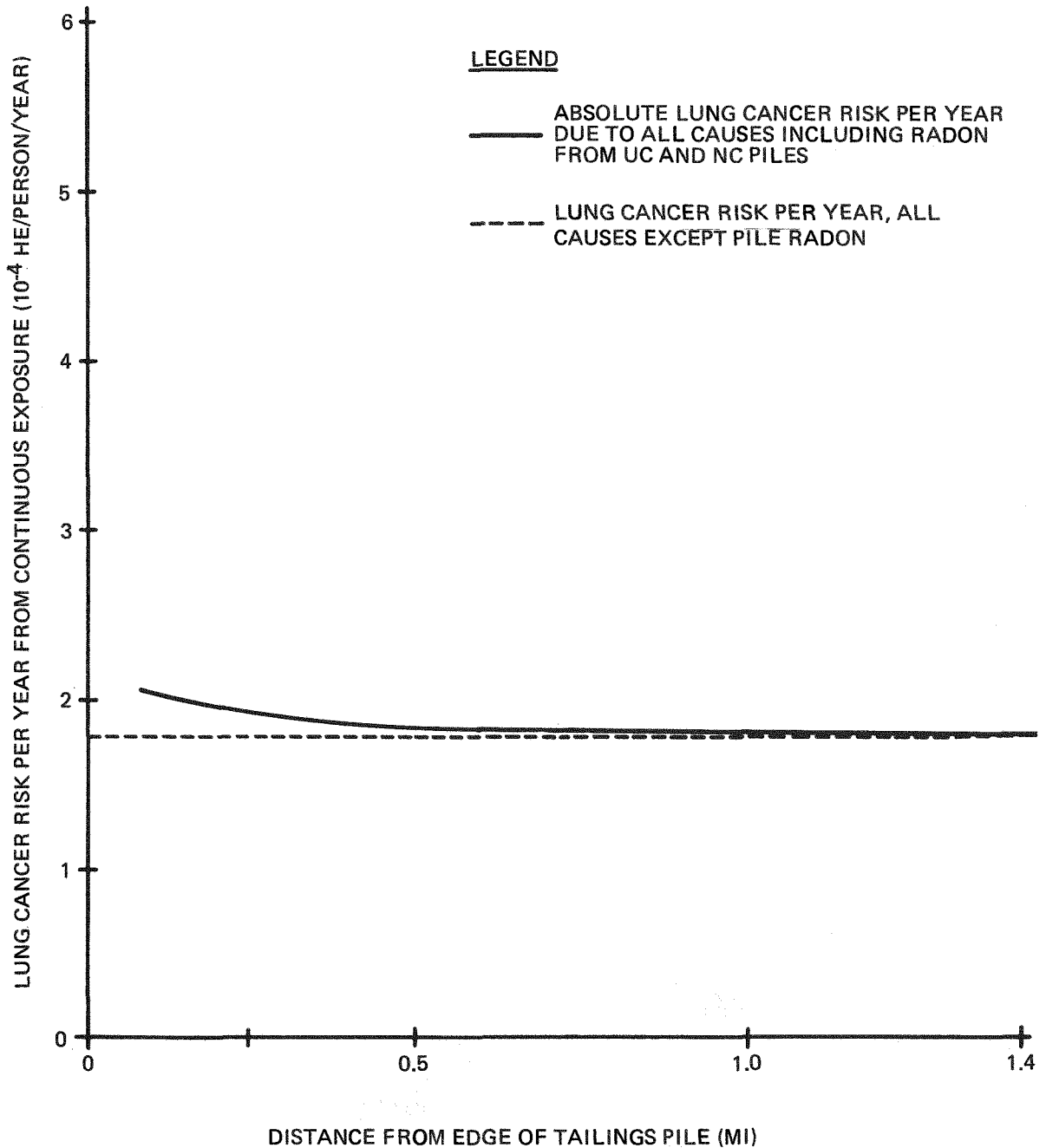


FIGURE 3-16B-2. RADIOMETRIC PROFILE AT DRILL HOLE SRNC-12

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**FIGURE 3-17. LUNG CANCER RISK FROM CONTINUOUS EXPOSURE TO RADON AS A FUNCTION OF DISTANCE FROM THE EDGE OF EITHER THE UC OR NC PILE**

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TABLE 9-1

SUMMARY OF STABILIZATION AND DISPOSAL COSTS<sup>a</sup>

	Option				
	IA	IB	IC	II	III
1. Tailings Site Costs	3.7	5.1	2.8	2.8	2.8
2. Off-Site Remedial Action Other than Windblown	0.1	0.1	0.1	0.1	0.1
3. Off-Site Windblown Area Remedial Action	0.3	0.3	0.3	0.3	0.3
4. Transportation					
a. Capital Costs	--	--	--	0.1	0.1
b. Haul Costs	--	--	0.5	1.1	1.7
5. Disposal Site	--	--	1.8	1.7	2.0
6. Total Cleanup <sup>b</sup> (sum of lines 1 through 5)	4.0	5.5	5.5	5.9	6.9
7. Engineering Design and Construction Management (30% of the difference between lines 6 and 4b)	1.2	1.6	1.5	1.5	1.6
8. Total <sup>b</sup> (sum of lines 6 and 7)	5.3	7.1	7.0	7.4	8.5
9. Contingency (30% of line 8)	1.6	2.1	2.1	2.2	2.5
10. GRAND TOTAL <sup>b</sup> (sum of lines 8 and 9)	6.8	9.2	9.1	9.6	11.0

<sup>a</sup>Costs are presented in millions of year 1980 dollars.

<sup>b</sup>Totals may differ from the sum of component costs because of round-off.

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TABLE 9-2

POTENTIAL CANCER CASES AVOIDED  
AND COST PER POTENTIAL CASE AVOIDED

A. Number of Potential Cancer Cases Avoided					
Options:	IA	IB	IC	II	III
Option Cost (million \$)	6.8	9.2	9.1	9.6	11.0
Years After Remedial Action					
25	<0.010	0.010	0.010	0.010	0.010
50	<0.021	0.021	0.021	0.021	0.021
75	<0.032	0.032	0.032	0.032	0.032
100	<0.043	0.043	0.043	0.043	0.043

B. Cost Per Potential Cancer Case Avoided (Million \$)					
Options:	IA	IB	IC	II	III
Option Cost (million \$)	6.8	9.2	9.1	9.6	11.0
Years After Remedial Action					
25	690	920	910	960	1,100
50	329	438	433	457	524
75	216	288	284	300	344
100	161	214	212	223	256

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**GLOSSARY**

## GLOSSARY

### Terms/Abbreviations

### Definitions

absorbed dose	Radiation energy absorbed per unit mass.
A-E	Architect-Engineer.
AEC	Atomic Energy Commission.
alpha particle ( $\alpha$ )	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 ( $\alpha, \beta, \gamma$ ), hence is not dangerous unless alpha-emitting substances have entered the body.
amenability	The relative ease with which a mineral can be removed from an ore by a particular process.
anomaly (mobile gamma survey)	Any location detected by the mobile gamma survey where the recorded counts per second (c/s) from the large gamma-ray detector exceed the determined background for that area by 50 or more c/s.
aquifer	A water-bearing formation below the surface of the earth; the source of wells. A confined aquifer is overlain by relatively impermeable rock. An unconfined aquifer is one associated with the water table.
atmospheric pressure	Pressure exerted on the earth by the mass of the atmosphere surrounding the earth; expressed in inches of mercury (at sea level and 0°C, standard pressure is 29.921 in. Hg).

background radiation	Naturally occurring low-level radiation to which all life is exposed. Background radiation levels vary from place to place on the earth.
beta particle ( $\beta$ )	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 $3.7 \times 10^{10}$ 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 =  $7.4 \times 10^{-8}$  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 ( $\gamma$ )

High energy electromagnetic radiation emitted from the nucleus of a radioactive atom, with specific energies for the atoms of different elements and having high penetrating power.

GJO

Grand Junction Office.

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

	of people. It is obtained by summing individual dose equivalent values for all people in the population.
$\mu\text{R/hr}$	Microroentgen per hour ( $10^{-6}$ R/hr).
mR/hr	Milliroentgen per hour ( $10^{-3}$ R/hr).
MeV	Million electron volts.
maximum permissible concentration (MPC)	The highest concentration in air or water of a particular radionuclide permissible for occupational or general exposure without taking steps to reduce exposure.
NAS	National Academy of Sciences.
NIOSH	National Institute for Occupational Safety and Health.
noble gas	One of the gases, such as helium, neon, radon, etc., with completely filled electron shells, which is therefore chemically inert.
NRC	Nuclear Regulatory Commission.
nuclide	A general term applicable to all atomic forms of the elements; nuclides comprise all the isotopic forms of all the elements. Nuclides are distinguished by their atomic number, atomic mass, and energy state.
ORNL	Oak Ridge National Laboratory.
ORP-LVF (EPA)	Office of Radiation Programs, Las Vegas Facility (Environmental Protection Agency).
pCi/l	Picocurie per liter ( $10^{-12}$ Ci/l)
pCi/g	Picocurie per gram ( $10^{-12}$ Ci/g)
pCi/m <sup>2</sup> -s	Picocurie per square meter per second ( $10^{-12}$ Ci/m <sup>2</sup> -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 ( $^{238}\text{U}$ ). The most common isotope of radium, $^{226}\text{Ra}$ , 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 $^{222}\text{Rn}$ has a half-life of 3.8 days and is formed as a daughter product of radium ( $^{226}\text{Ra}$ ).
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 <sup>2</sup> -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 $2.58 \times 10^{-4}$ 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  $1.3 \times 10^5$  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.

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:

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

Radiations:

alpha particle	helium nucleus; easily stopped with thin layers of material, all energy deposited locally.
beta particle	electron; penetrates about $0.2 \text{ g/cm}^2$ 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 = $1.3 \times 10^5$ 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 $2.58 \times 10^{-4}$ coul/kg air. This is equal to the energy deposition of 88 ergs/g of dry air or 93 ergs/g of tissue.
$\mu$ R/hr	$10^{-6}$ roentgen/hr.
rad	energy deposition of 100 ergs/g of material.
picocurie (pCi)	unit of activity (1 pCi = 0.037 radioactive decays/sec or 2.2 min).
MeV	unit of energy; 1 MeV = $1.6 \times 10^{-6}$ erg.
rem	unit of energy deposition in man; 1 rem = 1 rad x quality factor; the quality factor = 20 for alpha particles.

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Note: Also see definitions of terms in Glossary.

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TABLE 3-2

## BACKGROUND RADIATION SOURCES IN SOIL FROM SOUTHWEST COLORADO

<u>Isotope (Decay Chain)</u>	<u>Average Value (pCi/g)</u>	<u>Range (pCi/g)</u>
$^{226}\text{Ra}$ ( $^{238}\text{U}$ )	1.48 $\pm$ 0.63	0.54 - 3.4
$^{232}\text{Th}$ ( $^{232}\text{Th}$ )	1.11 $\pm$ 0.32	0.10 - 1.46

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TABLE 3-3

ESTIMATED HEALTH IMPACT FROM SLICK ROCK TAILINGS  
FOR AN AREA WITHIN 1.5 MILES OF UNION CARBIDE TAILINGS EDGE

Time Period	Population (Persons)	Total Pile-Induced RDC Health Effects/Yr			Background RDC Health Effects/Yr
		UC	NC	Total	
1980	100	0.00028	0.000082	0.00036	0.0057
2005 (zero growth)	100	0.00028	0.000082	0.00036	0.0057
2005 (0.8% constant growth rate)	122	0.00033	0.00010	0.00043	0.0068
2005 (5.0% declining growth rate)*	190	0.00053	0.00016	0.00068	0.011
<u>25-Yr Cumulative RDC Health Effects</u>					
Pile-Induced					
<u>Growth Projection</u>		UC	NC	Total	Background
Zero growth		0.0069	0.0021	0.009	0.14
0.8% constant growth rate		0.0077	0.0023	0.010	0.16
5.0% declining growth rate*		0.0011	0.0031	0.013	0.22

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

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TABLE 3-4

## CHEMICAL ANALYSES OF SLICK ROCK WATER SAMPLES (mg/l)

Sample <sup>a</sup>	As	Ba	Cd	Cr	V	Fe	Pb	Se
A - North of UC site along river	0.024	0.159	<0.001	<0.001	<0.001	9.400	0.035	0.030
B - North of UC site along river	0.048	0.241	<0.001	<0.001	<0.001	11.500	0.077	0.089
C - South of NC site by bridge	0.068	0.229	<0.001	<0.001	<0.001	12.600	0.084	0.061
EPA Interim Primary Drinking Water Regulations <sup>b</sup>	0.05	1.0	0.01	0.05	--	0.3 <sup>c</sup>	0.05	0.01

<sup>a</sup>See Figure 3-15 for locations.

<sup>b</sup>Federal Register, Dec 24, 1975.

<sup>c</sup>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 Piles at Slick Rock, Colorado"; ORNL-5452; Oak Ridge National Laboratory; Oak Ridge, Tennessee; June 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; "<sup>222</sup>Rn Flux Measurement with a Charcoal Canister"; Health Physics; Vol 31, p. 455; 1976.
5. D.H. Slade, ed; "Meteorology and Atomic Energy"; AEC report TID-24190; July 1968.
6. "Gamma Radiation Surveys at Inactive Uranium Mill Sites"; U.S. Environmental Protection Agency; Technical Note ORP/LV-75-5; 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. "Radiological Criteria for Decontamination of Inactive Uranium Mill Sites, Phase I"; USEPA/ORP; Washington, D.C.; Dec 1974.
9. 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).
10. A.J. Breslin and H. Glauberman; "Uranium Mill Tailings Study"; AEC Technical Memorandum; HASL-64-14; July 1964.
11. "Engineering Assessment of Inactive Uranium Mill Tailings, Vitro Site, Salt Lake City, Utah"; DOE/UMT-0102; FB&DU; Apr 1981.
12. 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.
13. "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation: 1980"; Report Advisory Committee on Biological Effects of Ionizing Radiation, NAS, National Research Council; 1980.

14. 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.
15. "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.
16. Statistical Abstract of the United States; 100th Edition; p. 29, Table 29.
17. "Health Effect Risk Estimators for Radon Daughters"; report to Ford, Bacon & Davis Utah Inc., by Rogers and Associates Engineering Corp.; Jan 1981.
18. Vital Statistics of the U.S.; Vol II; Mortality; National Center for Health Statistics; HEW; 1968.
19. EPA Interim Primary Drinking Water Regulations; Federal Register; Dec 24, 1975.

CHAPTER 4

SOCIOECONOMIC AND LAND USE IMPACTS

## CHAPTER 4

### SOCIOECONOMIC AND LAND USE IMPACTS

Slick Rock, an unincorporated town in southwestern Colorado, lies less than 10 mi east of the Utah-Colorado border. The town is in a semiarid mountainous area just north of an agricultural region extending south from Egnar to Cortez. Slick Rock is isolated from other communities, even ones of modest size. The San Miguel County seat, Telluride, is located 80 road miles to the east. The boundaries of San Miguel County, in which the site is located, and the highway linking Slick Rock to other Colorado towns are shown in Figure 4-1.

#### 4.1 SOCIOECONOMIC BACKGROUND

The Slick Rock area originally was settled as agricultural and low-density grazing land. The majority of land is still used for low-density grazing. Demographic and economic conditions of Slick Rock, of San Miguel County, and of the Gladel Census Division, which includes the Slick Rock area, contrast sharply with the steady growth of Colorado as a whole.

Ethnically, the inhabitants of San Miguel County are predominantly Caucasian, although 7% are American Indian.<sup>(1)</sup> A relatively high percentage of the residents and working population is male. The median age was 26.2 yr in 1970. Educational attainment and income levels consistently rank below the average for the State of Colorado. Most workers are employed as miners, managers, operators, farmers, ranchers, and craftsmen. Managers and farmers show a steady decline in number. Recreation and public services have been employing a greater percentage of the work force.

From the 1930's through the 1950's, the area experienced considerable mining activity, and the mining industry has been a major employer since 1940. Pioneer Uravan Inc. intends to construct and operate a uranium mill approximately 4 mi east of Slick Rock. Several new uranium and vanadium mines are already in operation in the area, and a coal mine to be located in Disappointment Valley, east of Slick Rock, is in the planning stages. Other than development of mineral resources, however, there is little stimulus for growth in the Slick Rock area, and the mining industry is expected to continue to be the major employer of area residents.

#### 4.2 POPULATION ESTIMATES

Table 4-1 includes the 1980 census figures for the Gladel Census Division and San Miguel County. As shown, the population of the Gladel Census Division increased less than 1% over the last decade, from 328 to 330 people, suggesting that the

population of the Slick Rock community is stable. However, because of the area's small population base and its extreme dependence on mining activities, projection of future growth patterns is difficult. The Pioneer Uranium mill that is proposed for the area will employ about 100 people. Planning reports project that the population of the region surrounding Slick Rock will increase by as many as 550 people when the mill is completed. Some of these people will probably settle in the Slick Rock community; however, the incorporated towns of Naturita, Dove Creek, Egnar, and Norwood will undoubtedly absorb the majority of the new population.

Based on a site inspection and the San Miguel County Commissioners and Planning Department estimates, the 1980 population of the area within 1.5 mi of the UC site is estimated to be 100 persons.<sup>(2)</sup> The estimated distribution of this population is presented in Table 4-2, where the major concentration of people (about 60) are shown to reside between 0.25 and 0.5 mi southwest of the Union Carbide tailings.

Figure 4-2 shows three possible population projections for Slick Rock. The projection considered to be the most probable is the 0.8% constant annual growth projection, which is based on the current growth rate of the United States. This growth pattern would result in an increase in Slick Rock's population from its present figure of 100 persons to a total of 122 persons by the year 2005.

A more optimistic projection is presented in Figure 4-2 by the 5% declining annual growth rate scenario. This projection assumes that the annual growth rate of Slick Rock will decline linearly from its initial value of 5%/yr to zero growth after 25 yr. If this pattern were experienced, the population of Slick Rock would increase from its present population of 100 people to 190 people by the year 2005. This projection may be realized if mining activities are increased for the long term.

The growth projection labeled "zero growth" in Figure 4-2 is presented as a lower limit on the growth expected for Slick Rock and is based on the growth pattern experienced by the Slick Rock area during the last decade.

#### 4.3 LAND USE

The area near the Slick Rock tailings is characterized as agricultural land primarily used for low-density grazing. Figure 4-3 illustrates land use in the vicinity. Land along the river designated as agricultural land is used for pasture and growing hay. Although 93% of the land in the area is put to agricultural use, mining activities sustain the area's economy. The amount of land devoted to mineral exploration, extraction, and milling fluctuates with market conditions. Some of the

area's many mining camps, such as Slick Rock, are still in use, but most have been abandoned.

The only residential concentration near Slick Rock is a trailer park with about 20 mobile homes located approximately 0.5 mi southwest of the UC tailings. The trailer park has sewage and water hook-ups for about 40 units. The only local nonmining industrial activity is the gas sweetener plant located immediately west of the tailings. The only commercial activity in the vicinity is the combination restaurant-post office located on State Highway 141 just west of the Dolores River.

#### 4.4 IMPACT OF THE TAILINGS ON LAND VALUES

Figure 4-4 shows the land ownership at Slick Rock according to the February 1980 plats and ownership records at the San Miguel County Assessor's office. Most private land is located along the Dolores River and is owned by Union Carbide Corporation, Katheryn Ann Redd Mullins, et al., or Troy Rose.

The current estimated market values of the land at Slick Rock are as follows:<sup>(3)</sup> The land owned by Mullins, et al., is grazing land and is valued at about \$30/acre. Sixty-eight acres of grazing land owned by Rose is worth about \$20/acre. The market value of other land owned by Rose, 50 acres of cropland that can be irrigated, has been estimated at about \$530/acre.

The land owned by Union Carbide--160 acres on which the North Continent site is located and 115 acres on which the Union Carbide site lies--has an assessed value of less than \$10/acre.

The presence of the tailings restricts the use of the actual tailings areas; however, if the tailings were not present the value of the surrounding land would remain virtually unchanged. There are no apparent future uses for the land on the two sites, although the availability of the mobile home facilities would be attractive should mineral activity expand.

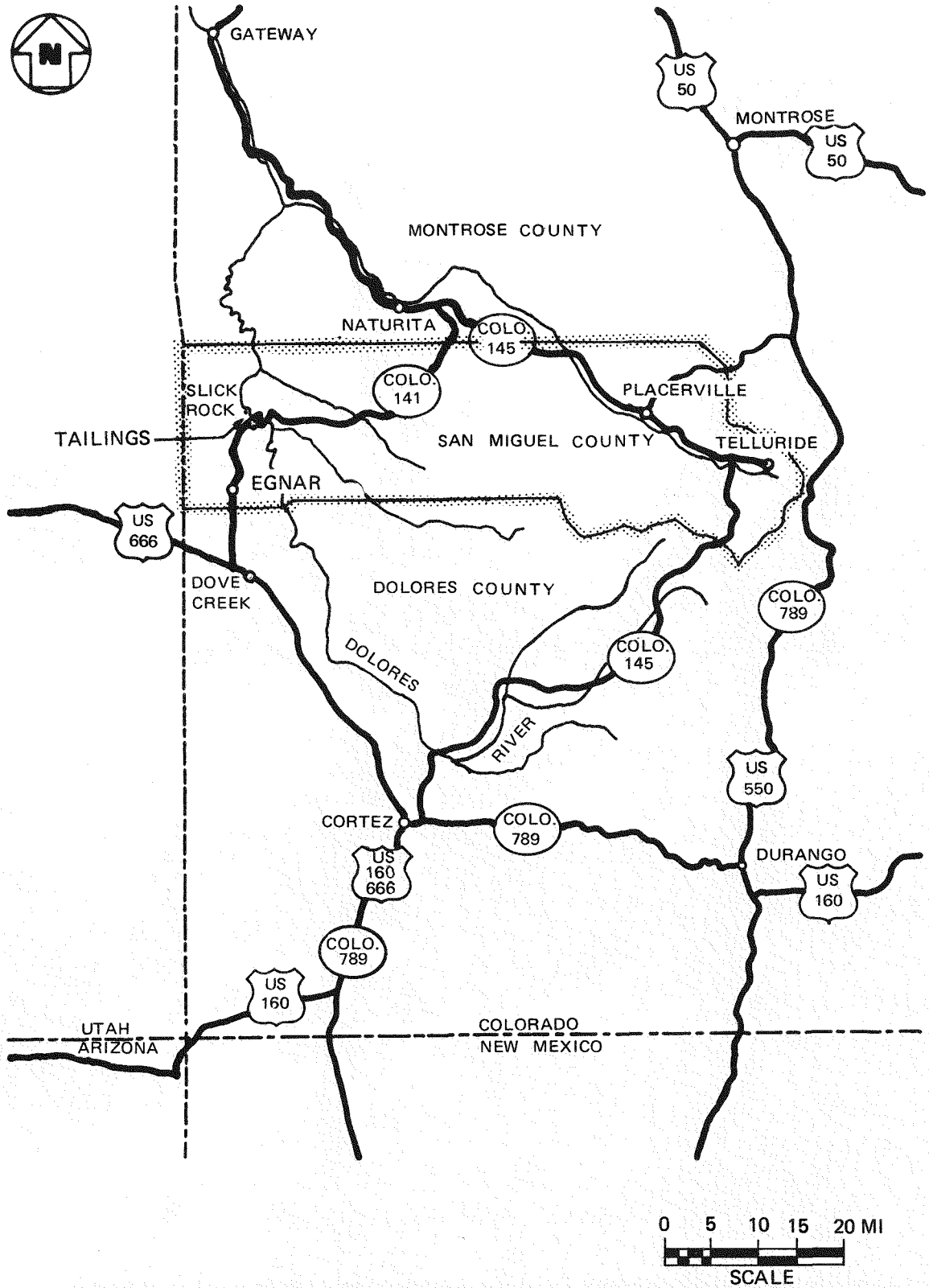


FIGURE 4-1. MAP OF SAN MIGUEL COUNTY BOUNDARIES

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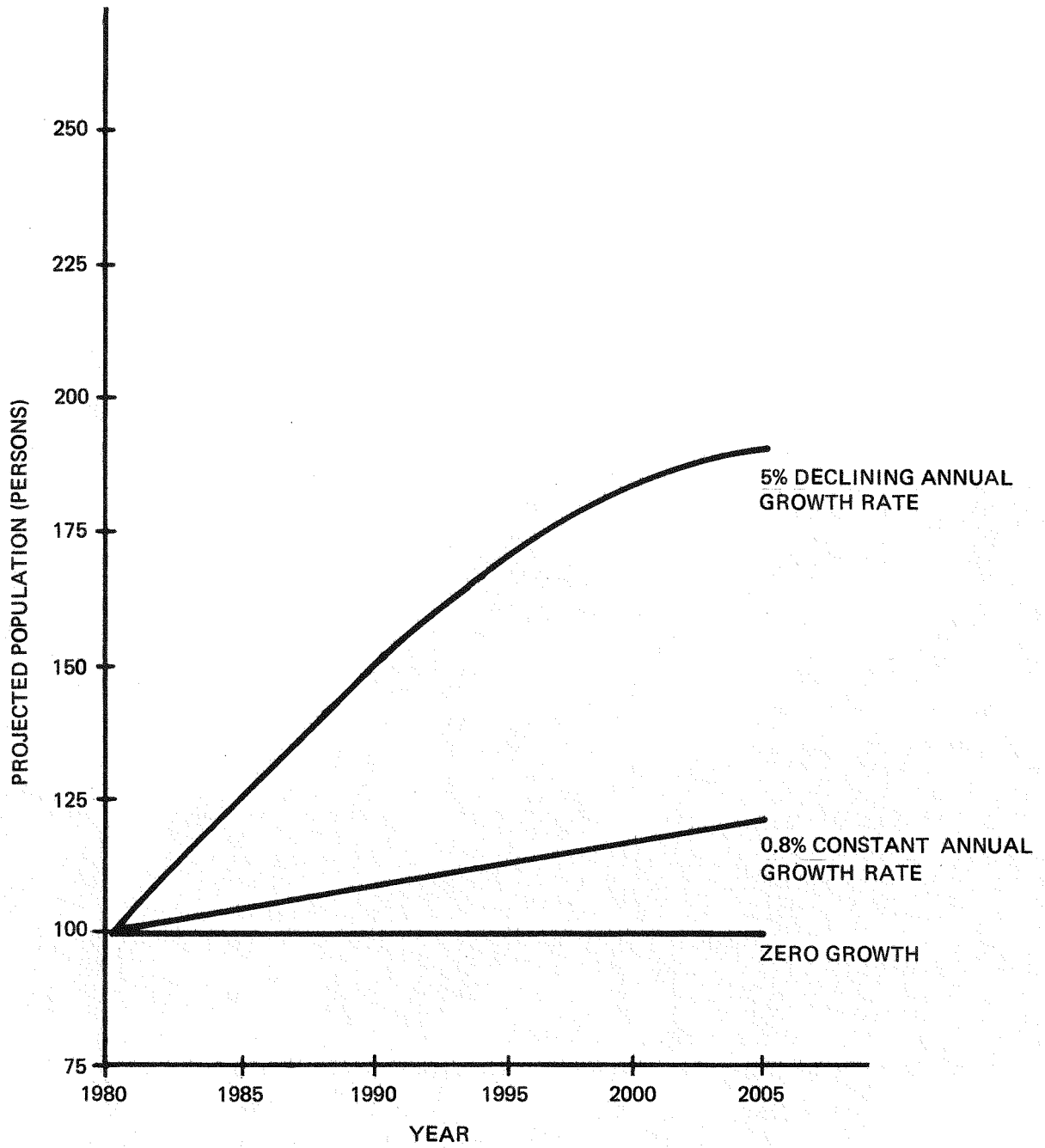
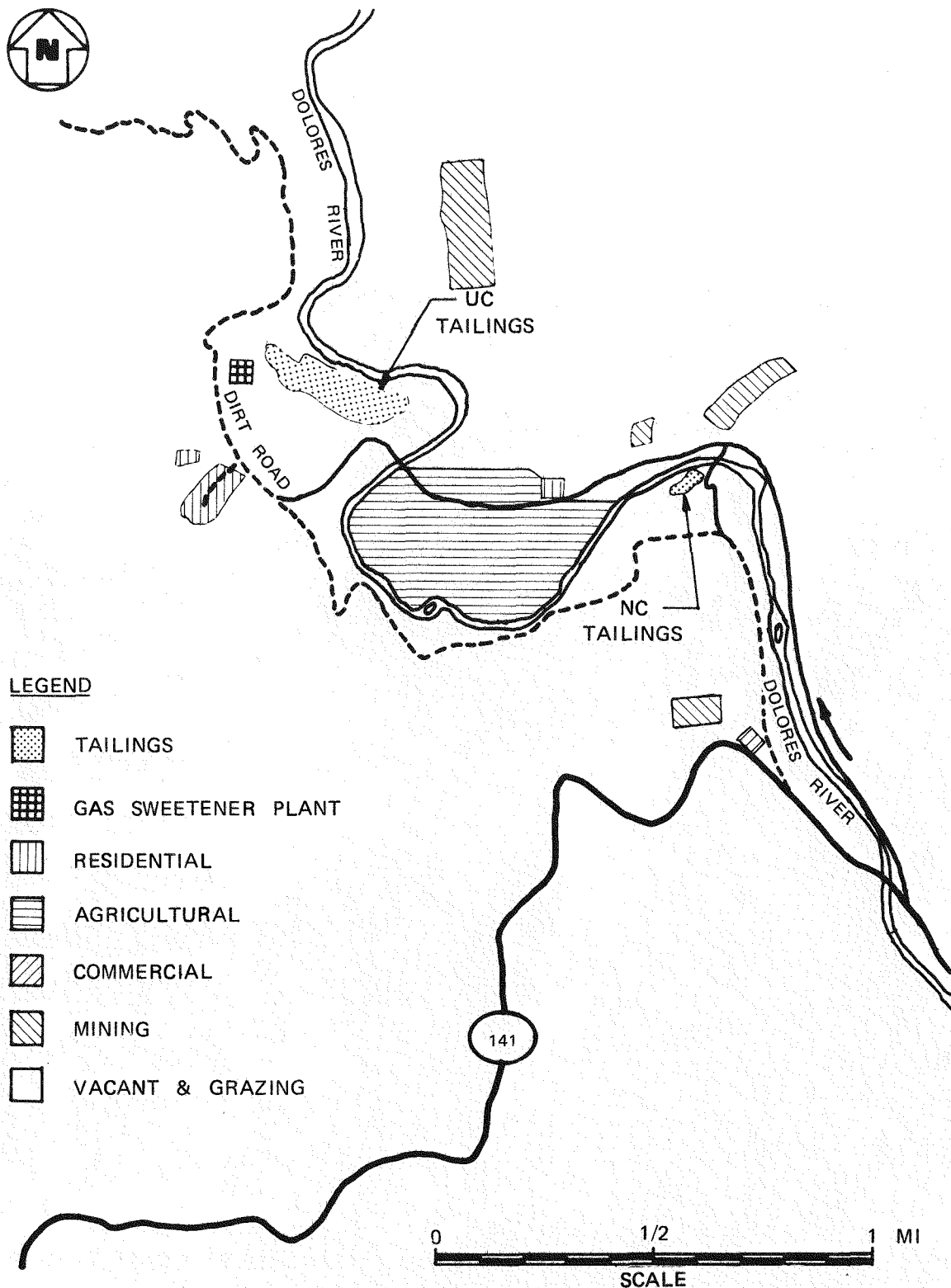









FIGURE 4-2. PROJECTED POPULATIONS

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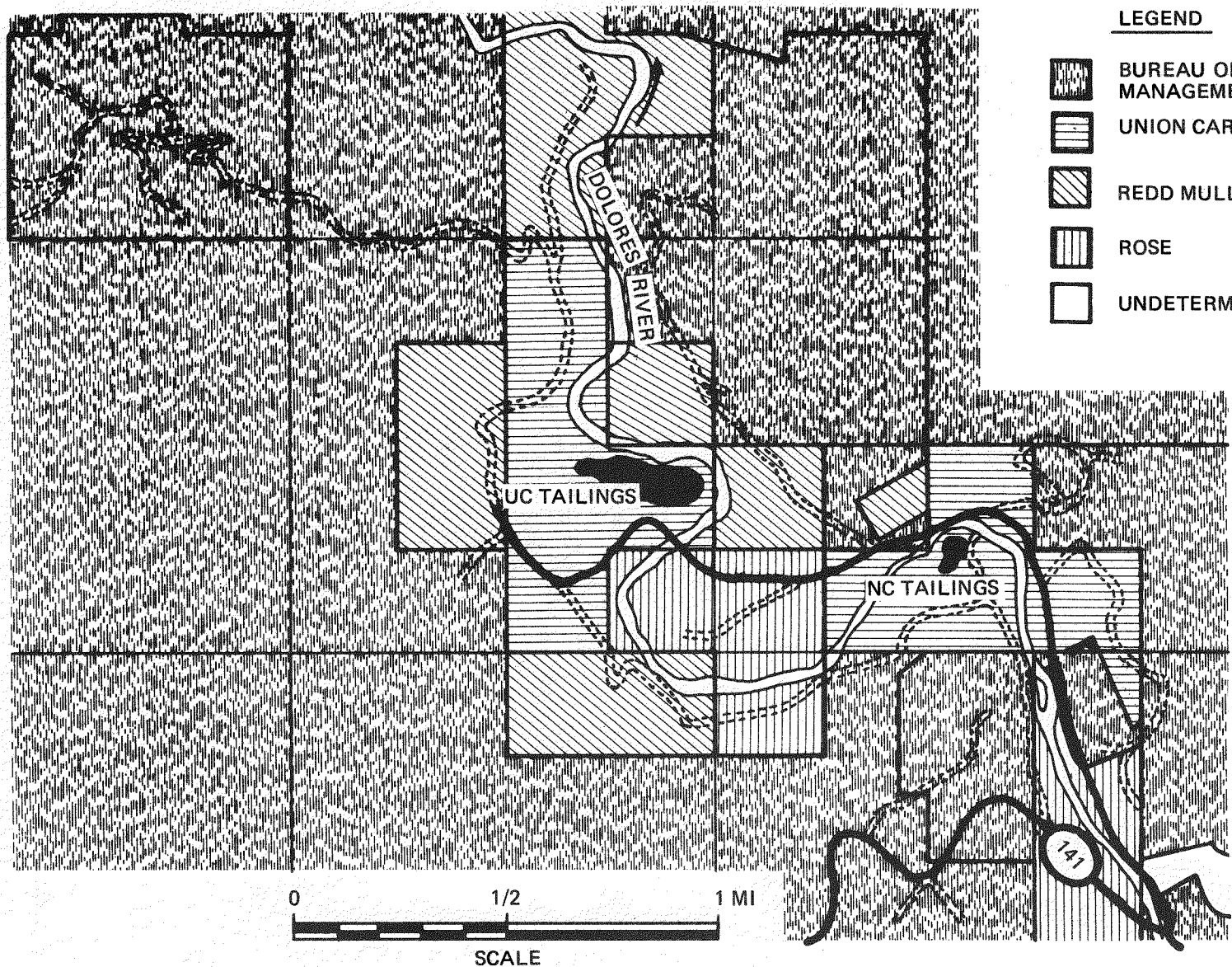


**LEGEND**






-  TAILINGS
-  GAS SWEETENER PLANT
-  RESIDENTIAL
-  AGRICULTURAL
-  COMMERCIAL
-  MINING
-  VACANT & GRAZING

**FIGURE 4-3. VICINITY LAND USE**

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**LEGEND**

-  BUREAU OF LAND MANAGEMENT
-  UNION CARBIDE
-  REDD MULLINS
-  ROSE
-  UNDETERMINED

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**FIGURE 4-4. SLICK ROCK VICINITY LAND OWNERSHIP**

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Forb, Bacon & Davis Inc.

TABLE 4-1

POPULATION HISTORY OF SAN MIGUEL COUNTY  
AND THE SLICK ROCK AREA\*

<u>Year</u>	<u>Gladel Census Division (Slick Rock Area)</u>		<u>San Miguel County</u>	
	<u>Size</u>	<u>Change (%)</u>	<u>Size</u>	<u>Change (%)</u>
1980	330	+ 0.4	3,017	+ 55
1970	328	- 234	1,949	- 34
1960	1,095	+ 267	2,944	+ 9
1950	298	- 4	2,693	- 27
1940	312	--	3,664	--

\*Based on U.S. Census Bureau information

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TABLE 4-2

ESTIMATED 1980 POPULATION DISTRIBUTION AT SLICK ROCK

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<u>Distance (mi)</u>	<u>Direction</u>	<u>Population (persons)</u>
0.25	SW	20
0.25	WNW	5
0.50	ESE	10
0.50	SSE	5
0.50	SW	30
0.50	WSW	10
0.75	SE	5
1.00	E	5
1.50	SE	10
Total		100

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#### CHAPTER 4 REFERENCES

1. J.L. England; "Baseline Data and Land Use Impact of the Slick Rock Uranium Tailings Sites"; Center for Health and Environmental Studies, Brigham Young University; Provo, Utah; 1976.
2. Dan Woodard, San Miguel County Commissioner and Planning Department; personal communication; July 16, 1980.
3. San Miguel County Assessor's Records.

CHAPTER 5

RECOVERY OF RESIDUAL VALUES

## CHAPTER 5

### RECOVERY OF RESIDUAL VALUES

In this evaluation of the potential for reprocessing the tailings for further recovery of metal values, the two tailings piles near Slick Rock will be considered as one. The Union Carbide Corporation tailings pile contains 350,000 tons of tailings with a uranium content, as derived from AEC records of plant operation, of 0.005%  $U_3O_8$ . Table 5-1A gives the assay results on a composite sample taken in 1977, which also shows 0.005%  $U_3O_8$ . There are only 37,000 tons of tailings on the North Continent site. The uranium content, as shown in Table 5-1B, is 0.008%. The combined tailings from the two sites are 387,000 tons, with an average uranium content of 0.005%  $U_3O_8$  and a vanadium content of 0.135%  $V_2O_5$ . There are no other metals present in significant concentrations in the tailings. As will be shown in the discussion that follows, 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 Slick Rock tailings to determine the recovery of uranium or vanadium that could be achieved in a reprocessing operation. In the absence of specific testing, the estimate of uranium recovery from retreatment of the tailings is based on the graph provided by DOE's Grand Junction Office, as shown in Figure 5-1. For the purpose of this chapter it is assumed that the uranium content of 0.005%  $U_3O_8$  indicated by AEC records is correct. It is expected that recovery of uranium by a conventional process will be about 40% or 0.04 lb  $U_3O_8$ /ton of tailings. By pelletizing with acid and heap leaching, recovery would be about 30% or 0.03 lb/ton. By normal heap leaching, the recovery would be about 23% or 0.02 lb. At November 1980 prices of \$28/lb of  $U_3O_8$ , the total income from uranium recovery would be \$0.60 to \$1.20/ton processed. Vanadium was recovered from ores processed at Slick Rock. The composite tailings sample contains 0.135%  $V_2O_5$ . At 40% recovery and a price of \$3/lb of  $V_2O_5$ , the recoverable vanadium would be worth about \$3.25/ton of tailings treated, which is well below the reprocessing cost.

#### 5.1 PROCESS ALTERNATIVES

There are three principal alternatives for the reprocessing of uranium-bearing tailings. They are as follows:

- (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 feet 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.

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.

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 it is necessary that such a mill with significant excess capacity 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 387,000 tons of tailings, there is a substantial quantity of contaminated waste at the Slick Rock site,<sup>(1)</sup> mainly contaminated soil from windblown tailings which extend considerable distances off site.

The site has good access. Trucks could remove material from the site at a rate of about 2,000 tons/day. At this rate, all tailings and contaminated materials could be removed from the site in 1 yr. However, the nearest operating mill is about 60 mi away at Uravan, Colorado. The transportation costs would far exceed the value of the uranium and vanadium that could be recovered from the Slick Rock tailings. Even if the tailings were delivered without charge to Uravan, reprocessing would not be economically feasible.

### 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 Slick Rock tailings would feed a 500 ton/day plant for about 2.5 yr. Normally, amortization of a plant is based on planned operation for 10 to 20 yr. There are still some operating mines in the area, and good potential for development of new reserves which might be able to supply ore to feed such a plant. Pioneer Uravan is planning a new mill about 4 mi east of Slick Rock. Even in this plant, reprocessing the Slick Rock tailings would not be economically attractive.

## 5.2 SLICK ROCK 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<sup>(2)</sup> rose from \$30/lb of U<sub>3</sub>O<sub>8</sub> 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<sub>3</sub>O<sub>8</sub> 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<sub>3</sub>O<sub>8</sub>, representing nearly 3 times the current annual consumption rate. Projected domestic uranium supply exceeds apparent buyer requirements each

year through 1985.<sup>(3)</sup> Under these circumstances, no basis is evident for a turnaround in uranium prices for about 5 yr.<sup>(2)</sup> 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.<sup>(1)</sup> 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.<sup>(4)</sup> 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<sup>(5)</sup> publishes reports quarterly on various construction cost indexes. The following data are derived from this source:

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

The Producer Price Index of Industrial Commodities<sup>(2)</sup> has increased as follows in the 1977 to 1980 period:

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

From the above indexes, an increase in plant construction cost of 25% from January 1977 to mid-1980 has been applied as a conservative estimate. As indicated in Figure 5-2, the capital cost of a 500 ton/day heap leach facility would be about \$4.8 million. As indicated in Figure 5-3, the cost for a conventional mill of similar capacity would be about \$6 million. If these capital costs were to be amortized on the Slick Rock tailings only, the unit costs would be \$12 to \$16/ton, or from \$390 to \$410/lb of U<sub>3</sub>O<sub>8</sub> recovered.

### 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<sup>(1)</sup> the direct operating costs of a 500 ton/day facility were estimated at \$3.25 and \$5.80/ton for heap leach and conventional acid leach mills, respectively. However, R.B. Coleman<sup>(4)</sup> 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<sub>3</sub>O<sub>8</sub> 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 Slick Rock tailings in a 500 ton/day conventional plant of about \$17.50/ton, or \$440/lb of U<sub>3</sub>O<sub>8</sub> recovered (assuming 0.04 lb recovered/ton). For a heap leach plant of the same size the corresponding figures would be \$13.75/ton and \$460/lb recovered. In view of these operating costs, which far exceed the market price, no detailed analysis of optimum plant size is warranted. The 500 ton/day plant size is about the smallest that would be built today for an operation processing high grade ore.

### 5.2.4 Competitive Market Factors

The average grade of ore processed in conventional mills has decreased from 0.15% U<sub>3</sub>O<sub>8</sub> in 1977 to 0.11% in 1979. The average recovery rate for the industry has been 91±1% during

this period.(6) However, since tailings have been processed previously, the recoveries in reprocessing are likely to be much lower, as reflected in Figure 5-1. To produce a given quantity of uranium, about 20 times as much Slick Rock 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 per unit of production is correspondingly greater. 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 Slick Rock tailings.

### 5.3 CONCLUSION

Based on the foregoing analysis, it is concluded that the processing of Slick Rock 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 under any foreseeable conditions. Even if all the uranium could be recovered, the cost of the uranium produced, exclusive of any transportation cost, would be over 10 times the current market price. For processing this material, assuming a plant of about 500 tons/day capacity, the cost of the uranium recovered would be over \$800/lb of U<sub>3</sub>O<sub>8</sub>. Vanadium recovery is also unattractive and will not improve the economics of reprocessing. A comparison of costs by process method is given below.

	<u>Conventional Plant</u>		<u>Heap Leach</u>	
	<u>\$/ton</u>	<u>\$/lb U<sub>3</sub>O<sub>8</sub></u>	<u>\$/ton</u>	<u>\$/lb U<sub>3</sub>O<sub>8</sub></u>
Capital Cost	15.50	390	12.40	410
Operating Cost	<u>17.50</u>	<u>440</u>	<u>13.75</u>	<u>460</u>
Total	33.00	830	26.15	870

The spot market price for uranium in September 1980, when the economic analyses in this chapter were prepared, was \$28.50/lb of U<sub>3</sub>O<sub>8</sub>. Since that time, construction costs have continued to rise, while the spot market price for uranium has declined to about \$25/lb of U<sub>3</sub>O<sub>8</sub> early in 1981. These trends further reduce the economic attractiveness of tailings reprocessing.

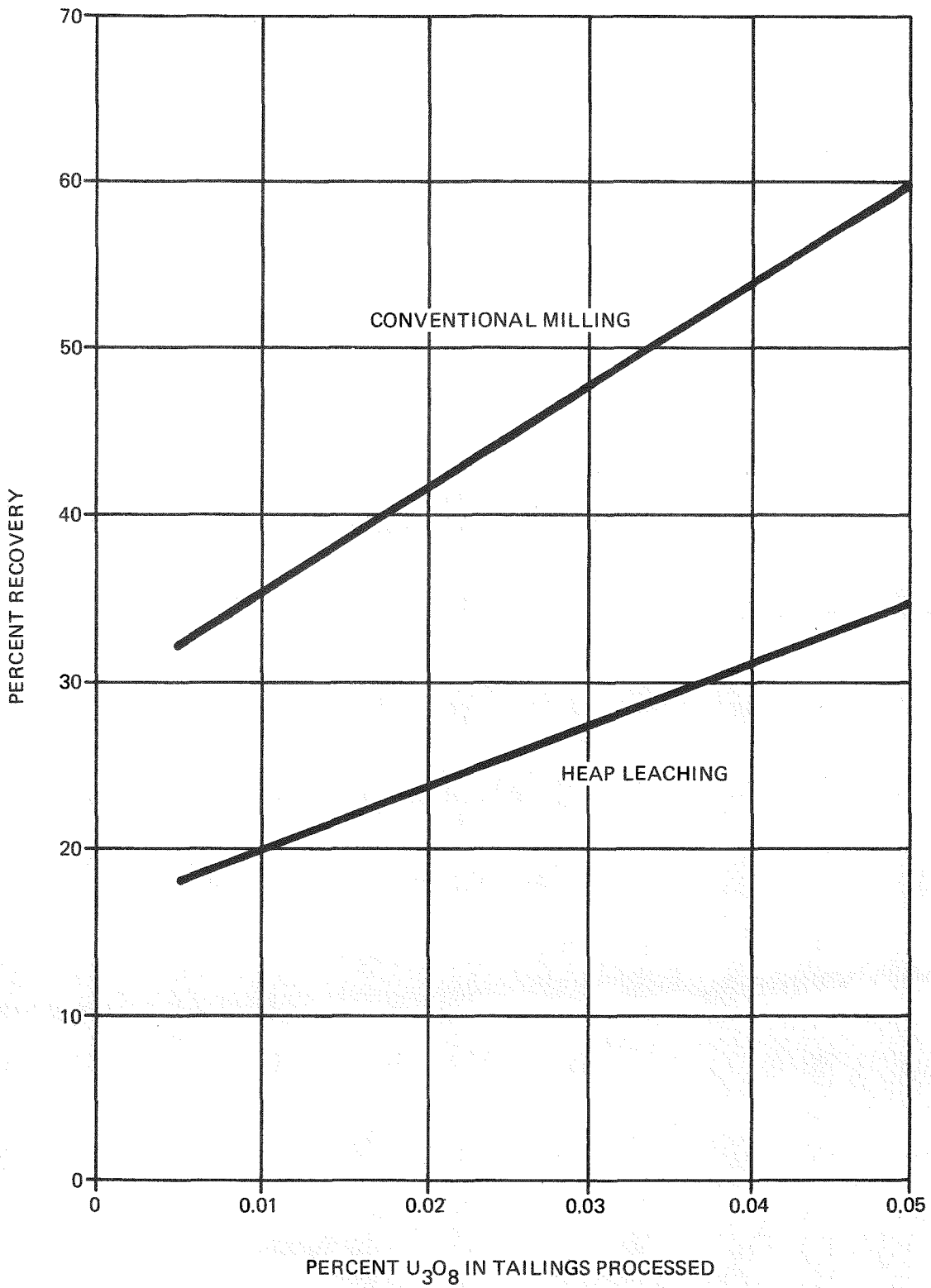
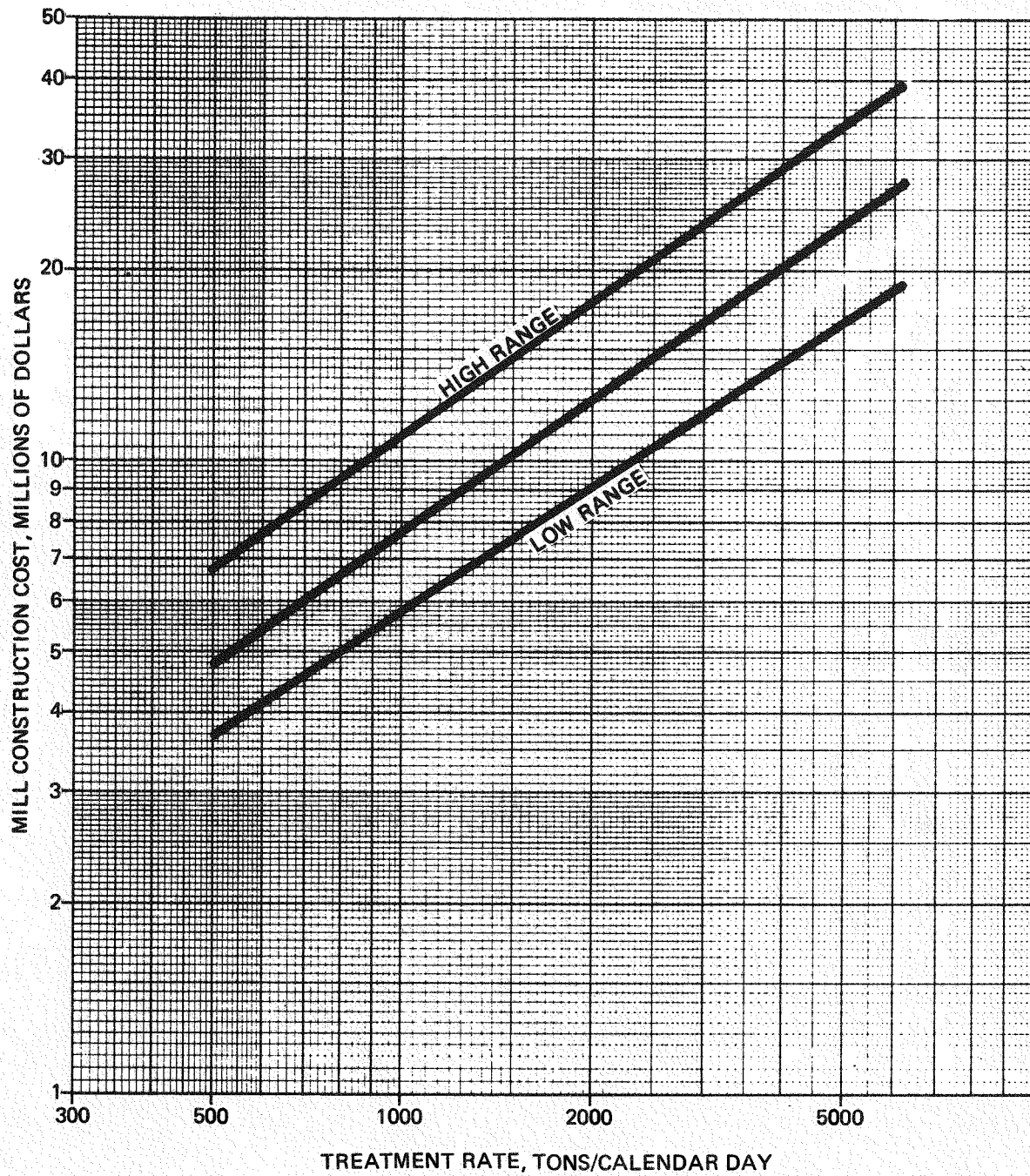


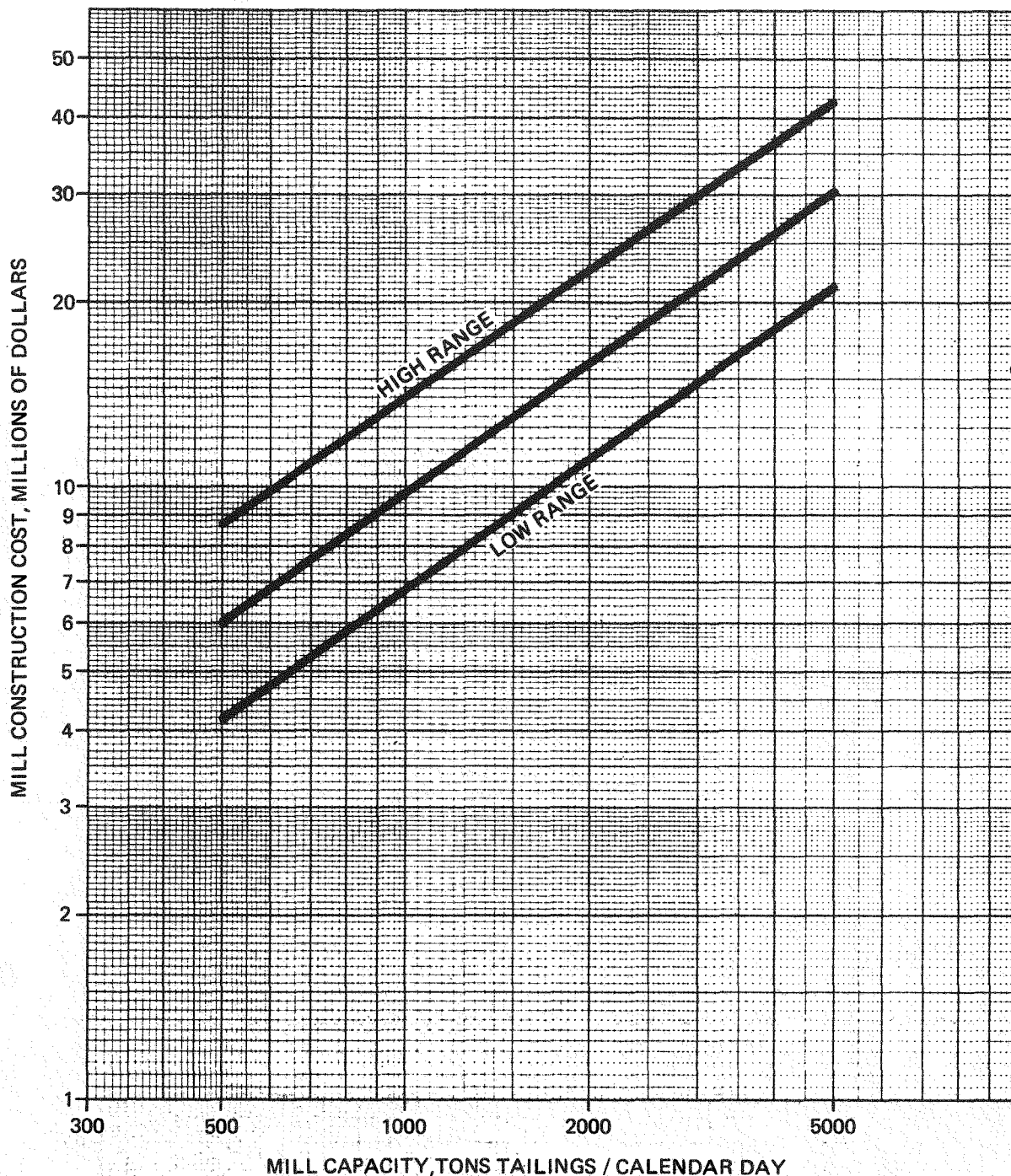
FIGURE 5-1. URANIUM RECOVERY FROM MILL TAILINGS AS A FUNCTION OF U<sub>3</sub>O<sub>8</sub> CONTENT IN TAILINGS

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

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

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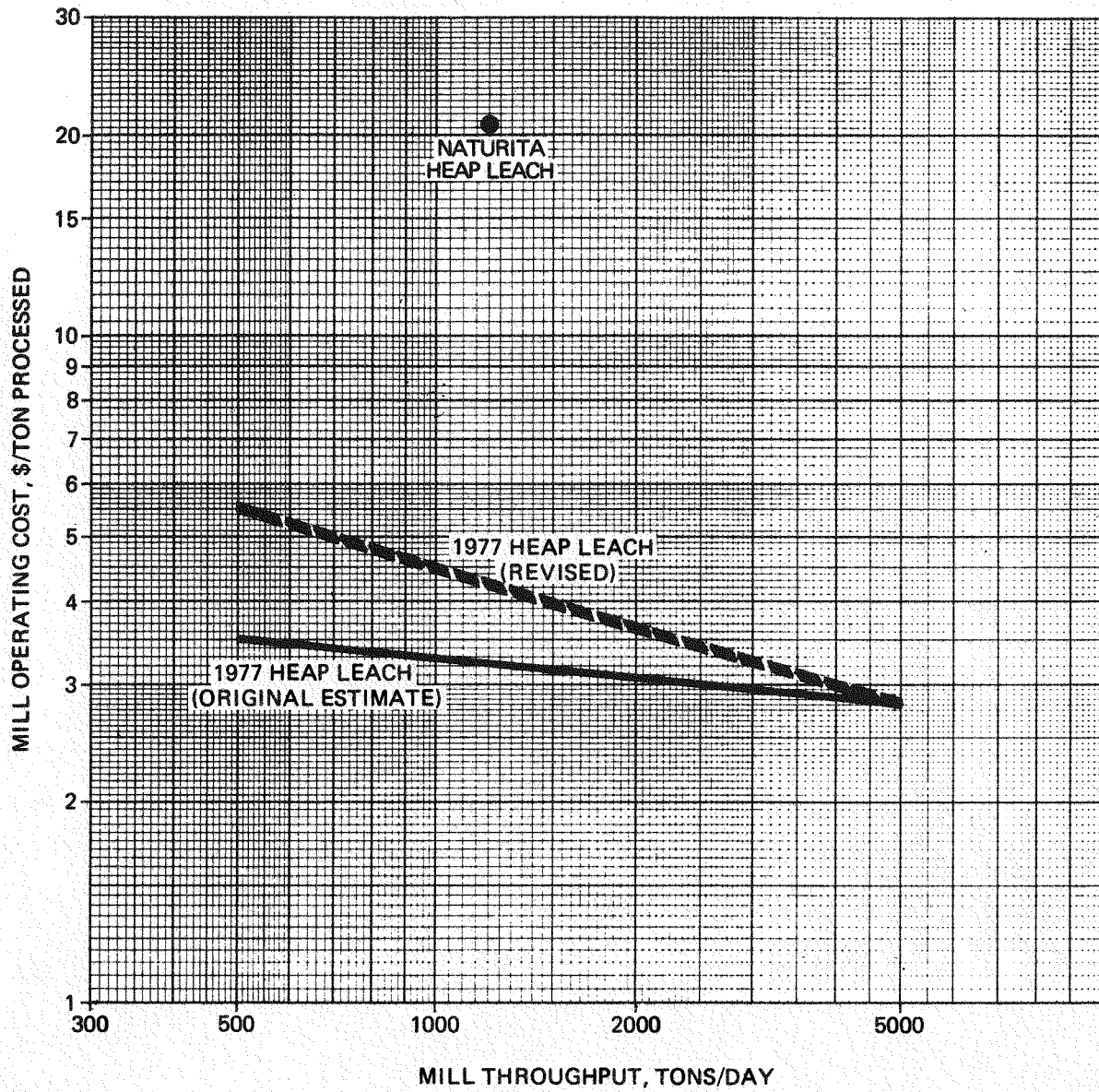


FIGURE 5-4. OPERATING COSTS OF HEAP LEACHING OF URANIUM MILL TAILINGS

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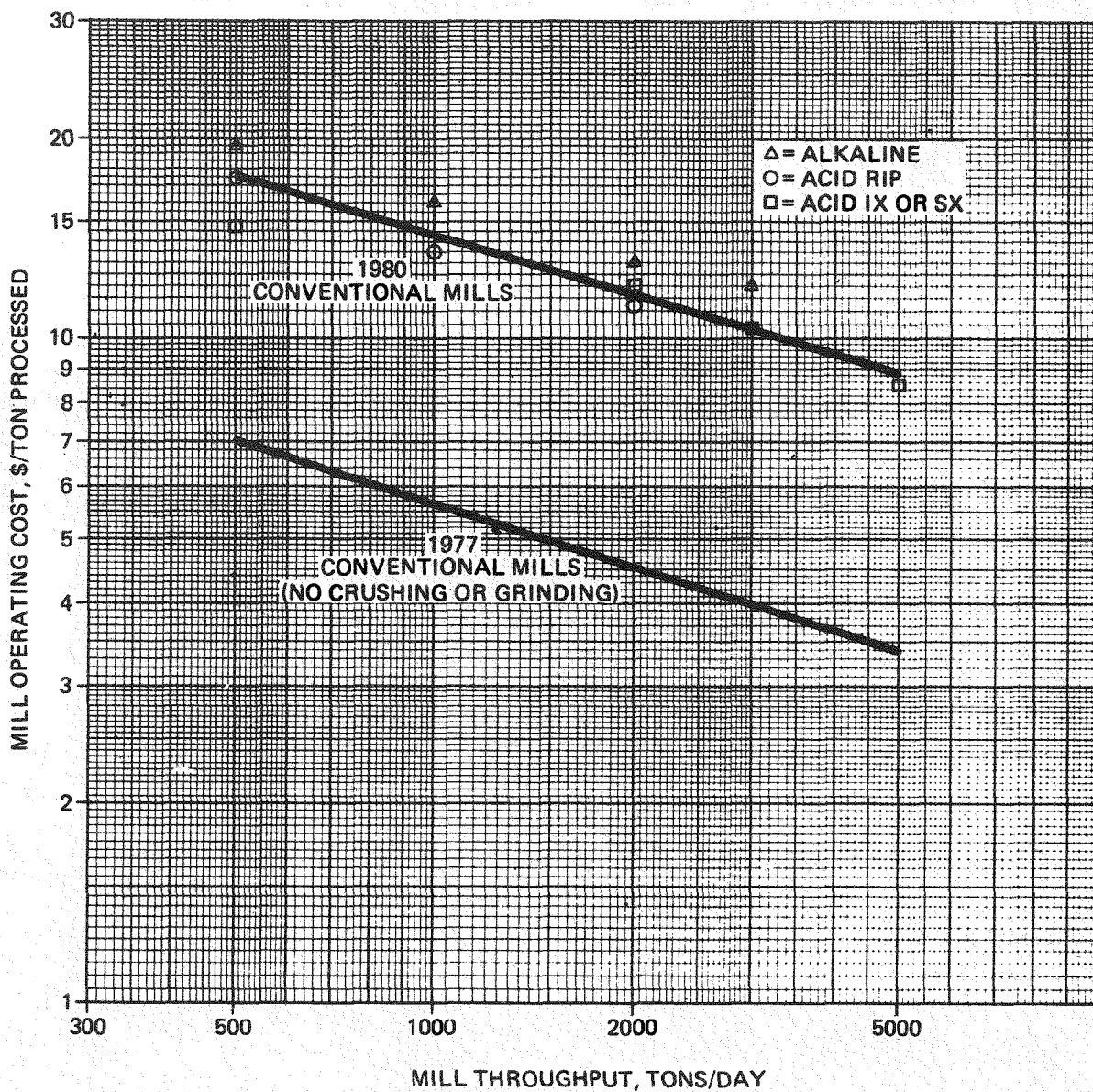


FIGURE 5-5. OPERATING COSTS OF CONVENTIONAL MILLING W/O CRUSHING AND GRINDING FACILITIES TO REPROCESS TAILINGS (COST ADJUSTED TO JULY 1980)

TABLE 5-1A  
 ASSAY RESULTS OF COMPOSITE TAILINGS AND BACKGROUND SAMPLES  
 UNION CARBIDE SITE

Element	Percentage by Weight				Background Composite
	Atomic Absorption	Spectrographic	Chemical	AEC* Estimate	
Aluminum	--	1.0-0.01	--	--	--
Arsenic	0.00066	--	--	--	0.00017
Barium	0.0134	--	--	--	--
Boron	--	<0.01	--	--	--
Cadmium	0.0000075	--	--	--	--
Calcium	--	<0.01	--	--	--
Chromium	0.00034	--	--	--	--
Cobalt	0.00020	--	--	--	--
Copper	0.00168	<0.01	--	--	--
Cyanide	<0.000001	--	--	--	--
Gallium	--	--	--	--	--
Iron	0.4080	>0.01	--	--	--
Lead	0.00287	<0.01	--	--	--
Magnesium	--	1.0-0.01	--	--	--
Manganese	--	<0.01	--	--	--
Mercury	0.0000074	--	--	--	--
Molybdenum	--	<0.01	--	--	--
Nickel	--	--	--	--	--
Potassium	--	1.0-0.01	--	--	--
Selenium	0.000221	--	--	--	0.0000029
Silicon	--	>1.0	--	--	--
Silver	0.000057	--	--	--	--
Sodium	--	--	--	--	--
Titanium	--	<0.01	--	--	--
Uranium (U <sub>3</sub> O <sub>8</sub> )	--	--	0.005	0.005	--
Vanadium (V <sub>2</sub> O <sub>5</sub> )	--	--	0.148	--	--
Zinc	0.0021	--	--	--	--

\*Calculated tailings assay based on plant operation(1)

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TABLE 5-1B

ASSAY RESULTS OF COMPOSITE TAILINGS AND BACKGROUND SAMPLES  
NORTH CONTINENT SITE

Element	Percentage by Weight			
	Atomic Absorption	Spectrographic	Chemical	Background Composite
Aluminum	--	1.0-0.01	--	--
Arsenic	0.00341	--	--	0.00017
Barium	0.0453	--	--	--
Boron	--	<0.01	--	--
Cadmium	0.000003	--	--	--
Calcium	--	1.0-0.01	--	--
Chromium	0.00048	--	--	--
Cobalt	0.00054	--	--	--
Copper	0.00352	--	--	--
Cyanide	<0.000001	--	--	--
Gallium	--	<0.01	--	--
Iron	0.6540	--	--	--
Lead	0.0125	--	--	--
Magnesium	--	1.0-0.01	--	--
Manganese	--	<0.01	--	--
Mercury	0.0000054	--	--	--
Molybdenum	--	<0.01	--	--
Nickel	--	<0.01	--	--
Potassium	--	1.0-0.01	--	--
Selenium	0.0000765	--	--	0.0000029
Silicon	--	>1.0	--	--
Silver	0.000128	--	--	--
Sodium	--	1.0-0.01	--	--
Titanium	--	<0.01	--	--
Uranium (U <sub>3</sub> O <sub>8</sub> )	--	--	0.008	--
Vanadium (V <sub>2</sub> O <sub>5</sub> )	--	--	0.062	--
Zinc	0.00214	--	--	--

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TABLE 5-2

## U.S. URANIUM SUPPLY AND MARKET SUMMARY

Year	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Sales Commitments To Domestic Buyers	To Foreign Buyers	Est. U <sub>3</sub> O <sub>8</sub> To Be Available For Sale	Procure- ment of Foreign Uranium	Reported Unfilled Requirement	Total Domestic Production Potential (1+2+3)	Total Domestic Supply (1+3+4)	Apparent Buyer Requirements (1+4+5)
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, Slick Rock Sites, Slick Rock, Colorado"; GJT-7; Ford, Bacon & Davis Utah Inc.; Oct 1977.
2. NUEXCO No. 144, p. 27; published by Nuclear Exchange Corporation, 3000 Sand Hill Road, Menlo Park, California, 94025; Aug 1980.
3. Survey of United States Uranium Marketing Activity; DOE/RA-0053; U.S. Department of Energy; July 1980.
4. Uranium Milling Costs by R.B. Coleman, Hazen Research, Inc.; presented at Colorado School of Mines Seminar; Mar 12, 1980.
5. Engineering News Record; Vol 204, No. 25, pp. 75 and 79; June 19, 1980.
6. 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.<sup>(1)</sup>

#### 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.<sup>(2,3)</sup> 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.<sup>(4)</sup> 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<sup>(2)</sup> 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<sup>(5,6)</sup> 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.<sup>(7)</sup> Both were shown to be effective for short

periods of time when applied as a fine spray on sandy soils. On clay soils, the film disintegrated within a few weeks of application, apparently because of expansion and contraction of the clays during cycles of wetting and drying. The film was porous, allowed infiltration of water, and did not interfere with germination of wheat, grass, or legume seeds. The film is damaged by insects and rodents, and respraying may be necessary. Three to five years after application of the asphalt treatment, the amount of dry erodible surface area in the tested soils had increased, suggesting that asphalt treatments may not be desirable under all conditions.

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

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

#### 6.1.2 Volumetric Stabilization

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

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

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

### 6.1.3 Physical Stabilization

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

Covers of gravel or crushed rock have been shown to be effective in preventing wind erosion and allow infiltration of water without permitting substantial erosion.<sup>(13)</sup> Riprap, a cover of substantial rocks, armors the surface against erosion and may enhance growth of vegetation.<sup>(14,15)</sup> 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.<sup>(11)</sup> 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:<sup>(11)</sup>

- (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 Slick Rock, precipitation averages about 7 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

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\*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<sup>(4)</sup> 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<sup>(18,19)</sup> 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

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\*Registered trademark.

exhalation control. However, proposed NRC standards for stabilizing inactive mill tailings require a minimum of 3 m of cover over the tailings.<sup>(1)</sup> 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.<sup>(11)</sup>

Studies of multilayer physical stabilization systems presently in progress are directed at identifying cost effective cover systems to satisfy proposed EPA standards for disposal.<sup>(1)</sup> 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<sup>2</sup>-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.<sup>(8,21)</sup> 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.

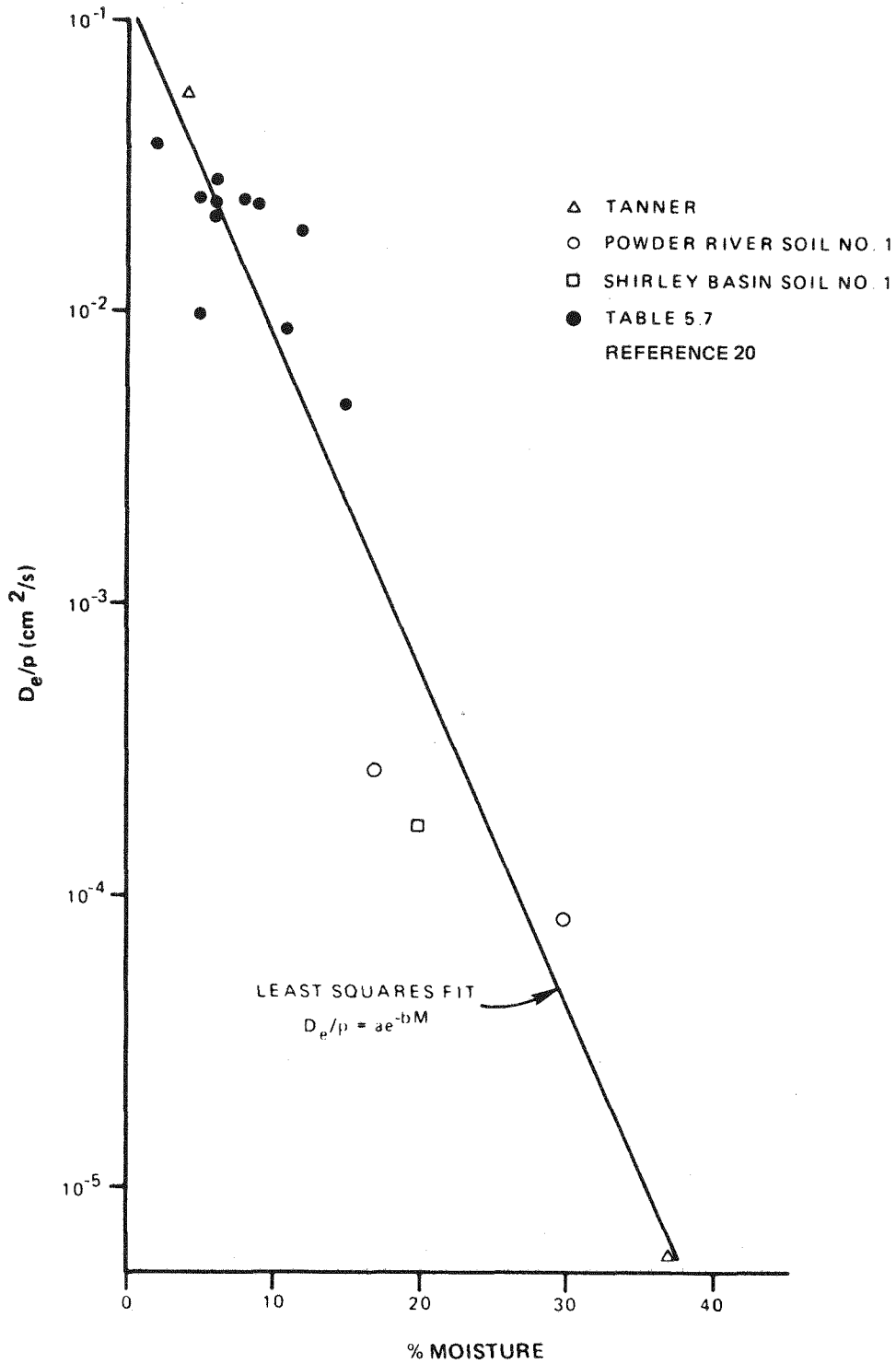
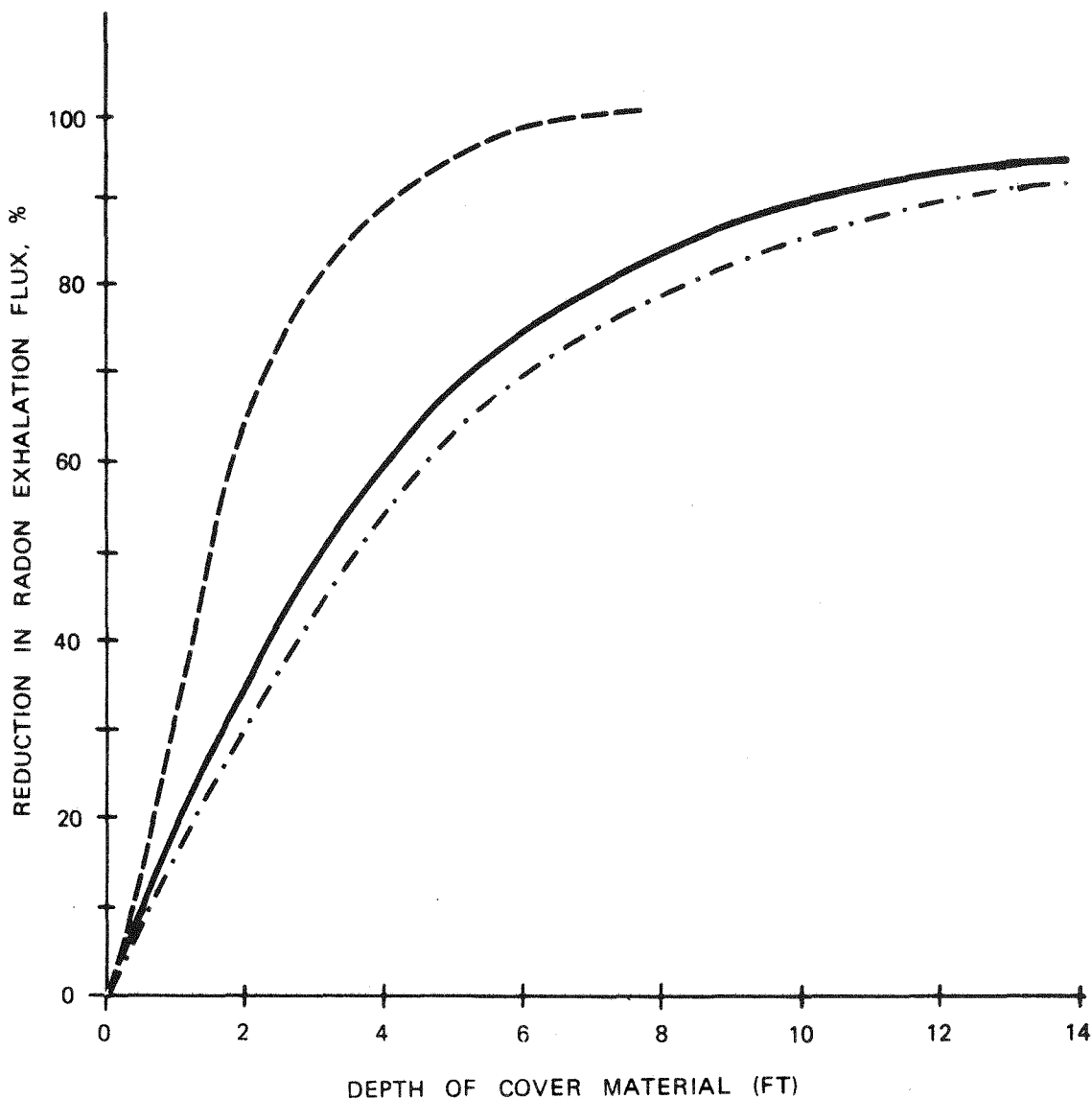


FIGURE 6-1. EXPONENTIAL MOISTURE DEPENDENCE OF THE DIFFUSION COEFFICIENT

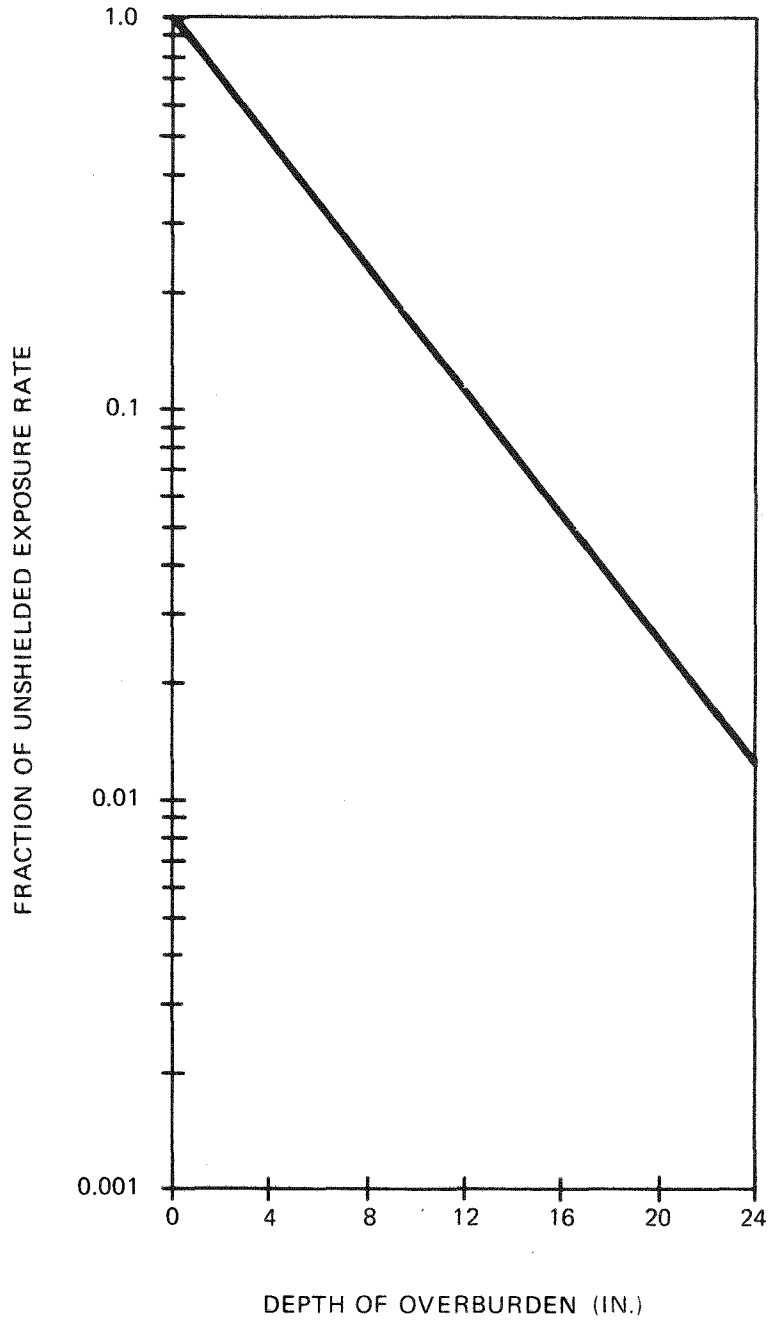


**LEGEND**

- RESULT FOR SOIL (USED IN THIS EVALUATION)
- . - RESULT FOR DRY SAND
- - - RESULT FOR CLAY

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

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

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## CHAPTER 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 off-site properties contaminated with tailings. Discussed in this chapter are those locations where tailings have been transported away from the designated sites. Such off-site locations are classified as off-site windblown properties and off-site properties other than windblown. Costs associated with the cleanup of the tailings sites themselves are considered in Chapter 9.

#### 7.1 DATA SOURCES

A mobile scanning unit operated by the AEC performed a gamma radiation survey of the Slick Rock area in 1971. Of the 16 structures scanned, six anomalies were discovered where the radiation was significantly above background. 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 the six locations and an additional three locations that were not reported to determine the source of the anomalies and, if tailings, how they had been used. High and low inside and outside gamma readings were recorded. A map was drawn of areas where gamma readings inside the structures exceeded 20  $\mu$ R/hr.<sup>(1)</sup> This survey was the data source used for consideration of the remedial action required for off-site locations and structures.

The EPA gamma survey<sup>(2)</sup> for windblown tailings was the data source for consideration of remedial action for the windblown areas.

#### 7.2 REMEDIAL ACTION FOR OFF-SITE PROPERTIES OTHER THAN WINDBLOWN

A follow-up survey of the anomalies<sup>(1)</sup> identified three locations where tailings had been used. Tailings were identified on a vacant lot at the south end of West 2nd Street, along the side of the road. At a second location, tailings were used in the mortar for an outdoor fireplace. The fireplace was located greater than 10 ft from adjacent structures. The third location was listed as the entire trailer park. General contamination was found throughout the trailer park, specifically in fire brick used in walkways and in one permanent structure.

Although tailings were identified at these three locations, possible remedial action will be minimal since only one permanent structure was found contaminated.

The presence of ore was noted in several places, but these locations are not given further consideration in this study. Additional tailings use locations may be identified during future work.

For the purpose of this engineering assessment, a cost of \$46,000, exclusive of engineering and contingency allowances, has been estimated for off-site structures and trailer park cleanup. This cost is based on available information and adjusted Grand Junction off-site remedial action costs, and includes cleanup, backfill, restoration, and health physics and monitoring services.

### 7.3 REMEDIAL ACTION FOR OFF-SITE WINDBLOWN PROPERTIES

The extent of off-site contamination spread by windblown or waterborne mechanisms is indicated by the EPA data in Figures 3-12A and 3-12B. There are approximately 16 acres at the Union Carbide site and 2 acres at the North Continent site that are inside the contaminated boundaries but outside the designated site boundaries. Decontamination of these areas would involve removing the off-site contaminated soil and replacing it with clean fill. The result of this action is assumed to satisfy remedial action criteria as described in Paragraph 3.5. The proposed decontamination plans showing the actual areas that must be cleaned up are presented in Figures 9-1A and 9-1B. These figures also show the assumed depths of soil removal to meet the required cleanup criteria.

The cost for cleanup and restoration of the 18 acres described above is estimated to be \$275,000, exclusive of engineering and contingency allowances. This cost includes cleanup, backfill, restoration, and health physics and monitoring services.

## CHAPTER 7 REFERENCES

1. "Summary Report of the Radiation Surveys Performed in the State of Colorado at Slick Rock, Colorado"; EPA-ORP-LV; Mar 1973.
2. R.L. Douglas and J.M. Hans, Jr.; "Gamma Radiation Surveys at Inactive Uranium Mill Sites"; Technical Note ORP/LV-75-5; EPA; Office of Radiation Programs; Las Vegas, Nevada; Aug 1975.

CHAPTER 8

DISPOSAL SITE SELECTION

## CHAPTER 8

### DISPOSAL SITE SELECTION

Since the two tailings piles are located on the flood plain of the Dolores River, it may be advisable to move the tailings from their present sites and dispose of them at a hydrologically superior site. If the tailings are to remain in their present locations, significant upgrading of the existing dikes around the sites will be required.

Descriptions of two possible disposal sites are included in this chapter. Since the NRC regulations require a 3-m depth of cover for the disposal of tailings, potential sources of these large amounts of cover material have been identified. The distances of the sources of cover material and of the present tailings site from the possible disposal sites will have a direct impact on the cost of each of the two options.

#### 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<sup>(1)</sup> 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.

Two potential disposal sites have been identified for disposal of the Slick Rock tailings and contaminated materials. Figure 8-1 shows the relative locations of the two sites. A reconnaissance survey was made of both sites, and cost estimate studies based on their characteristics are included as Options II and III in Chapter 9.

Each of the sites was evaluated to a limited extent on the basis of hydrology and on-site inspections. The hydrologic conditions were assessed with regard to such factors as wind and water erosion, water contamination, flooding and drainage characteristics, depth to bedrock, and location of confined aquifers. Special consideration was given to drainage basin configuration, surface and subsurface drainage, and natural disposal basin features. Economic considerations included distance from the tailings sites, preliminary estimates of support facilities such as highways and railroads, and the extent of site preparation and long-term maintenance required at the site.

Returning the Slick Rock tailings to the mines from which the ores were originally obtained is not feasible. The ore treated at the mills came from many mines scattered throughout the Slick Rock area (many of these mines contributed only a few hundred tons). The costs and logistics involved in hauling to the mines make such a proposal too impractical for consideration.

## 8.2 DESCRIPTIONS OF DISPOSAL SITES CONSIDERED AS OPTIONS

The proposed disposal sites, one located in southeast Cougar Canyon and the other in Disappointment Valley, are within 1.5 and 6.5 mi of the UC tailings pile, respectively. Vegetative cover in the area is 30% or less, and average annual precipitation is approximately 7 in./yr. Combinations of paved, gravel, and dirt roads provide access to both sites. There are no railroad facilities in the area.

### 8.2.1 Southeast Cougar Canyon Area, Site 1 (Option II)

As shown in Figure 8-1, the southeast Cougar Canyon area is approximately 1.5 road miles northwest of the UC site. This location is adequate for deposition of the tailings from both the UC and NC sites. The site lies on approximately 100 acres situated in a natural depression upland from the Dolores River and the tailings locations. Elevation above sea level is about 5,780 ft. The site is more than 1 mi from any permanent human habitation and is on apparently idle land.

Sufficient materials can be obtained from the suggested disposal site to satisfy the stabilization requirement of 3 m of cover. The erosion hazard due to precipitation averaging 7 in./yr is moderate; however, natural riprap used to control erosion is available within the site area.

The site is reached by traveling northward for 0.5 mi along an unimproved roadway on the eastern edge of the UC site, then westward for 0.5 mi, and finally by proceeding on jeep trail onto the site. Upgrading of approximately 1 mi of the access roads would be required to accommodate heavy truck traffic.

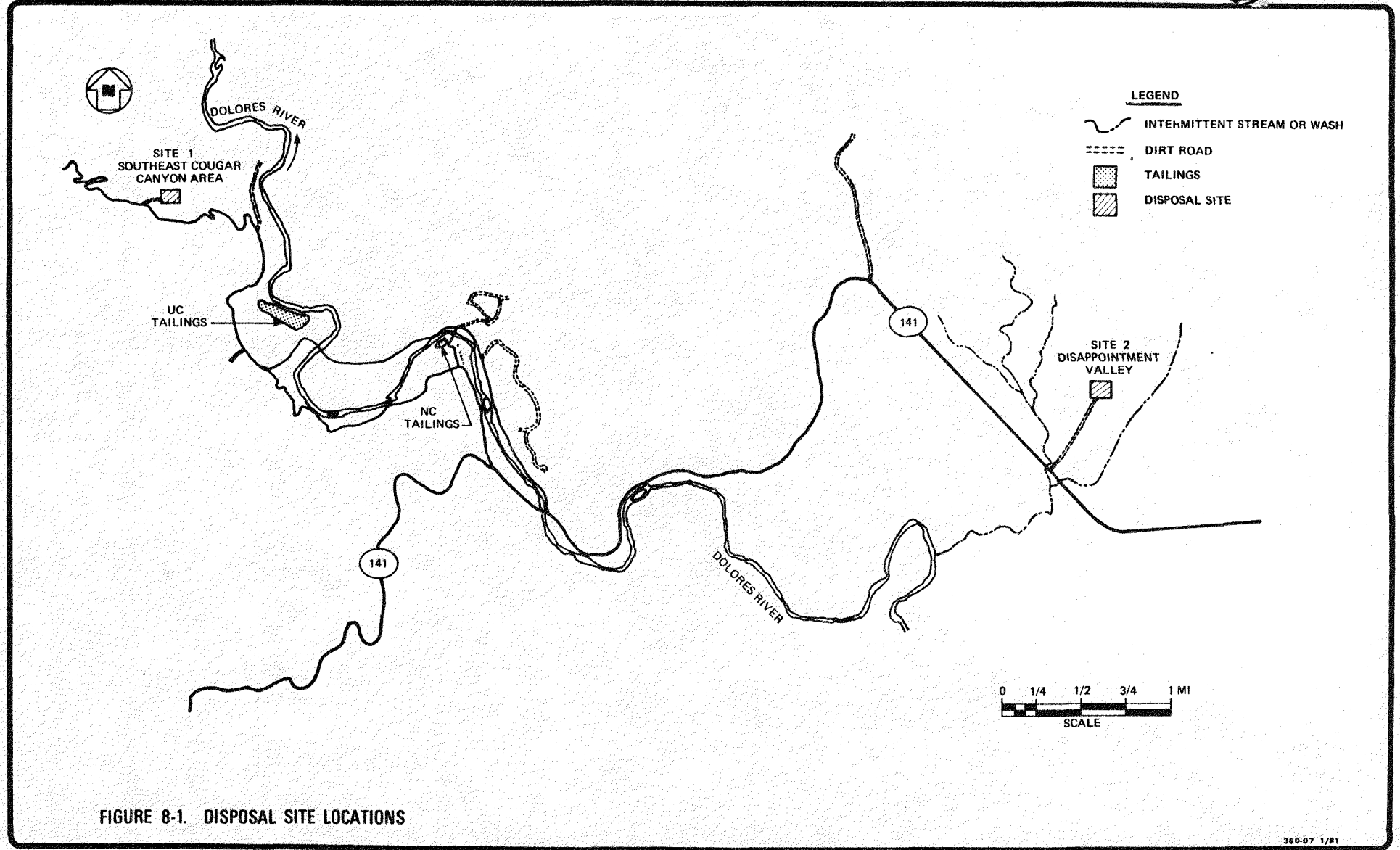
Advantages of this proposed disposal location are its size, ease of tailings deposition and subsequent coverage, and distance from human habitation and bodies of surface water. Disadvantages include the difficulty of hauling the tailings over the steep terrain, the necessity of upgrading approximately 1 mi of haul road, and the possibility that this site may abut private land.

#### 8.2.2 Disappointment Valley, Site 2 (Option III)

The Disappointment Valley site is located on flat, barren, isolated land in Disappointment Valley, about 6.5 road miles east of the UC tailings pile. This is about 0.5 mi east of Nicholas Wash and 0.5 mi north of State Highway 141. Access to the site is east along the highway from the Slick Rock bridge for about 4 mi, then northeast over a haul road for about 0.5 mi. The site lies at 5,650 ft above sea level. The site is and will probably remain isolated from human habitation. The nearest residence is located about 3.5 mi from the site, and no further development of this area is foreseen.

The site can be easily prepared to prohibit water erosion because of its flat topography and its location more than 0.25 mi from any washes or intermittent streams. Sufficient material can be obtained from the site and from adjacent land to fulfill the stabilization requirement of a 3-m depth of cover. Gravel for riprap can be obtained from gravel pits located about 5 mi west of the site, along State Highway 141. Deposition of contaminated materials below grade is the preferred method of tailings disposal. However, it is uncertain whether the depth of soil development in this area is sufficient to excavate to depths of 3 m.

Advantages of this proposed disposal site are its ease of haul along flat grades, isolation from human habitation, good hydrologic conditions, and ease of site preparation. Disadvantages include its distance of 6.5 mi from the tailings and the necessity of constructing a 0.5-mi haul road.



CHAPTER 9

REMEDIAL ACTIONS AND COST-BENEFIT ANALYSES

## CHAPTER 9

### REMEDIAL ACTIONS AND COST-BENEFIT ANALYSES

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

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

Remedial actions designed to meet the EPA interim and proposed remedial action criteria were investigated. Two disposal sites, identified in Chapter 8, were evaluated in terms of the cost of disposal. Although each alternative disposal site has specific and unique characteristics that were considered in estimating costs, great care must be exercised in the use of these site-specific cost estimates since there are insufficient data and information to characterize the sites completely for estimating site development costs.

The process of obtaining the necessary permits and the associated costs were considered to be included in the various agency budgets and were not included in this report. Similarly, the tailings sites and the proposed disposal sites 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 were not included in this estimate. Funding for such future costs was assumed to come from separate contracts administered by the Federal Government.

The disposal options would provide for the relocation of all debris and contaminated materials from the tailings piles, millsites, and off-site locations. Thus, in all of the disposal options, 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  $^{226}\text{Ra}$  above background concentration.

A discussion of the concepts involved in tailings stabilization and their applicability to the Slick Rock sites has been

detailed in Chapter 6. It is assumed that vegetation will be planted or riprap provided if the tailings are stabilized on site. However, for disposal options, a riprap or gravel cap of 0.3 m on top of 3 m of cover material is assumed to suffice for erosion control in lieu of vegetation.

### 9.1 STABILIZATION OF THE TAILINGS WITH A 3-METER COVER (OPTIONS IA, IB, AND IC)

In this section, the conceptual designs of the options to stabilize the Slick Rock tailings piles are discussed and the estimated cost of the corresponding remedial actions is presented.

#### 9.1.1 Stabilization of the Tailings at Their Present Locations (Option IA)

The disadvantage of stabilizing the Slick Rock tailings at their present locations is their situation on the flood plain of the Dolores River. This option is included to provide a means of comparison among the alternatives for these sites, and also among options in this report and those in reports for other mill tailings sites. Therefore, in preparing the cost estimate for this option, the possible problem 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 the present sites. The windblown tailings, millsites, ore-storage areas, and off-site properties would be cleaned up and the contaminated materials placed on top of the existing tailings piles. The tailings sites would then 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<sup>2</sup>-s. Decontamination plans for both the Union Carbide and North Continent sites, showing the areas around both tailings piles that would require cleanup, are presented in Figures 9-1A and 9-1B. The depth of soil removal proposed for each area on the decontamination plans is assumed to reduce the residual radium concentration in the soil to less than the required level of 5 pCi/g above background.

Stabilization of the tailings at their present locations would require extensive diking to protect the sites from the flood waters of the Dolores River. Figures 9-2A and 9-2B illustrate the proposed dike locations. At the Union Carbide site, a 2,400-ft-long earthfill dike would be constructed. This dike would be approximately 15 ft high with a maximum slope of 1.5-to-1 on the side exposed to the river. This slope would be covered with riprap consisting of boulders from 6 in. to 2 ft in diameter. The end of the dike to the southeast of the pile

would converge with an embankment that supports the road bridge over the river, affording additional protection of the tailings from flood waters. The dike would stand approximately 300 ft from the river on the southeast side of the tailings. On the north side of the pile, the dike would be only 15 ft from the river and run parallel to it.

At the North Continent site, a 100-ft-long earthfill dike similar to the one described above would be constructed between the river and the tailings.

The stabilization and dike construction operations described above would disturb most of the established vegetative cover; consequently entire areas, including the sides of the dikes toward the tailings piles, would be revegetated with indigenous plants or covered with riprap to limit erosion. Irrigation would be required for a period of time in order to establish vegetative growth.

If the Slick Rock sites were stabilized in place, they would have limited future use.

As shown in Table 9-1, the cost for stabilization at the Slick Rock sites is estimated to be \$6,800,000. Costs include cleaning up of the millsites, windblown contamination, and off-site locations, placing 3 m of cover over all contaminated materials, contouring the surface, establishing vegetation or providing a riprap cap, reclaiming of all areas, and construction of the proposed diking at both sites.

#### 9.1.2 Consolidation and Stabilization of the Tailings at the Union Carbide Site (Option IB)

Under this option, the North Continent tailings, windblown tailings, and contaminated materials from the millsite, ore storage, and off-site properties would be consolidated with the Union Carbide contaminated materials and tailings on the Union Carbide site. The consolidated pile would be stabilized with 3 m of cover material, and 0.3 m of riprap placed for erosion control.

The NC site would be backfilled to natural grade and indigenous vegetation established. The dike construction and revegetation described in Paragraph 9.1.1 would be required at the UC site.

The cost of Option IB is estimated to be \$9,200,000. This cost includes removal of the NC contaminated materials, reclamation of the NC site, and stabilization of all contaminated materials at the UC site with a 3-m depth of cover material and natural vegetation or a 0.3-m-deep riprap cap.

### 9.1.3 Relocation and Stabilization of the Tailings at the Southwest Corner of the Union Carbide Property (Option IC)

This option provides for the relocation of the contaminated materials from both sites to the southwest corner of the Union Carbide property. The UC tailings would be moved approximately 2,000 yd, while the NC materials would require an approximate 1-mi haul. A pit 3-m deep would be excavated and the tailings placed in it. The excavated material could be used as cover material.

Under this option, relocation of the trailer park and the road adjacent to the UC site may be required. The trailer park could be moved to reclaimed land at the NC site. The road could be rerouted onto reclaimed land at the UC site, and the new road construction could take place during the fill process at the UC site. Costs of these actions have not been included in the total cost of this option.

The total cost of this option is estimated to be \$9,100,000. This cost includes cleanup of all windblown and off-site contamination, stabilization of the tailings with 3 m of cover material, backfilling all affected areas to natural grade, and establishing natural vegetation or placing 0.3 m of riprap for erosion control.

## 9.2 REMOVAL OF TAILINGS AND ALL CONTAMINATED MATERIALS FROM THE SITES (OPTIONS II AND III)

Options II and III would provide for the complete removal of all tailings, contaminated soil, existing cover material, buildings, and rubble from the tailings sites and off-site areas to a disposal site. The amount of soil to be removed depends on the depth of contamination. In Figures 9-1A and 9-1B the areas that would require cleanup are illustrated. The depth of soil removal shown in these figures is assumed to be adequate to reduce the residual radium concentration in the soil to less than the allowed level of 5 pCi/g above background. Finally, the site would be backfilled to natural grade and then released for unrestricted use.

### 9.2.1 Excavation and Loading of Tailings and Soils

Based on site examination, review of the limited data characterizing the physical properties of the tailings, and discussions with earthmoving contractors in the area, it appears that there would be little difficulty in removing the tailings from their present sites. The contractor performing this work could use any number of conventional loading methods, e.g., front-end tractor loaders or overhead loaders with conveyor belt feed. There is ample room on the sites for fast loading and easy truck ingress and egress.

Because of the proximity of the tailings to the Dolores River, a system for dewatering the contaminated subsoil during excavation will probably be required. To eliminate any possible dispersion of tailings during loading and transportation operations, dust control equipment and washdown facilities might also have to be provided.

The decontaminated tailings sites would be backfilled to natural grade with local material hauled onto the site. No special treatment of the surface at the decontaminated sites other than establishment of native grass cover is considered in this report.

### 9.2.2 Transportation of the Materials

Railroad transportation is not feasible for tailings transport since there are no rail facilities in the vicinity of the tailings or disposal sites.

Slurry pipeline technology was evaluated. While water for this method of transport is available from the Dolores River, 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 the 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 numerous 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 does not appear to warrant the use of conveyors, making transportation by truck preferable. At the time a specific site is chosen, a detailed evaluation would disclose whether this generalization holds true for the selected site and routes.

If trucks could move the materials at the rate of about 4,800 tons/day, working 5 days/wk, all contaminated materials could be removed in approximately 1 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 the cost of hauling all 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.

### 9.2.3 Disposal at Alternative Sites

A discussion of proposed disposal sites is included in Chapter 8. Each disposal site has unique physical, geological, and hydrological characteristics. However, because the Federal Government, with input from the State, is ultimately responsible for the selection of disposal sites, there is no assurance that either of the disposal sites considered in this report will be selected. Nevertheless, an effort was made to quantify these differences based on the limited data available for each site and to show the costs that would result if the contaminated materials were actually disposed of at one of the two sites discussed in Chapter 8.

The disposal sites are located within 1.5 and 6.5 mi of the tailings piles. Vegetation covers 30% or less in the vicinity of Slick Rock, and the average rainfall at the disposal areas is approximately 7 in./yr. Both sites are presently accessible by using a combination of paved, gravel, and in some cases, dirt, roads. Where existing dirt roads are to be traveled by trucks carrying tailings, the cost estimates include construction of a gravel-based surface sufficient to handle the heavy loads.

The disposal sites can be isolated from drainage basins naturally, or by dikes and drainage ditches. In general, disposal of the tailings would be above ground, requiring transportation of cover material to the site. Extensive diking and contouring for erosion control may be necessary in such situations. Figure 9-3 is a schematic representation of how these disposal sites would be developed.

The costs for the disposal options, shown in Table 9-1, are about \$9,600,000 for Option II and about \$11,000,000 for Option III. Disposal site costs consist of preparation of the site, placement of tailings and cover material, construction of dikes and contouring, and necessary reclamation of surface areas.

The cost differential is attributed to varying requirements for transporting tailings and cover material, preparing the disposal site, and protecting the disposed tailings from erosion. Consequently, the overall cost is largely dependent on the distance from the tailings site to the disposal site, ease of excavation at the disposal site, and availability of cover material to the disposal site.

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

In Options II and III the estimated costs include cleaning up of off- and on-site tailings locations; backfilling the former tailings sites; establishing vegetative cover at and around the tailings sites; covering all tailings and contaminated materials at the disposal site with 3 m of cover material; contouring the stabilized disposal site; and establishing natural 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 Slick Rock tailings piles in their 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 piles 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 disposal of uranium mill tailings, radon fluxes were assumed to be reduced from their predicted values under present conditions (as conservatively calculated in Paragraph 3.6.2) to the required flux of 2 pCi/m<sup>2</sup>-s for Option I. In all other options, radon flux was assumed to be reduced to zero by the removal of the tailings. Since health effects are proportional to radon flux, more than 99% of the present health effects rate was estimated to be eliminated because of stabilization in-place and 100% because of tailings removal.

The potential cancer cases avoided (health benefits) for each option are given as a function of time in part A of Table 9-2. The cost per potential cancer case avoided for each option is included as part B in Table 9-2.

As an alternative to the presentation in Table 9-2, the number of potential cancer cases avoided per million dollars expended was calculated and plotted in Figure 9-4. Option IA yields the maximum health benefit per unit cost, whereas Option III yields the minimum benefit per unit cost.

### 9.3.2 Land Value Benefits

Most of the land surrounding the two sites is Bureau of Land Management lease blocks. Less than 10% of the land in this part of the Dolores River Valley is privately owned.

The presence of the two tailings piles affects land usage and values only slightly. The actions taken under Option IA would have little effect on the values of the sites or on their surrounding areas. Under Option IB, the NC site could be used for other purposes and its value would increase slightly. Were Options IC, II, or III to be implemented, both tailings sites could be released for unlimited use and the value of the sites would increase slightly. However, at the present time there is no pressure to use the land at either site for other purposes.

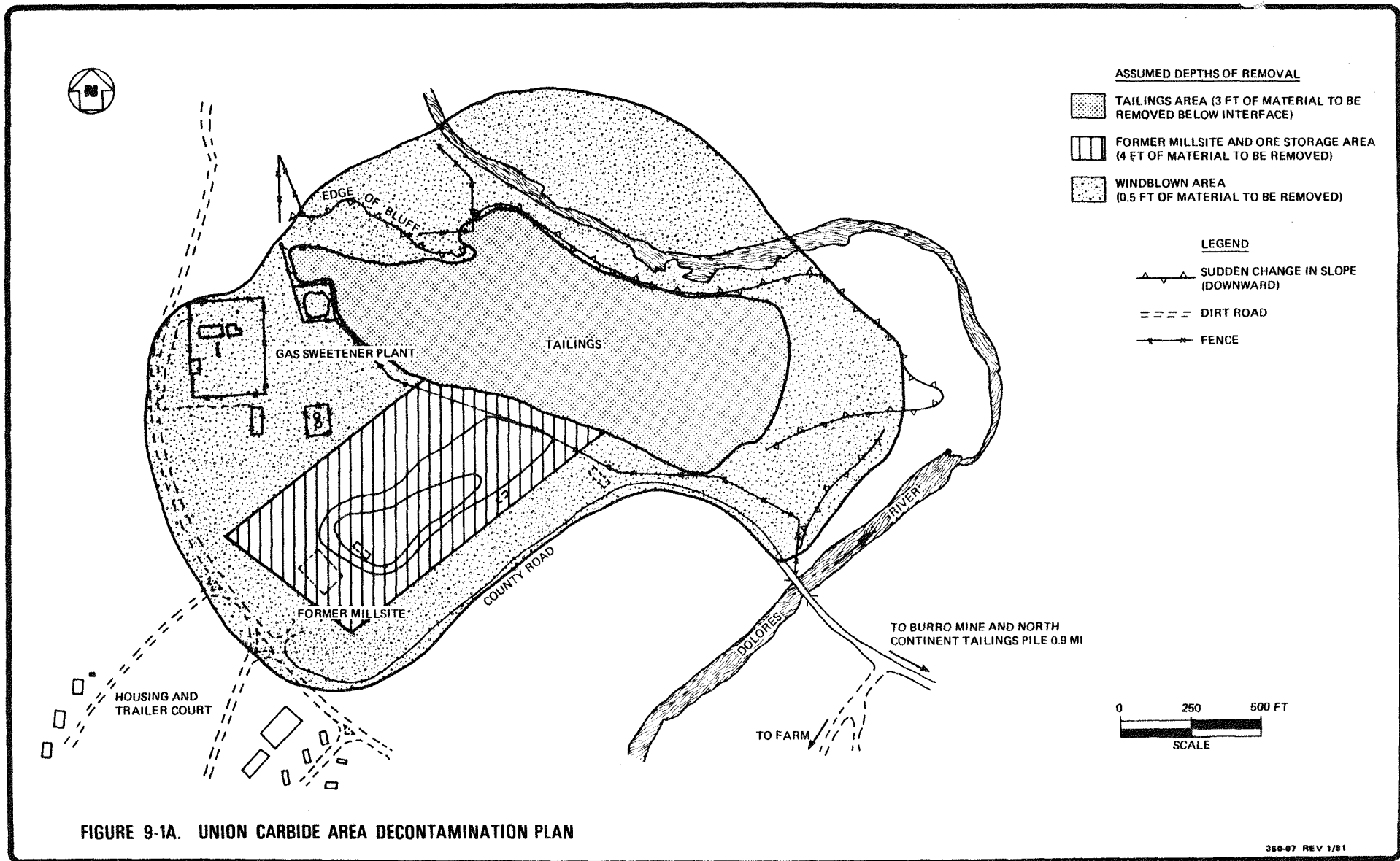
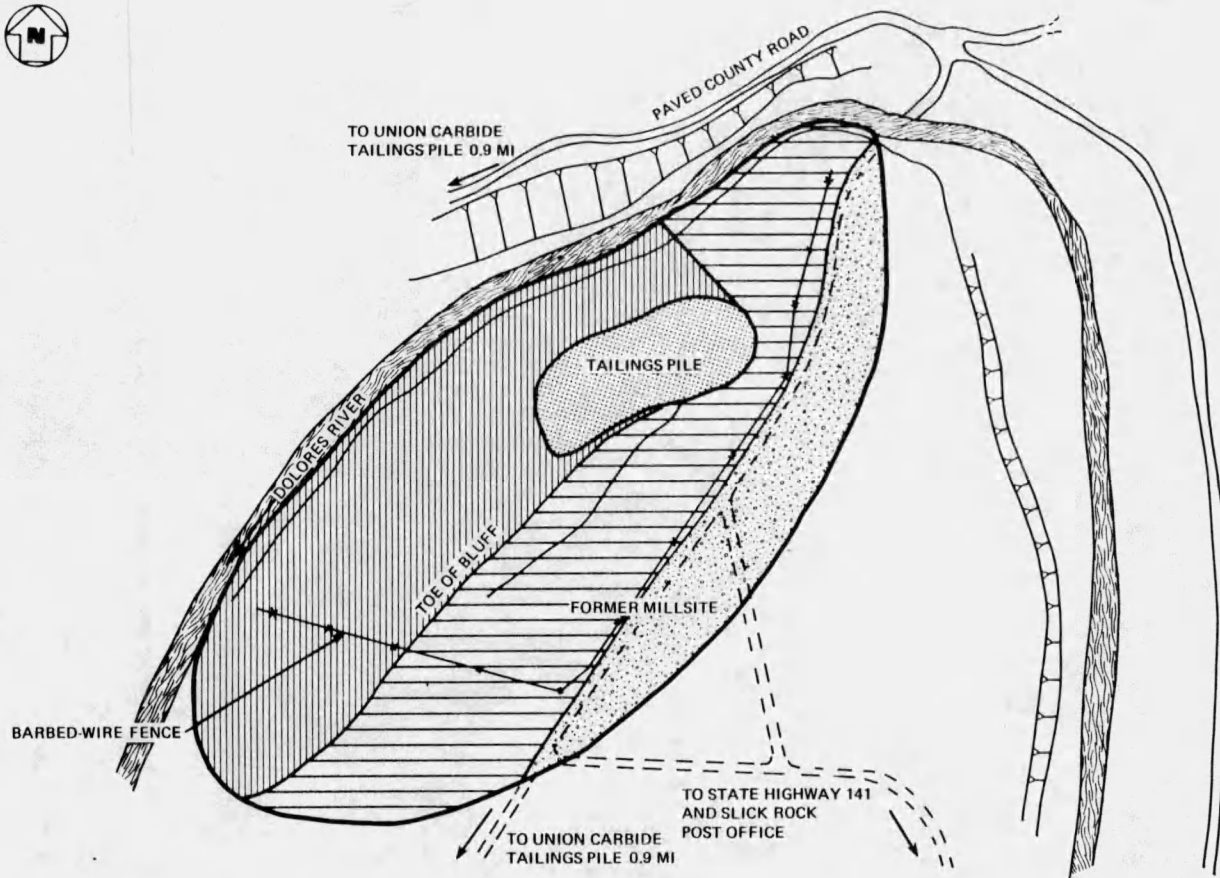






FIGURE 9-1A. UNION CARBIDE AREA DECONTAMINATION PLAN




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**ASSUMED DEPTHS OF REMOVAL**

-  TAILINGS AREA (10 FT OF SUBSOIL TO BE REMOVED BELOW INTERFACE)
-  AREA OF HIGH RADIUM LEACHING TO BE DECONTAMINATED BY REMOVAL OF 8 FT OF MATERIAL
-  MILL AND ORE STORAGE AREAS TO BE DECONTAMINATED BY REMOVAL OF 3 FT OF MATERIAL
-  WINDBLOWN AREA TO BE DECONTAMINATED BY REMOVAL OF 0.5 FT OF MATERIAL

**LEGEND**

-  SUDDEN CHANGE IN SLOPE (DOWNWARD)
-  FENCE
-  DIRT ROAD

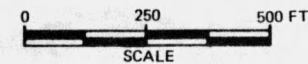


FIGURE 9-1B. NORTH CONTINENT AREA DECONTAMINATION PLAN

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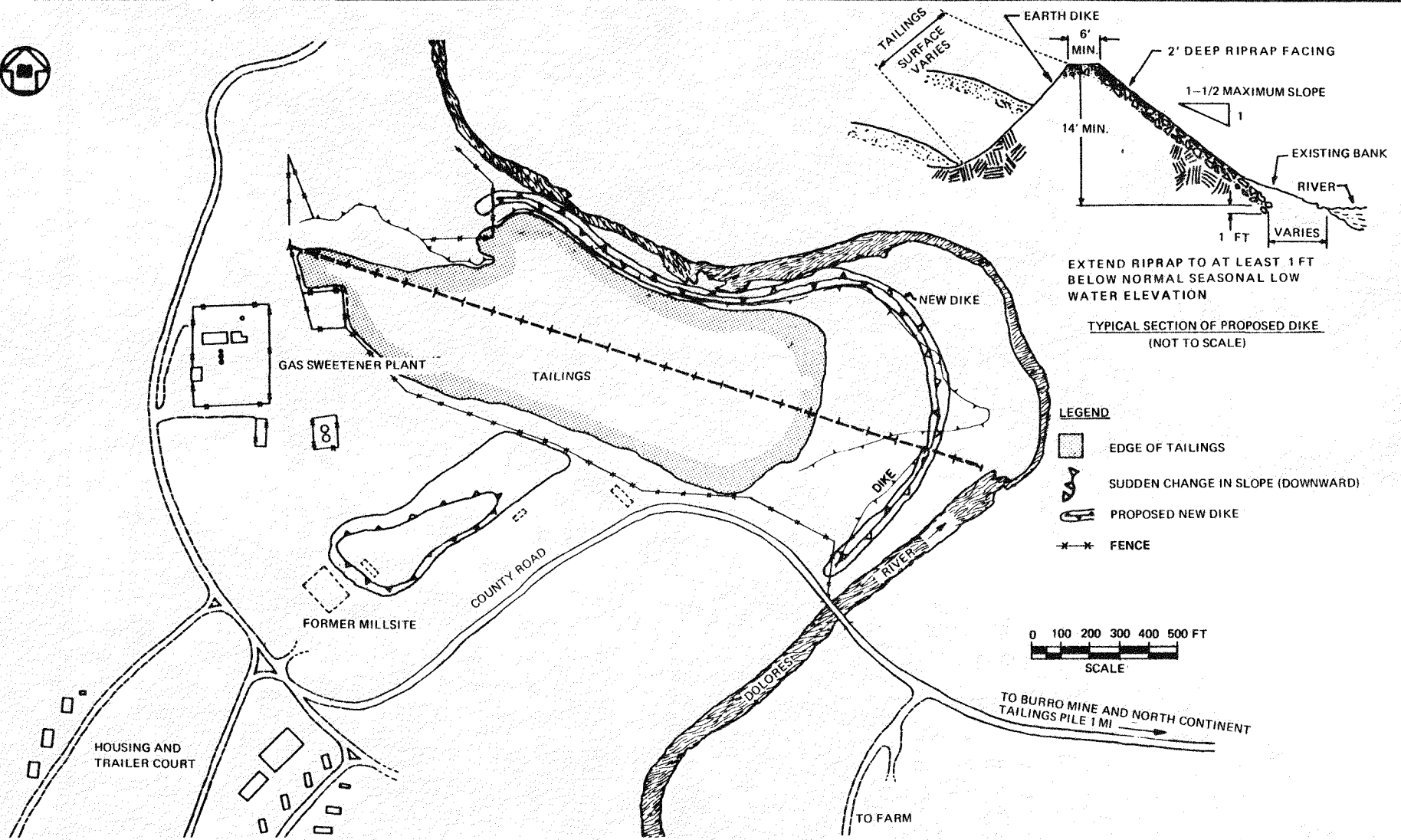
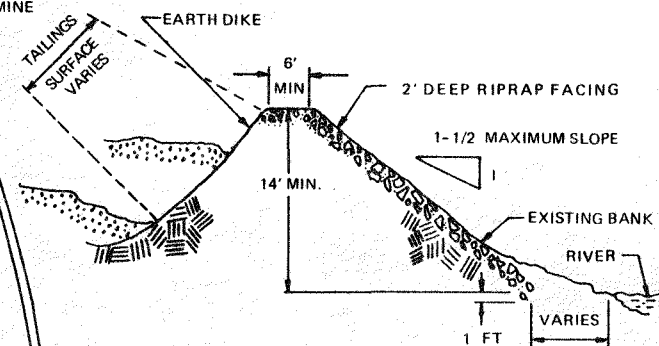
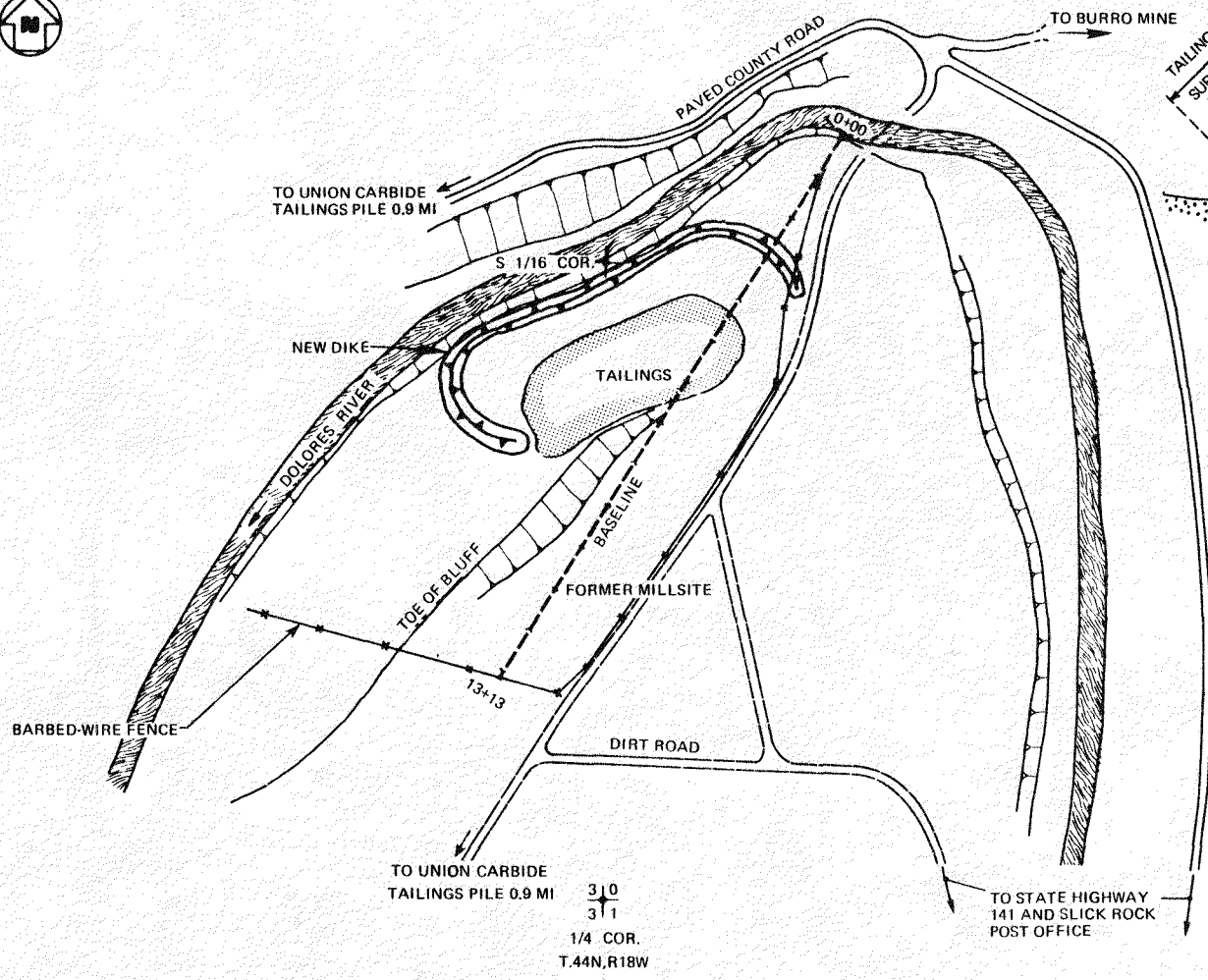


FIGURE 9-2A. UNION CARBIDE PROPOSED DIKE LOCATION AND CONSTRUCTION

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EXTEND RIPRAP TO AT LEAST 1 FT BELOW NORMAL SEASONAL LOW WATER ELEVATION

TYPICAL SECTION OF PROPOSED DIKE (NOT TO SCALE)

LEGEND

- PROPOSED NEW DIKE
- EDGE OF TAILINGS
- SUDDEN CHANGE IN SLOPE (DOWNWARD)
- FENCE

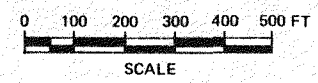


FIGURE 9-2B. NORTH CONTINENT PROPOSED DIKE LOCATION AND CONSTRUCTION

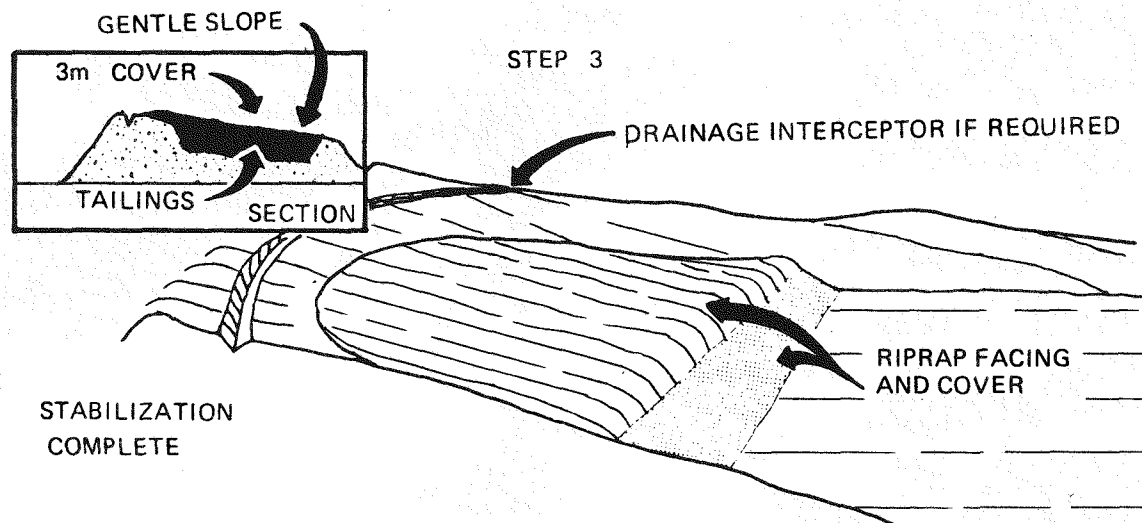
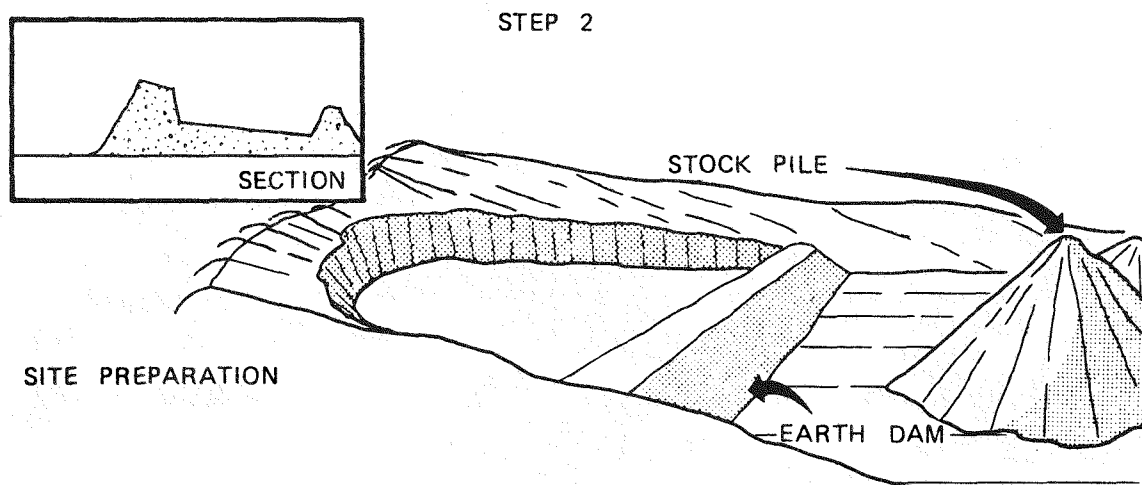
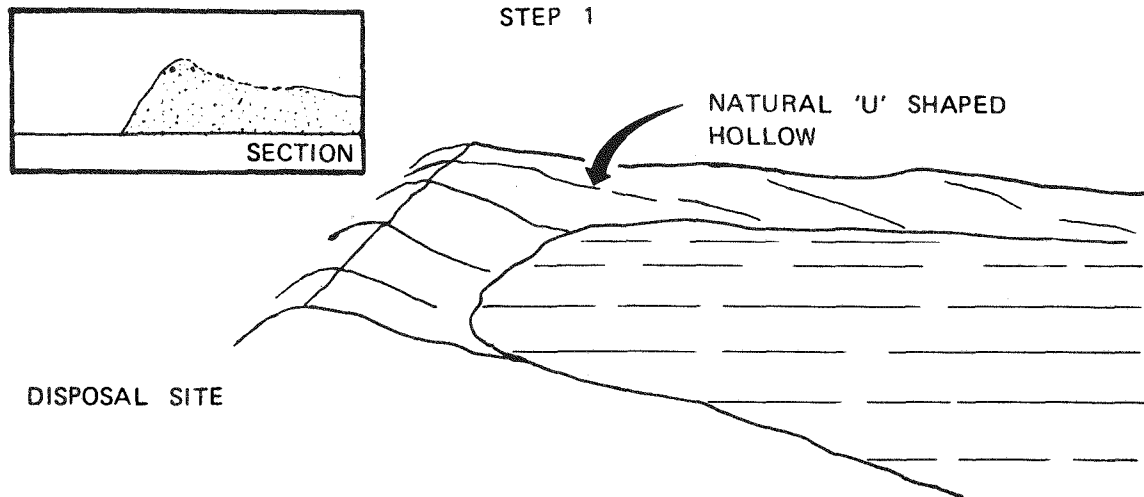
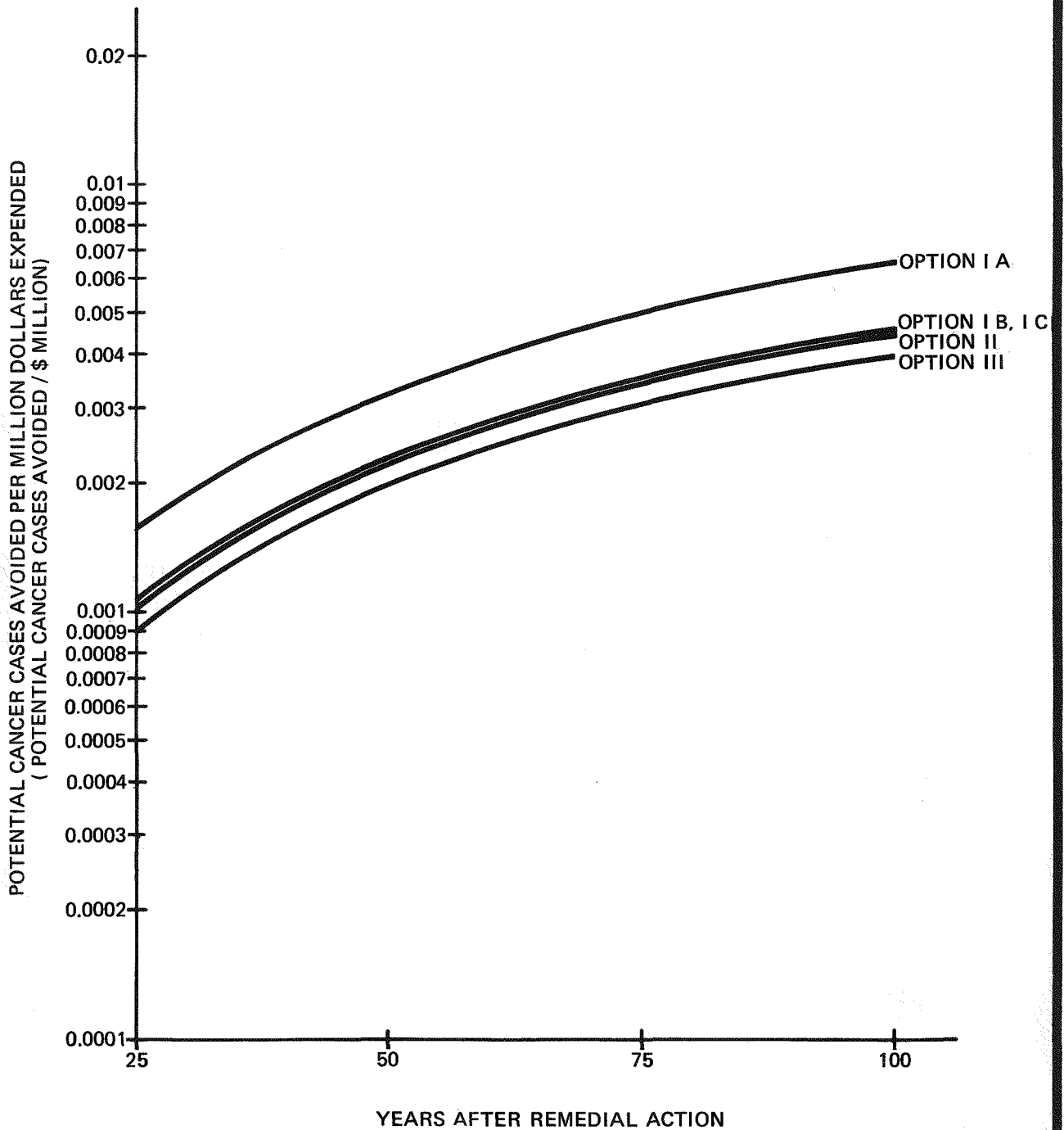


FIGURE 9-3. SCHEMATIC OF TYPICAL TAILINGS DISPOSAL SITE

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**FIGURE 9-4. POTENTIAL CANCER CASES AVOIDED PER MILLION DOLLARS EXPENDED**

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