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MASTER

ENGINEERING ASSESSMENT OF INACTIVE URANIUM MILL TAILINGS

MONUMENT VALLEY SITE
MONUMENT VALLEY, ARIZONA

OCTOBER 1981

PREPARED FOR

UNITED STATES DEPARTMENT OF ENERGY
ALBUQUERQUE OPERATIONS OFFICE
URANIUM MILL TAILINGS
REMEDIAL ACTIONS PROJECT OFFICE
ALBUQUERQUE, NEW MEXICO

CONTRACT NO. DE-AC04-76GJ01658

BY

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375 Chipeta Way
Salt Lake City, Utah 84108

NOTICE

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

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

FOREWORD

This report has been authorized by the U.S. Department of Energy (DOE), Albuquerque Operations Office, Uranium Mill Tailings Remedial Action Project Office, Albuquerque, New Mexico, under Contract No. DE-AC04-76GJ01658. The report is a revision of an earlier report dated March 1977, entitled "Phase II - Title I Engineering Assessment of Inactive Uranium Mill Tailings, Monument Valley Site, Monument Valley, Arizona," 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 Monument Valley site and vicinity, as well as changes in remedial action criteria. The new data reflecting these changes are presented in this report. Evaluation of the current conditions is essential to assessing the impacts associated with the options suggested for remedial actions for the tailings.

Ford, Bacon & Davis Utah Inc. (FB&DU) has received excellent cooperation and assistance in obtaining new data to prepare this report. Special recognition is due Richard H. Campbell and Mark Matthews of DOE, as well as Harold Tso and Ben Benally of the Environmental Protection Commission, Navajo Nation, and Chris Eastin of NECA. The Bureau of Indian Affairs, Western Agency, contributed information, as did several local, county, and state agencies and private individuals.

ABSTRACT

Ford, Bacon & Davis Utah Inc. has reevaluated the Monument Valley site in order to revise the March 1977 engineering assessment of the problems resulting from the existence of radioactive uranium mill tailings at Monument Valley, Arizona. 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 1.1 million tons of tailings at the Monument Valley site constitutes the most significant environmental impact, although windblown tailings and external gamma radiation also are factors. The four alternative actions presented in this engineering assessment range from millsite decontamination with the addition of 3 m of stabilization cover material (Option I), to removal of the tailings to remote disposal sites and decontamination of the tailings site (Options II through IV). Cost estimates for the four options range from about $6,600,000 for stabilization in-place, to about $15,900,000 for disposal at a distance of about 15 mi.

Three principal alternatives for reprocessing the Monument Valley 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 more than \$500/lb of U_3O_8 by heap leach or conventional plant processes. The spot market price for uranium was \$25/lb early in 1981. Therefore, reprocessing the tailings for uranium recovery is economically unattractive.

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CHAPTER 1

SUMMARY

1.1 INTRODUCTION

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

A preliminary survey (Phase I) was carried out in 1974 by the U.S. Atomic Energy Commission (AEC) in cooperation with the U.S. Environmental Protection Agency (EPA) and the affected states. In a summary report,(1) ERDA identified 17 sites in Arizona, Colorado, Idaho, New Mexico, Utah, and Wyoming for which practical remedial measures were to be evaluated. Subsequently, ERDA added five additional sites (Riverton and Converse County, Wyoming; Lakeview, Oregon; Falls City and Ray Point, Texas). More recently, DOE has added a site in Canonsburg, Pennsylvania, and two sites in North Dakota (Belfield and Bowman), and deleted Ray Point, Texas, for a total of 24 sites. Most of the mills at these sites produced by far the greatest part of their output of uranium under contracts with the AEC during the period 1947 through 1970. After operations ceased, some companies made no attempt to stabilize the tailings, while others did so with varying degrees of success. Recently, concern has increased about the possible adverse effects to the general public from long-term exposure to low-level sources of radiation from the tailings piles and sites.

Prior to 1975, the studies of radiation levels on and in the vicinities of these sites were limited in scope. The data available were insufficient to permit assessment of risk to people with any degree of confidence. In addition, information on practicable measures to reduce radiation exposures and estimates of their projected costs was limited. The purposes of these recent studies performed by FB&DU have been to revise the information necessary to provide a basis for decision making for appropriate remedial actions for each of the 24 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 Monument Valley site:

(a) Exhalation of radon gas from the tailings

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

(c) Land contamination from windblown tailings

(d) Hydrology and contamination by water pathways

(e) Potential health impact

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

Investigation of these and other factors originally led to the evaluation of two potential practicable remedial action alternatives. Since that time, these 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 I - Stabilization of tailings on site with a 3-m cover

(b) Option II - Disposal at an unspecified site located 5 mi from the tailings piles

(c) Option III - Disposal at an unspecified site located 10 mi from the tailings piles

(d) Option IV - Disposal at an unspecified site located 15 mi from the tailings piles

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, 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 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 Monument Valley site appears as Appendix I to Reference 3.

the initial task, and work began immediately. The original work at Monument Valley was performed early in 1976. The original Phase II - Title I Engineering Assessment was published in March 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 June 23, 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 Monument Valley site.

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

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

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

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

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

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

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

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

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

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

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

(1) Gamma radiation

(2) Radon

(3) Radon daughter concentrations

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

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

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

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

(n) Evaluation of the alternative corrective actions for each site in order to arrive at recommendations, estimated costs, and socio-economic 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 Monument Valley site.

1.2 SITE DESCRIPTION

1.2.1 Location and Topography

The Monument Valley site, on the Navajo Indian Reservation, covers approximately 90 acres in Cane Valley just east of Monument Valley, Arizona. It is located approximately 20 mi east of U.S. Highway 163 as this road passes through Monument Valley and is about 5 mi south of the Utah-Arizona border. The site and its relationship to the surrounding area are shown in the aerial photograph in Figure 2-1. The country generally is arid desert with hills, steep ridges, and mesas. Red sandstone cliffs are prominent on the west edge of Cane Valley. Vegetation is sparse. The elevation of the site is about 4,900 ft above sea level.

1.2.2 Ownership and History of Milling Operations and Processing

The mill was constructed and operated from 1955 to 1968 by Vanadium Corporation of America and its successor, Foote Mineral Company.

Before and during the milling operations the site was leased from the Navajo Indian Tribe. When the lease expired in 1968, full control of the site reverted to the Navajo Nation.

The source of ore for the mill was the Monument No. 2 mine, about 1 mi west of the site. From the summer of 1955 through July 1964, the method employed to recover the uranium from the ore was a sand-slime separation process. In October 1964, equipment was installed for batch-leaching of the sand fraction that had been stored on the property from the earlier operations. About 1 million tons of sand tailings were treated, and an additional 100,000 tons of low-grade ore were heap-leached. The plant ceased operations in November 1967. Recovery of both uranium and vanadium from the ore while using the aforementioned processes was between 65 and 70%.

Because the radium in the ore was contained mainly in the fine clay fraction, most of the radium was in the upgraded ore concentrates hauled to Durango, Colorado, and to Shiprock, New Mexico. However, some residual radium does remain in the tailings. Therefore, at the request of the Navajo Tribal Council, an environmental radiological survey of the site was performed in May 1968.(4) The results of the survey indicated that radiation levels did not exceed guidelines applicable at that time. However, the report did recommend that the tailings be stabilized against wind erosion and that periodic monitoring be continued.

1.2.3 Present Condition of the Site

Figure 2-5 is a descriptive map of the 90-acre site as it now exists. The tailings are located in two piles and cover approximately 30 acres. The old heap-leach pile covers 10 acres to an average depth of 2 to 3 ft. The new tailings pile is cone-shaped, approximately 55 ft high, covers 20 acres, and contains approximately 85% of the tailings at the site. Figure 2-6 is a cross-section of the site.

The old mill buildings have been removed, although foundations, rubble, and portions of the old and all of the new tailings piles remain. The site is neither fenced nor posted. The tailings have not been stabilized.

1.2.4 Tailings and Soil Characteristics

The new tailings pile is composed of coarse-grained sand and small pebbles containing less than 2% minus 200-mesh material. The old tailings pile is composed of material that is slightly finer. Bulk densities run between 97 and 103 lb/ft^3. As listed in Table 2-1, there are approximately 1,100,000 tons of tailings on the site.

The soil beneath both piles is mainly fine-textured sand containing little moisture. Rock of the Chinle Formation lies beneath this alluvium.

1.2.5 Geology, Hydrology, and Meteorology

The Monument Valley tailings site is located in a strike-valley developed on shale members of the Chinle Formation. On the west the site is bordered by an outcropping of the Shinarump Member of the Chinle Formation and on the east by Comb Ridge, a hogback of resistant sandstones of Triassic and Jurassic age. A stratigraphic cross-section of the area is illustrated in Figure 2-8.

There are no continually active streams in the area. The site drains naturally into Cane Valley Wash, for which stream flow data are not available. Approximately 1,000 acres of land are in the drainage basin that passes through the tailings area to the wash. There is some evidence of surface water erosion of tailings, but because of their coarse-grained nature, little downstream transport of the tailings has occurred. A major flash flood of longer than a 1-hr duration could carry a significant quantity of the tailings into Cane Valley Wash.

The tailings likely will have very little effect on the radioactive content of the Shinarump aquifer, which surfaces just west of the tailings area, considering that this member has served as the host for uranium mineralization and contains uranium ore bodies throughout the Navajo Reservation. Also, local wells do not receive their water from the Shinarump aquifer.

Unconfined ground water is very near the surface along the main axis of Cane Valley Wash because the area is underlain by impermeable beds of Monitor Butte and Petrified Forest members of the Chinle Formation. These members consist of siltstones and claystones and are about 700 ft thick in the millsite area. The unconfined water moves through the alluvium of Cane Valley Wash and is recovered near the site from shallow wells. These shallow wells and springs are water table sources and their recharge is from local runoff.

There are no precipitation records at the Monument Valley site, but annual precipitation recorded at two locations, 28 mi from the site in different directions, is 7.5 and 8.3 in. The maximum 24-hr precipitation at these two locations was 3.6 and 2.5 in. The precipitation at the tailings site should be similar to that of these sources. The Monument Valley site could expect to receive a 24-hr maximum precipitation of 1.3 in. once every two years, typically during August, September, or October.

On-site observations show that the prevailing winds at the tailings location are from the southwest, and that periodically there is some movement of the finer tailings material at the northeastern edge of the tailings as a result of these winds. There are no residences within 2 mi of the tailings in this major wind direction.

1.3 RADIOACTIVITY AND POLLUTANT IMPACTS ON THE ENVIRONMENT

About 85% of the total radioactivity originally in uranium ore remains in the tailings after removal of the uranium. The principal environmental radiological impact and associated health effects arise from the ^{230}Th, ^{226}Ra, ^{222}Rn, and ^{222}Rn daughters contained in the uranium tailings. Although these radionuclides occur in nature, their concentrations in tailings material are several orders of magnitude greater than their average concentrations in the earth's crust. Because of the chemical treatments these radionuclides have experienced, it appears that ^{226}Ra is more soluble and, therefore, more mobile.

1.3.1 Radiation Exposure Pathways, Contamination Mechanisms, and Background Levels

The major potential environmental routes of exposure to man are:

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

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

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

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

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

1.3.1.1 Radon Gas Diffusion and Transport

Short-term radon measurements were performed by FB&DU in 1976 with continuous radon monitors supplied by ERDA at seven locations in the vicinity of the Monument Valley tailings site. The locations and values of the radon measurements are shown in Figure 3-5. The average background radon concentration for four 24-hr measurements was 0.6 pCi/l. One set of measurements between the old and new piles indicated an average radon concentration of 6.8 pCi/l for a 24-hr period. Two values of 24-hr average radon concentration were in the 3- to 4-pCi/l range at measurement locations 0.1 and 0.6 mi north of the tailings site.

1.3.1.2 Direct Gamma Radiation

Background values of gamma radiation around the Monument Valley site averaged 9 μR/hr.(3) Previous measurements yielded an average background value of 9.4 μR/hr.(5) The range of values was from 7 to 11 μR/hr, although the gamma radiation increased away from the pile toward the west in the vicinity of the Monument No. 2 mine.(3) Above the surface of the exposed tailings piles, gamma readings ranged from 23 to 137 μR/hr.

1.3.1.3 Windblown Contaminants

An iso-exposure line due to residual windblown tailings, resulting from the EPA gamma survey of 1975, is illustrated in Figure 3-12. In 1980, measurements and data analyses were performed to establish a boundary around the site contaminated in excess of 5 pCi/g of ^{226}Ra. In most instances, traverses with a scintillometer extended well beyond the 10 μR/hr contour of the 1975 EPA gamma survey,(6) and surface contamination readings remained at or near background levels. It is apparent from Figure 3-14 that the extent of windblown contamination is greatest to the north and west of the old tailings pile, where the ^{226}Ra concentration does not fall below 5 pCi/g for a distance of 800 ft from the edge of the pile. In all directions around the new tailings pile, the 5-pCi/g boundary is reached within 200 to 400 ft from the edge of the pile.

1.3.1.4 Ground and Surface Water Contamination

The confined ground water aquifers underlying the site are protected against contamination by both an upward pressure gradient and a thick aquiclude, and there is no possibility of contamination of these aquifers from the tailings. Previous radiometric analyses indicated from 0.1 to 1.5 pCi/l of ^{226}Ra in water from four wells within a 0.5-mi radius of the site and 0.5 pCi/l from a well 4 mi north of the site.(4) Five water samples taken in a 7-mi radius from the piles contained radium concentrations ranging from 0.05 to 2.9 pCi/l.(3) The highest ^{226}Ra concentration was measured in water from the same artesian spring 0.5 mi east of the tailings as the 1.5-pCi/l sample measured previously.[4] This water is not used for human consumption. These values are less than the 5-pCi/l level for ^{226}Ra and ^{228}Ra in the EPA Interim Primary Drinking Water Regulations for radionuclides.[7] Uranium concentrations ranged from 2 to 18 µg/l in these well waters, with the highest value in water from a well at the millsite.[4]

Because the old heap-leach tailings pile is placed over a natural drainage channel that drains about 1,000 acres of relatively steep watershed, there is considerable potential for surface runoff to erode some of the tailings material. Examination of the ground at the west and south edges of the tailings pile shows evidence that some surface drainage has found its way around the tailings pile and has cut a small channel into the tailings. Considering the size, slope, and characteristics of the watershed area, a potential flow of several thousand cubic feet of water per second could occur in the channel at the tailings during a time of extraordinary thunderstorms. An interceptor channel could be provided to divert the drainage around the tailings pile to Cane Valley Wash, thus averting the potential deposition of tailings in the wash.

The near-surface unconfined ground water at the site is found in the Cane Valley Wash alluvium. Recharge is from local runoff. It is not believed that any precipitation falling on the tailings piles will ever reach this shallow unconfined aquifer along the Cane Valley Wash since there is little evidence of surface runoff from the tailings piles.

The Shinarump Conglomerate Member of the Chinle Formation forms the shallowest confined aquifer in the vicinity of the millsite. This rock unit was the source rock for the ore processed at the millsite and contains uranium ore bodies throughout the reservation area. The millsite tailings have little effect on the radioactive content of the Shinarump aquifer. Local wells do not derive their water from this member.

1.3.1.5 Soil Contamination

The leaching of radium from the tailings into the subsoil reached depths from 1 to 8 ft beneath the new tailings pile as determined by radiometric logging in boreholes and sample assays. The ^{226}Ra concentration reached background levels about 2 ft beneath the old tailings pile in the hard but porous sandstone.[4]

1.3.2 Remedial Action Criteria

For the purpose of conducting the original engineering assessment,[2] provisional criteria provided by the EPA were used. The criteria were in two categories, and applied either to structures with tailings present or to land areas to be decontaminated. For structures, the indoor radiation level below which no remedial action was indicated was considered to be an external gamma radiation level of less than 0.05 mR/hr above background and a radon daughter concentration of less than 0.01 WL above background. Land could be released for unrestricted use if the external gamma radiation levels were less than 10 μR/hr above background. When cleanup was necessary, residual radium content of the soil after remedial action should not exceed twice background in the area.

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

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

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

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

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

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

*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.

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

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

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

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

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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.

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

1.3.3 Potential Health Impact

Radon gas exhalation from the piles and the subsequent inhalation of radon daughters account for most of the total dose to the population from the Monument Valley site under present conditions. The gamma radiation exposure from the piles is very small since there are no persons who live or work within 0.1 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[8] earlier indicated that 13 ft of earth cover would be required to reduce the radon diffusion from the Monument Valley tailings by 95%. Later experimental work[9] has demonstrated that 2 to 3 ft of compacted clay may be sufficient to reduce radon flux to less than 2 pCi/m^2-s, assuming the continued integrity of the clay cover.

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

The risk estimators used in this report are given in the report of the National Academy of Sciences Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR-III report).(10) 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(11) 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 under present conditions, it was calculated that the average lung cancer risk attributable to radon released from the piles in the area within 4 mi of the Monument Valley site is 2.8×10^{-7} per person per year, or less than 0.3% of the average lung cancer risk due to all causes for the Navajo Reservation (1×10^{-4}).(12)

The 25-yr health effects were calculated for three population projections using the present population of 80 people in the 0- to 4-mi area. The results for pile-induced radon and background radon for the area were as follows:

25-Year Cumulative Health Effects within 4 Miles of the Edge of the Piles

Projected Population Growth	Pile-Induced RDC	Background RDC
Constant 0.8% growth rate	0.00050	0.050
2.5% declining growth rate*	0.00056	0.056
4% declining growth rate*	0.00064	0.064

Pile-induced radon daughter health effects are approximately 1% of the background radon daughter health effects for the 0- to 4-mi area. The exposure and consequent risk will continue as long as the radiation source remains in its present location and condition.

1.4 SOCIOECONOMIC AND LAND USE IMPACTS

Because all reservation land is owned commonly by the Navajo Tribe, there is no conventional market for Navajo properties. However, there are several criteria that can be used to assess the value of the site land: recent exchanges of tribal land for off-reservation land, lease payments for Navajo lands, comparisons to off-reservation land with similar uses, and the monetary value assigned to sheep production per acre. Also, taking into consideration factors such as the distance of the site from a paved highway and the absence of utilities, the probable value of the site land would be that of agricultural land with a value of $55 to $65/acre.

There is a substantial amount of land in the Cane Valley area that has greater accessibility to water and roads than does the Monument Valley site; therefore, the pressure to use the actual tailings location for any purpose is relatively low. In addition, the lack of buildings and utilities at the site, the lack of accessibility by rail, air, or paved road, and the poor potential for mineral resource development in the vicinity will contribute to a continuing low demand for use of the tailings area.

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

1.5 RECOVERY OF RESIDUAL VALUES

Only a few samples of tailings were obtained during this study. Consequently, calculations based on these samples would not be statistically representative. Assays on a composite sample of the tailings show an average content of 0.0062% U_3O_8 by weight.

There are, however, five factors that can be considered to evaluate whether reprocessing Monument Valley 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 Monument Valley 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 more than $500/lb of U_3O_8 by heap leach or conventional plant processes. The spot market price for uranium was $25/lb early in 1981. Therefore, reprocessing the 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

Following the Phase I study, the EPA performed a radiation survey in the Monument Valley area in August 1975.(5) Sixteen structures with anomalous radiation levels were identified among the 37 that were surveyed. Tailings were used in the construction of several buildings, and short-term working level measurements were made in many of the residential structures.

The use of tailings in the construction of several wells was also confirmed, but these well structures were substantial distances away from the dwellings. Therefore, these structures have not been included in the determination of remedial action costs.

Costs for remedial action at off-site properties other than windblown have been estimated to be $1,140,000, exclusive of engineering and contingency allowances, and based upon available information and adjusted Grand Junction off-site remedial action costs. This cost includes cleanup, backfill, restoration, and health physics and monitoring services. The estimated cost includes remedial action for the 16 locations where tailings use has been identified and remedial action is possible.

1.8 DISPOSAL SITE SELECTION

In this report, three of the alternative remedial action options include moving the Monument Valley tailings to a disposal site. Since the present site can probably meet the existing criteria for stabilization of the tailings, no specific disposal sites have been identified. However, to provide an understanding of the magnitude of costs involved with off-site disposal of the tailings, unspecified sites at distances 5, 10, and 15 mi from the present site were evaluated. Since site-specific characteristics could influence the cost of these options quite substantially, care must be exercised in the use of these cost estimates.

In each of the three 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 for erosion control and the entire site 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 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 one of three unspecified locations. The options are summarized in Table 1-2. The basis for comparison, from which the cost effectiveness of remedial alternatives can be judged, is the present condition of the site with no remedial action.

Option I represents remedial action activities to stabilize the tailings more completely 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^2-s above background. The tailings site would have limited future use.

Option II corresponds with disposal at the 5-mi site, Option III with disposal at the 10-mi site, and Option IV with disposal at the 15-mi site.

1.9.2 Cost-Benefit Analyses

As summarized in Table 9-1, the total costs for the four remedial action options vary from about $6,600,000 to about $15,900,000. Each of these options would have associated health and monetary benefits. The options are identified by number in Paragraph 1.1.

The number of cancer cases avoided per million dollars expended for each option is given in Figure 9-3. The curves in Figure 9-3 indicate an increase in benefit-cost ratio with time due to the greater reduction in population exposure over longer periods of time as a result of remedial action. The potential cancer cases avoided for each option and the cost per potential cancer case avoided are given in Table 9-2.

TABLE 1-1

SUMMARY OF CONDITIONS NOTED AT TIME OF 1980 SITE VISITS

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

TABLE 1-1 (Cont)

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

[a]S - Stabilized but requires improvement

P - Partially stabilized

U - Unstabilized

RMS - Reprocessed, moved and stabilized - contamination remaining

R - Removed - contamination remaining

[b]M - Mill intact

B - Building(s) intact

R - Mill and/or buildings removed

PR - Mill and/or buildings partially removed

O - Occupied or used

UO - Unoccupied or unused

[c]N - None

E - Existing

O - Occupied

P - Partially occupied

TABLE 1-2

SUMMARY OF REMEDIAL ACTION OPTIONS AND EFFECTS

Option Number	Site Specific Cost ($000)	Description of Remedial Action	Benefits	Adverse Effects
I	6,600	The piles would be stabilized in place with 3 m of local earth cover. A 0.3-m cover of riprap would be provided. On- and off-site contaminated materials would be cleaned up as necessary.	A-C,H	X,Y
II	14,300	The tailings, contaminated soil and rubble would be removed by truck to an unspecified site located about 5 mi from the tailings site. The tailings site would be decontaminated as in Option I and released for unlimited use.	A,C-G	--
III	14,900	Same as Option II, except tailings removed to an unspecified site located about 10 mi from the tailings site.	A,C-G	--
IV	15,900	Same as Option II, except tailings removed to an unspecified site located about 15 mi from the tailings site.	A,C-G	--

Notes

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

2. For Options II through IV, costs include removal of 3 ft of contaminated earth below the tailings.

TABLE 1-2 (Cont)

Definition of Benefits

A. Off-site structures decontaminated
B. Access to the tailings site controlled by fencing and posting
C. Off-site windblown radioactive sands cleaned up
D. Wind and water erosion controlled
E. Gamma radiation reduced
F. The source of gamma radiation and radon gas removed from the area
G. No building restrictions on or near site
H. The prime use of the final disposal location unchanged
I. A reduction in rate of radon exhalation to at least 2 pCi/m^2-s

Definition of Adverse Effects

X. Limited use of the tailings site
Y. Maintenance required indefinitely

CHAPTER 1 REFERENCES

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CHAPTER 2

SITE DESCRIPTION

CHAPTER 2

SITE DESCRIPTION

The purpose of this chapter is to describe the physical characteristics of the Monument Valley site, its surroundings, and the characteristics of the tailings materials present on the site.

2.1 LOCATION

The Monument Valley tailings site is located on the Navajo Indian Reservation. The site is not in Monument Valley proper, but rather in Cane Valley, immediately to the east of Monument Valley. Cane Valley runs almost north and south, and is bordered on the west by Monument Valley and on the east by Comb Ridge, as shown in Figure 2-1. The site is accessible from either of two gravel roads that originate at U.S. Highway 163. These roads are Bureau of Indian Affairs (BIA) Route 6440, which runs south from Halchita, near Mexican Hat, Utah, and BIA Route 6480, which runs southeast from U.S. Highway 163 about 9 mi southwest of Mexican Hat, at road mileage marker 12. These two roads merge as BIA Route 6440 and proceed south through Monument Valley into Cane Valley. The site is located approximately 18 road miles and 14 air miles south of Mexican Hat, Utah. The location of the site relative to its surroundings is shown in Figure 2-2. More specifically, the site is in unsurveyed Section 21, Township 41 North, Range 23 East, from the Gila and Salt River Meridian, Apache County, Arizona, at 36 deg 55 min 45 sec west latitude and 109 deg 51 min 48 sec north longitude.

2.2 TOPOGRAPHY

Cane Valley, where the site is located, is bordered on the east by a very prominent rock outcrop aptly named Comb Ridge, which runs in a generally north-south direction. The cliffs and ridges west of the site form the eastern boundary of the Monument Valley. The millsite and tailings are at an elevation of approximately 4,900 ft above sea level. Comb Ridge and the mesas and cliffs surrounding the site are about 5,000 to 6,000 ft in elevation. The red sandstone cliffs, which are typical of the Monument Valley area, are very prominent on the west side of the hills and ridges that separate Monument Valley from Cane Valley. The valley terrain can be described as barren and arid, and vegetation is sparse. The topographic relief of the site itself is 100 ft, as shown in Figure 2-3.

The total site contains approximately 90 acres. The area where the mill structures were located is on the west side of

Cane Valley and about 200 ft above the floor of the valley. Still higher and 0.75 mi west of the site is the Monument No. 2 open-pit mine.

There are two tailings areas on the site, approximately 500 ft apart. One is the old tailings area which contains the residue of the original heap leach process tailings. This area consists of approximately 10 acres with tailings at various depths because of the rocky terrain. It is estimated that there are approximately 165,000 tons (15%) of tailings in this old tailings area at an average depth of 2 to 3 ft. The new tailings pile is conical, approximately 55 ft high, covering 20 acres, and containing 935,000 tons (85%) of tailings, as shown in Table 2-1. This new pile was generated as a result of the concentrator process.

2.3 OWNERSHIP

The mill was constructed and operated from the summer of 1955 to 1968 by Vanadium Corporation of America (VCA) and its successor, Foote Mineral Company.

The mill was built on land leased from the Navajo Nation. Consequently, after the plant was shut down and dismantled, control of the tailings and the site reverted to the Navajo Nation, the current owner.

A land ownership and site description map prepared for DOE[1] is shown in Figure 2-4.

2.4 HISTORY OF MILLING OPERATIONS AND PROCESSING[2]

The upgrader and concentrator units were built to treat low-grade ore from the nearby Monument No. 2 mine, which could not economically bear the cost of transportation to VCA processing mills at Durango, Colorado (1955-1963), and Shiprock, New Mexico (1963-1968).

The Monument No. 2 mine, which was the sole source of ore for the upgrader and concentrator units, was discovered in 1943 and is estimated to have produced over 0.75 million tons of ore of approximately 0.35% U_3O_8 and 1.40% V_2O_5. Additionally, over 1 million tons of low-grade ore were mined for processing in the upgrader, the concentrator, or by heap leaching.

The first plant at this site was the upgrader, a sand-slime separation unit, which operated from the summer of 1955 through July 1964. The low-grade material fed to the upgrader averaged about 0.04% U_3O_8 and 0.40% V_2O_5, and the slime concentrate containing about 0.24% U_3O_8 and 2.60% V_2O_5 was shipped to Durango (later to Shiprock).[3] The sand fraction, containing 0.016% U_3O_8 and 0.18% V_2O_5, remained at the site.

In 1964, a batch-leaching and concentrator facility was installed at the same site. The facility was designed to process a blend of the sand tailings remaining from the previous operation and a low-grade ore of an approximate 0.02% U_3O_8 content. The mixture of sand and ore was leached with sulfuric acid; however, percolation of the acid liquors was so poor as a result of the clay content of the ore that batch leaching of the blend was abandoned and only the sand residues were treated in the batch leach circuit. About 100,000 tons of low-grade ore were treated by placing the ore in specially designed heaps and circulating sulfuric acid solutions through the heaps. The coarse ore (materials up to 0.75 in.) was amenable to the heap leach process. The pregnant acid liquors obtained from the leaching processes were neutralized with ammonia and lime that produced a bulk precipitate that was trucked to the Shiprock mill for further processing and refining.(4)

The ^{226}Ra content in ores of the Monument No. 2 mine that were shipped to the VCA processing plants in Colorado, at Naturita (1943-1958) and Durango (1949-1963), and to the Shiprock, New Mexico, plant is included in the inventory of those tailings piles. In addition, the concentrates (slimes) that were shipped to Durango and Shiprock from the upgrader and concentrator plants contained the bulk of the radium and are now included in the ^{226}Ra inventories at Durango and Shiprock. However, the sand fraction contained some ^{226}Ra, totaling about 50 Ci, which still remains in the tailings at the site. Consequently, at the request of the Navajo Tribal Council, the U.S. Public Health Service performed an environmental radiological survey of the site in May 1968.(5) The results of the survey indicated that existing radiation levels did not exceed recommended exposure limits. However, it was recommended that the tailings be stabilized against wind erosion and that periodic monitoring be continued.

A "screening" survey, conducted by the Navajo Environmental Protection Commission (NEPC) in Feburary 1975, revealed the use of uranium upgrader tailings and uranium ore in the construction of several dwellings in the Cane Valley area. A followup EPA survey(6) was conducted that verified these findings, as discussed in Chapter 7.

2.5 PRESENT CONDITION OF THE SITE

Figure 2-5 is a descriptive map of the Monument Valley site. To the west of the tailings pile, the original structures and equipment have been removed and only the remaining concrete foundations, broken pipe sections, and rubble are still visible. Some of the building materials and equipment have been buried in the new (concentrator) tailings pile.

The old tailings pile, which is the residue of the heap leaching tailings, was located east of the mill and west of the new tailings pile (hereafter referred to collectively as the old tailings pile). Figure 2-6 is a cross-section of the site.

The few dwellings that are on the east and south of the site are serviced by a dirt road running between the old and new tailings piles and by a network of dirt roads running around the eastern perimeter of the new tailings pile. Three of these dwellings are quite close to the eastern edge of the site. One corral is less than 600 ft away, and livestock can be seen occasionally on the site. The site is neither fenced nor marked as a uranium tailings area.

No attempt has been made to stabilize the tailings. The tailings are reasonably resistant to wind erosion, although there has been some wind erosion toward the northeast. There is little evidence of water erosion on the pile, around its base, or in any of the washes leading from the pile area into the Cane Valley Wash.

2.6 TAILINGS AND SOIL CHARACTERISTICS

The types, volumes, and weights of the contaminated materials at the Monument Valley tailings site are summarized in Table 2-1. As shown in the table, it is estimated that a total of 1,414,000 tons of tailings and contaminated material is present at the site. The tailings are a mixture of processed ore material and the chemicals used in the acid leach extraction process. These chemicals produced predominantly sulfate and chloride ion products. The presence of these ions has resulted in high concentrations of soluble sulfate salts in the tailings.

The new tailings pile is composed mostly of coarse-grained sand and small pebbles containing less than 2% minus-200-mesh material. This coarse material resists but is not immune to transportation by wind.

The new tailings pile is underlain by windblown sand and alluvium from the Cane Valley Wash, which lies to the east of the site. The sand under the new tailings pile is fine-textured, light brown in color, and contains little moisture. Rock from the Chinle Formation lies beneath this alluvium and also directly beneath the tailings in the old tailings storage area.

Analyses of borings of the tailings indicate the pH to be in the acidic range, which may be indicative of the infiltration by acid leach solutions. Radiometric measurements show that radioactive elements have migrated only a few feet into the underlying soil, as detailed in Chapter 3.

2.7 GEOLOGY, HYDROLOGY, AND METEOROLOGY

2.7.1 Geology[7]

Cane Valley, where the site is located, is a strike-valley developed on shale members of the Chinle Formation. Geologically, the valley is bordered on the west by strike-cuestas of the Shinarump Member of the Chinle Formation and on the east by Comb Ridge, a hogback of resistant sandstones of Triassic and Jurassic age.

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 Monument Valley tailings site is contemplated at this time.

The natural drainage from the vicinity of the Monument No. 2 mine and from the tailings is into the Cane Valley Wash, not far from the tailings piles. No records of streamflow are available. Figure 2-7 shows the topography in the vicinity of the mine and tailings and the boundary of the drainage area which collects water that runs onto or around the tailings piles.[8] The old tailings pile rests on a natural drainage channel, which drains an area of about 1,000 acres.

Examination of the ground at the west and south edges of the new pile shows evidence that some surface drainage has occured around this tailings pile and has cut a small channel. Considering the size, slope, and characteristics of the water-shed area, a potential flow of several thousand cubic feet of water per second could occur in the channel located at the eastern edge of the old tailings pile during a time of extraordinary thunderstorms. Such a flow would transport some of the material toward the Cane Valley Wash. Two main factors have minimized the extent of transport during normal runoffs: First, the tailings are coarse-grained and the relatively large size of particles would not let them be carried far; second, the storms usually are of short duration and ground absorption is rapid in this arid climate.

2.7.3 Ground Water Hydrology

The rock unit that forms the shallowest confined aquifer near the millsite is the Shinarump Conglomerate Member of the Chinle Formation. This rock unit is exposed immediately west of the tailings piles, and most of the abandoned mill foundations and settling pond sites are located directly on outcrops. The Shinarump Member consists of poorly sorted sand, grit, and pebble-size conglomerate. The uranium deposits at the

Monument No. 2 mine were found within the finer sands and silts in this unit. The stratigraphy and the regional thickness and distribution of the Shinarump Member have been described by several geologists[9,10] and are estimated to be between 50 and 75 ft thick in the millsite area. Figure 2-8 illustrates a simplified stratigraphic cross-section of the area.

Cooley and others[11] indicate that the Shinarump exposures west of the millsite may be capable of receiving ground water recharge, as shown in Figure 2-9. These same strata also are the uranium ore-bearing rocks; therefore, water taken into the Shinarump Member would pass through the natural ore bodies within the rock unit.

The millsite tailings likely have very little effect on the radioactive content of the Shinarump aquifer, considering that the Shinarump Member has served as the host for uranium mineralization and contains uranium ore bodies throughout the Navajo Reservation. The local wells, however, do not derive their water from the Shinarump aquifer; thus, the possibility of radioactive contamination of confined ground water directly from the millsite is not an immediate problem. In addition, percolation of rain water through the piles and into the Shinarump Member is unlikely because of the underlying shale.

Unconfined ground water is very near the surface along the main axis of Cane Valley Wash. Beneath this area are impermeable beds of Monitor Butte and Petrified Forest Members of the Chinle Formation. These members consist of siltstones and claystones and are about 700 ft thick in the millsite area. The unconfined water moves through the alluvium of Cane Valley Wash and is recovered near the site from shallow wells. These shallow wells and springs are water table sources and their recharge is from local runoff.

The tailings piles absorb all precipitation falling thereon. There is little evidence of any surface runoff from the piles. Any precipitation falling on the tailings piles probably will never reach the shallow unconfined aquifer along Cane Valley Wash. The maximum expectable thunderstorm in this area may result in as much as 4 to 6 in. of rainfall onto the tailings. This water probably would not penetrate more than about 6 ft into the coarse material of the piles; with the high evaporation rates that prevail in the area, the water would return to the surface of the tailings to be lost to the atmosphere by evaporation without entering the unconfined ground water system of Cane Valley Wash.

Recent[12,13] and ongoing research by the Research Institute for Geochemical and Environmental Chemistry suggests that the presence of soluble sulfate salts in the tailings greatly modifies the hydrologic environment of the piles. The principal investigator[12] states that "the general trend of material transfer within the pile 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.

The average annual precipitation at Bluff, Utah, is 7.5 in., and at Kayenta, Arizona, it is 8.3 in.[14,15] Bluff is located about 28 mi northeast and Kayenta about 28 mi to the southwest of the Monument Valley site. Precipitation at the Monument Valley site likely has characteristics similar to these locations. The maximum 24-hr precipitation recorded at Bluff over a 62-yr period of record is 3.6 in., measured on July 24, 1966. The maximum 24-hr precipitation at Kayenta over a 52-yr period is 2.5 in., measured on October 4, 1960. Measured against the 100-yr 24-hr precipitation estimated from these figures, the storm at Bluff on July 24, 1966, exceeded the 100-yr estimate by about 0.5 in.; however, the maximum at Kayenta was less than the 100-yr estimate.

The Monument Valley site location could expect a 24-hr precipitation rate of 1.3 in. once every 2 yr. The time of most frequent thunderstorm activity typical of much of the southwestern desert area occurs in August, September, and October.

There are no quantitative wind records for the Monument Valley site. Prevailing wind directions for the general area are shown in Figure 2-10. On-site observations show that the prevailing winds are from the southwest and that periodically there is some movement of the finer tailings material at the northeastern (downwind) edge of the pile. The material, however, generally has been moved a maximum distance of only about 500 ft, and there are no nearby residences within 1,000 ft of the piles in most directions. However, in the northerly direction from the piles there is evidence of tailings up to 2,000 ft. There are no residences within 2 mi of the piles in this direction.

2.7.4 Meteorology

For the purpose of health effects calculations, the site is considered to have wind conditions similar to those that exist at Farmington, New Mexico. Wind directions and speeds recorded at the Farmington Airport over a 5-yr period are presented in Table 2-2.[16] As shown in the table, the winds are calm 40% of the time and exceed moderate speeds (greater than 18 mi/hr) only 3% of the time. The most frequent winds are from the west, southwest, east, and northeast directions.

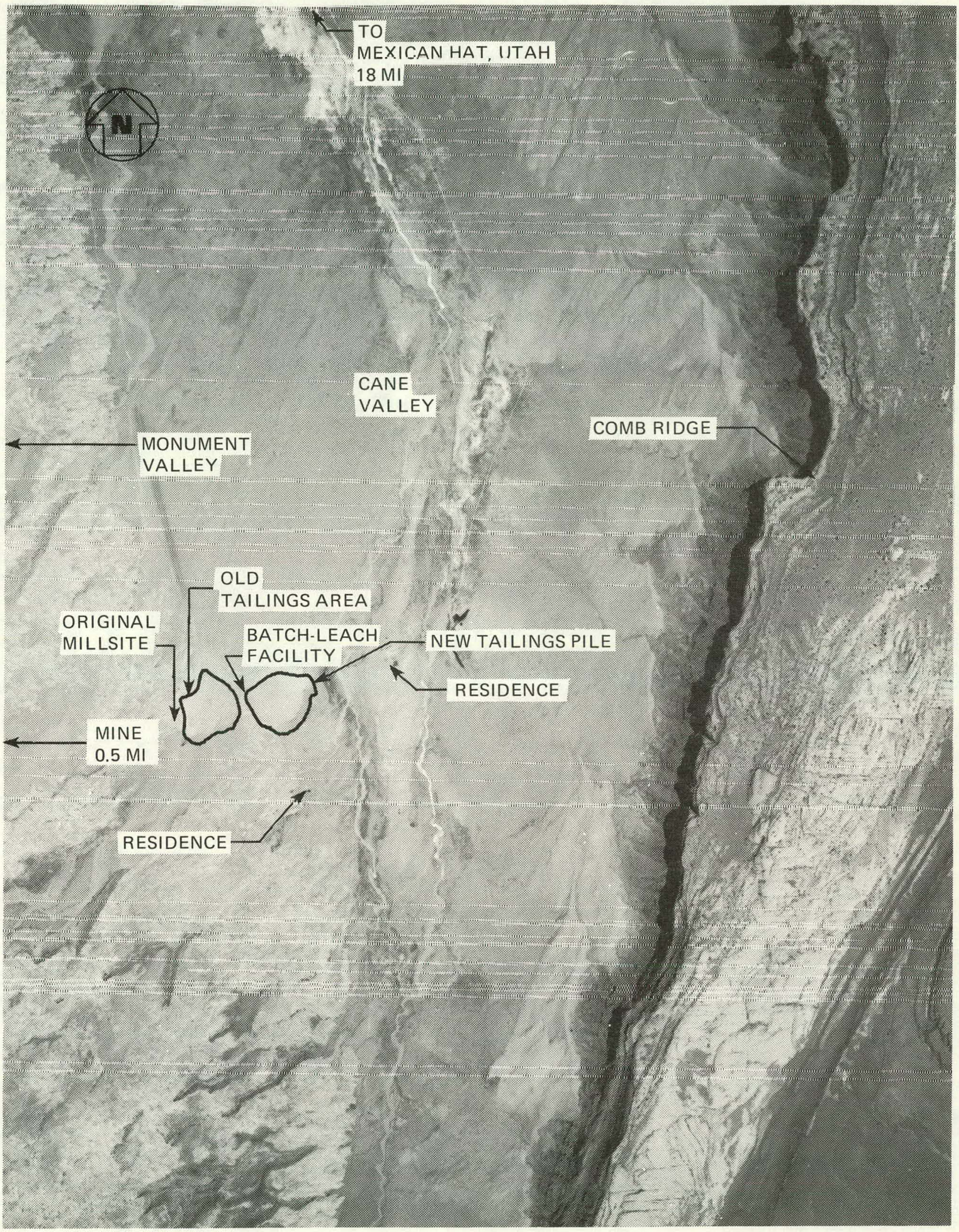

FIGURE 2-1. AERIAL PHOTOGRAPH OF SITE

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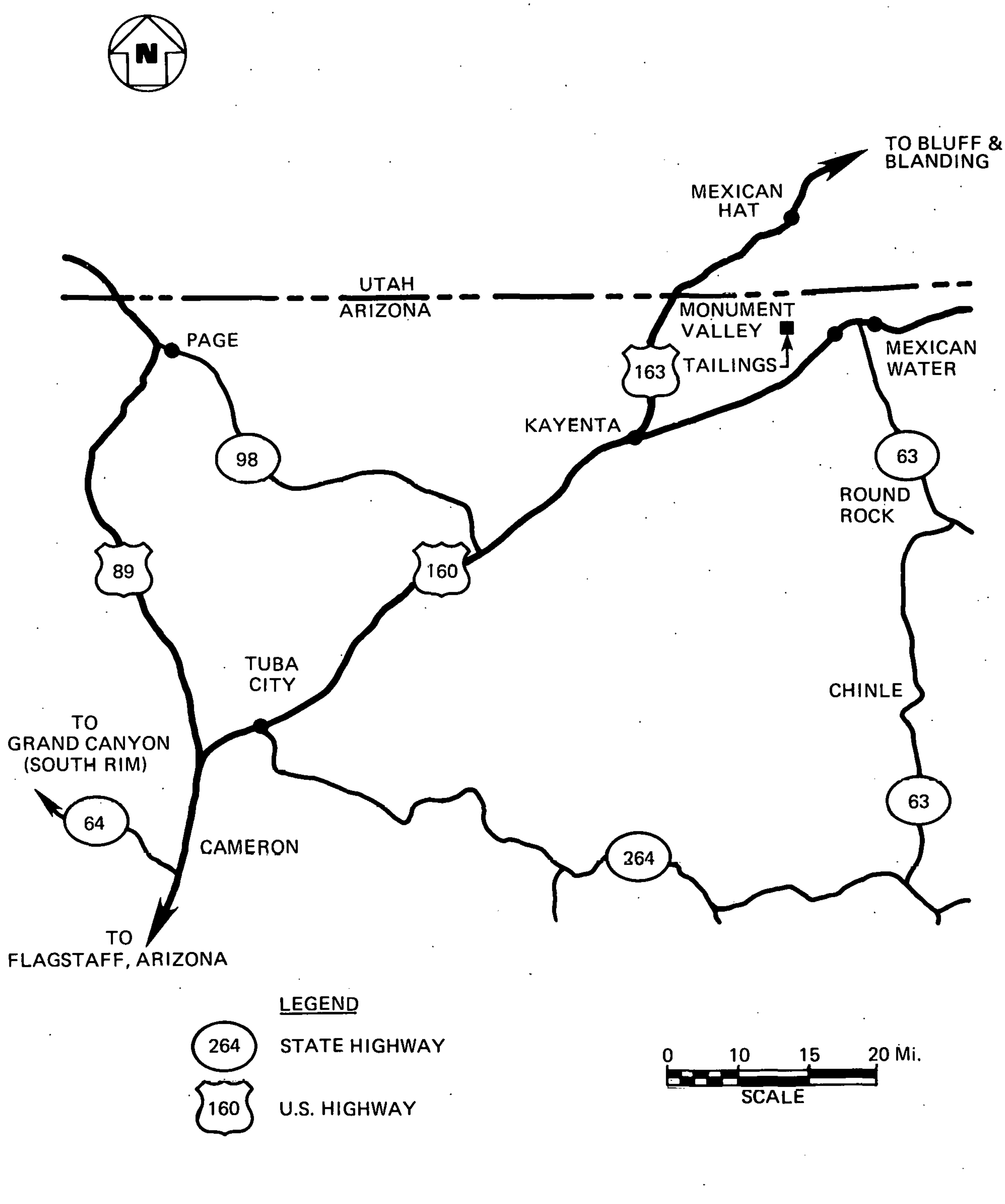

FIGURE 2-2. LOCATION OF SITE

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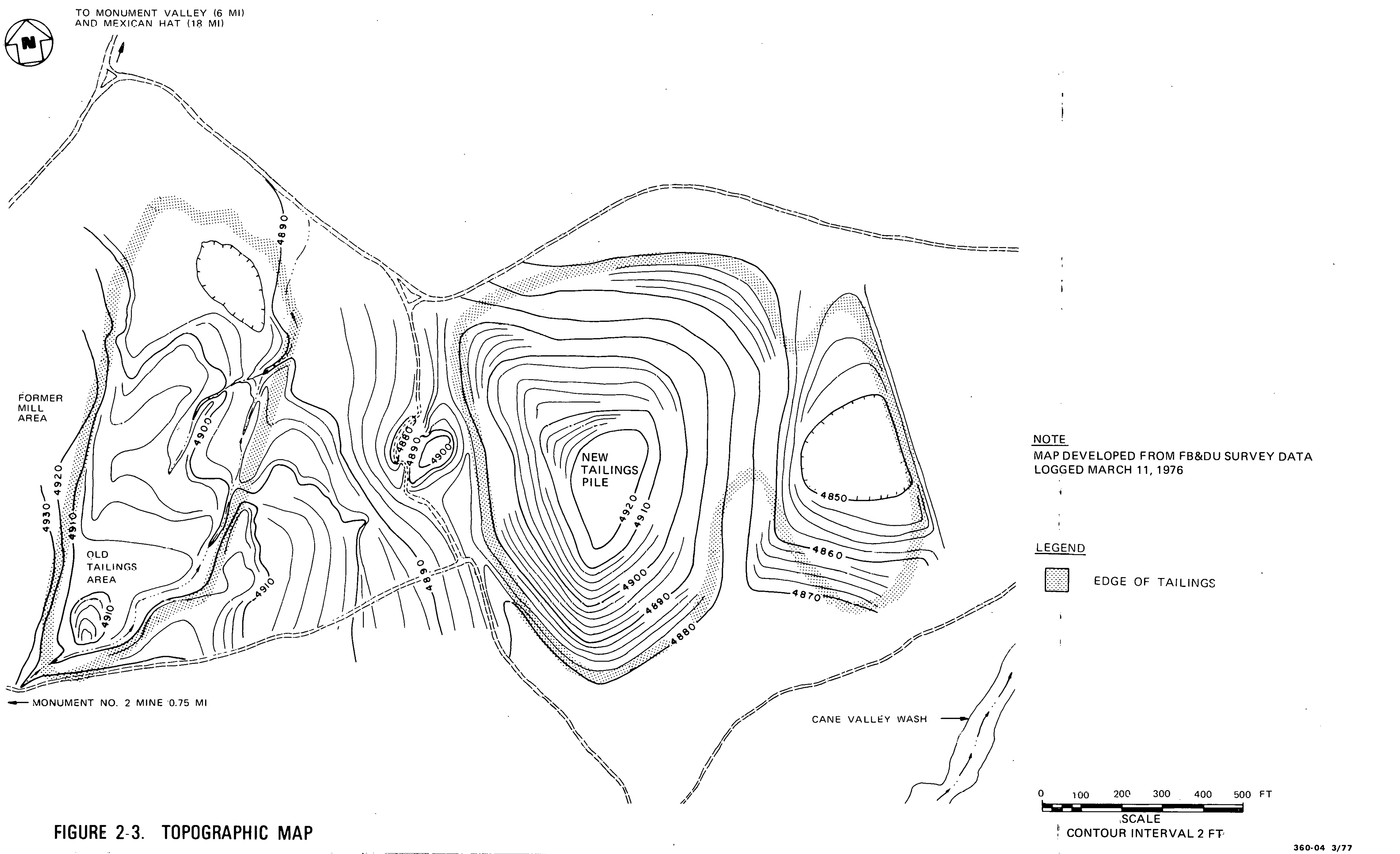
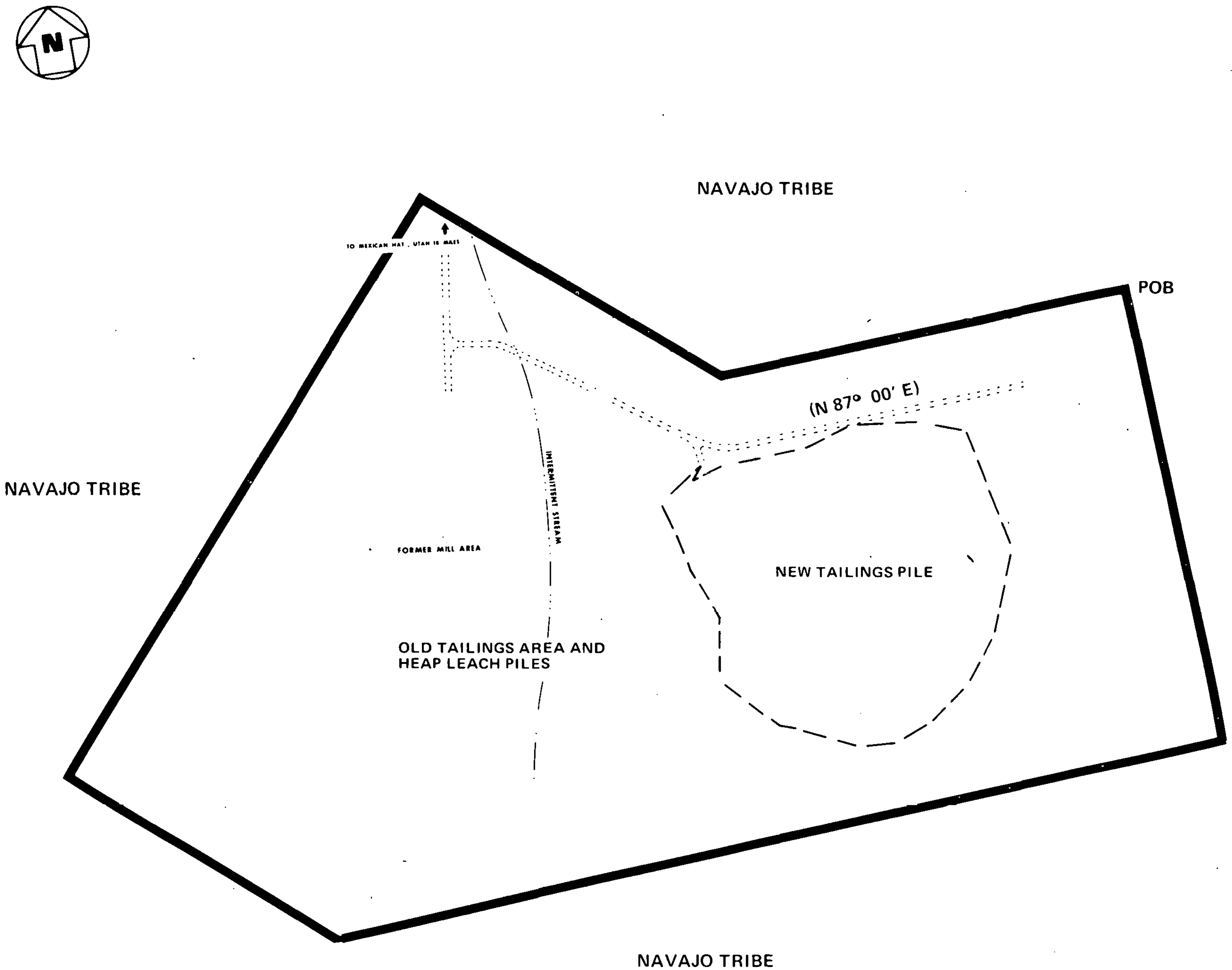


FIGURE 2-3. TOPOGRAPHIC MAP



MONUMENT VALLEY SITE

BEGINNING AT A POINT WHICH IS N 50°E, 1025 FT FROM AN ARIZONA STATE PLANE COORDINATE GRID LOCATION IN THE CENTER OF THE "NEW TAILINGS PILE" AS N = 2,158,200 & E = 587,900 AND RUNNING THENCE S 3°E, 1300 FT; THENCE S 87°W, 2541.84 FT; THENCE N 50°W, 868.67 FT; THENCE N 40°E, 1900 FT; THENCE S 50°E, 1000 FT; THENCE N 87°E, 1150 FT TO THE POINT OF BEGINNING.

CONTAINS 101 ACRES (MORE OR LESS)

NOTE:

1. *CENTER OF TAILINGS PILE LOCATED BY ARIZONA DEPARTMENT OF HIGHWAYS FROM CONTROLLED AERIAL PHOTOGRAPHY. SAID POINT LYING S 85°50′W, 14,130 FT (MORE OR LESS) FROM THE COMB RIDGE CONTROL MONUMENT.
2. ADAPTED FROM REFERENCE 1

NO SCALE

FIGURE 2-4. LAND OWNERSHIP AND SITE DESIGNATION MAP

360-04 2/81

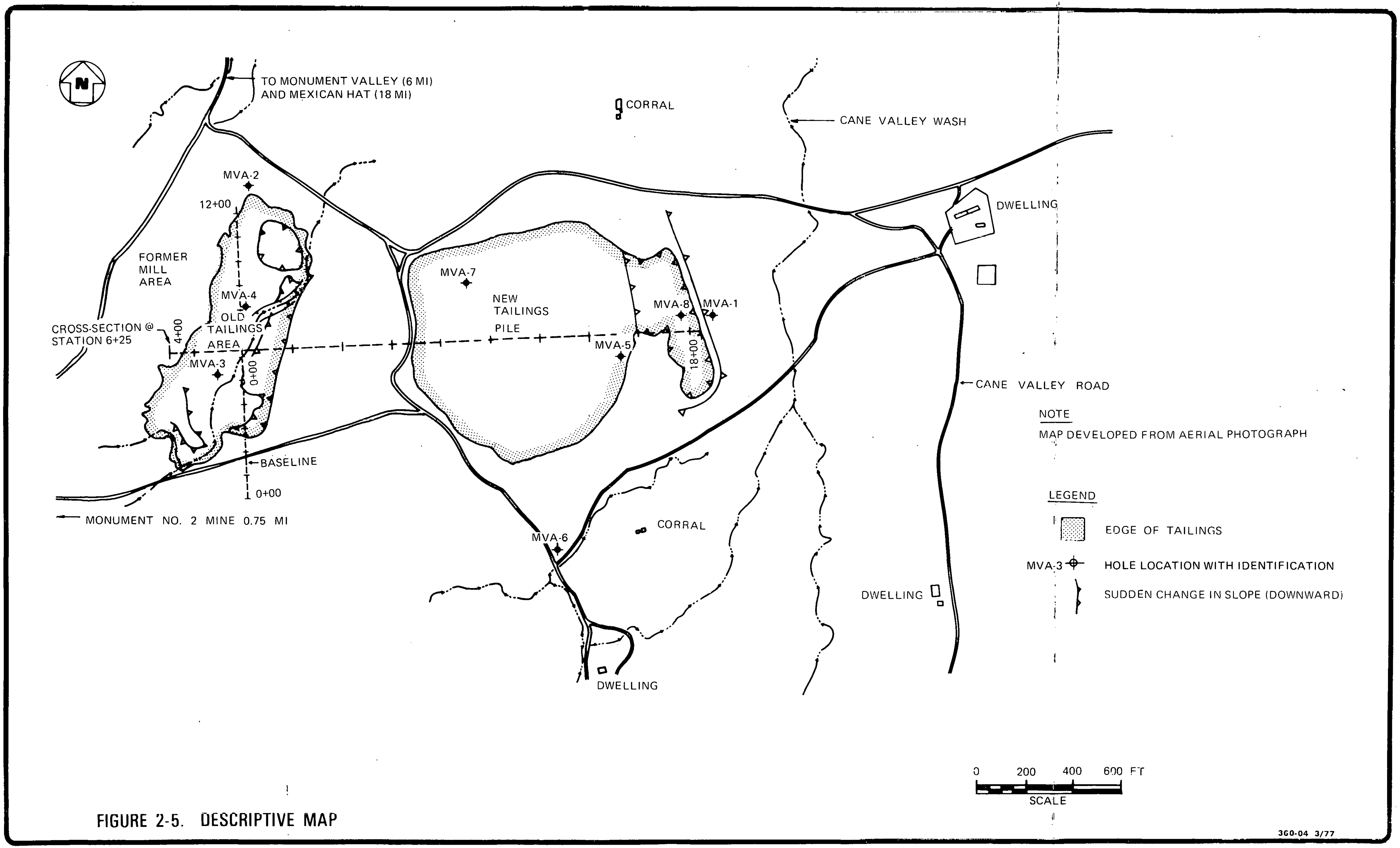


FIGURE 2-5. DESCRIPTIVE MAP

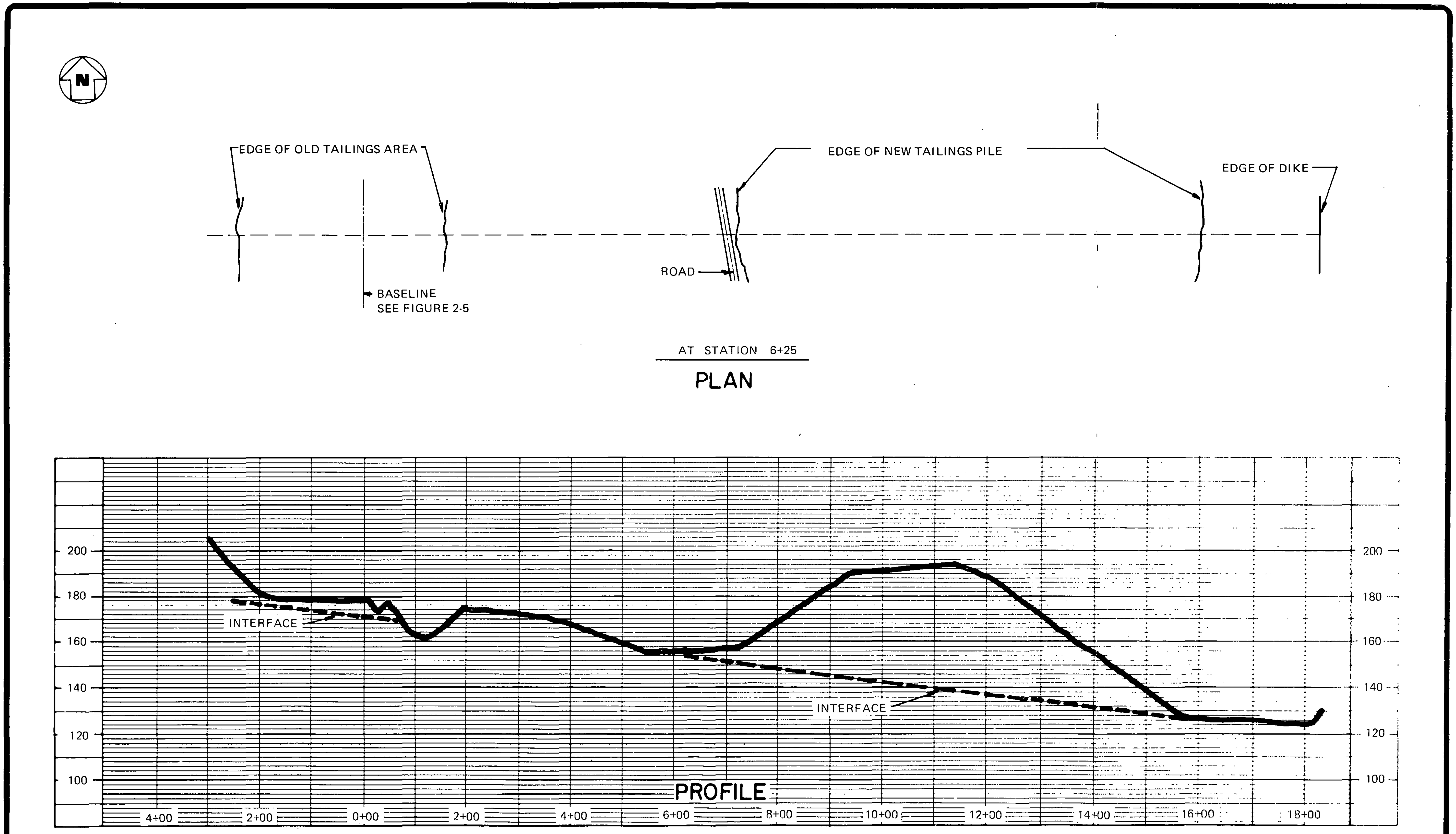


FIGURE 2-6. CROSS-SECTION AT STATION 6+25

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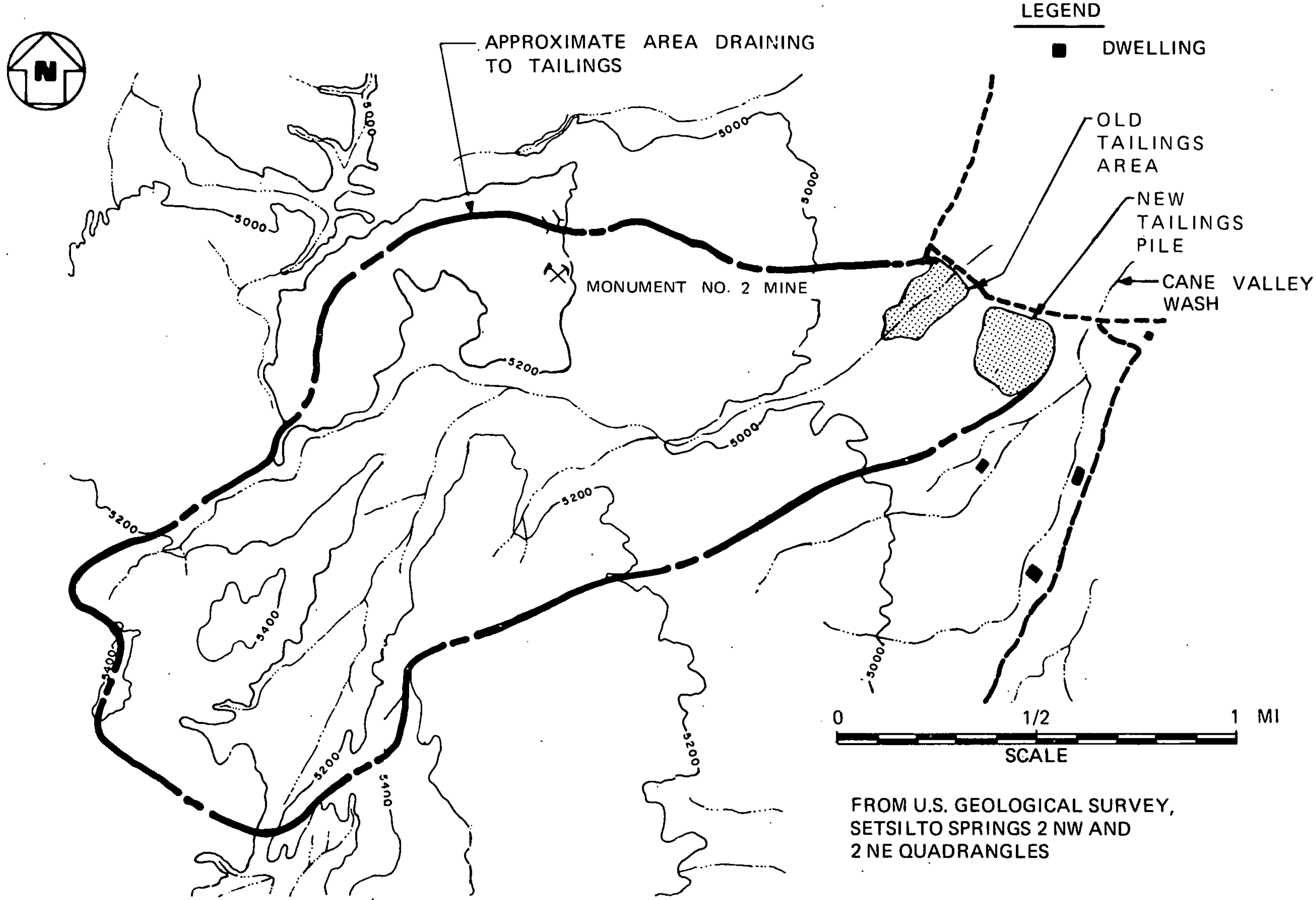

360-04 3/77

FIGURE 2-7. SURFACE DRAINAGE PATTERNS

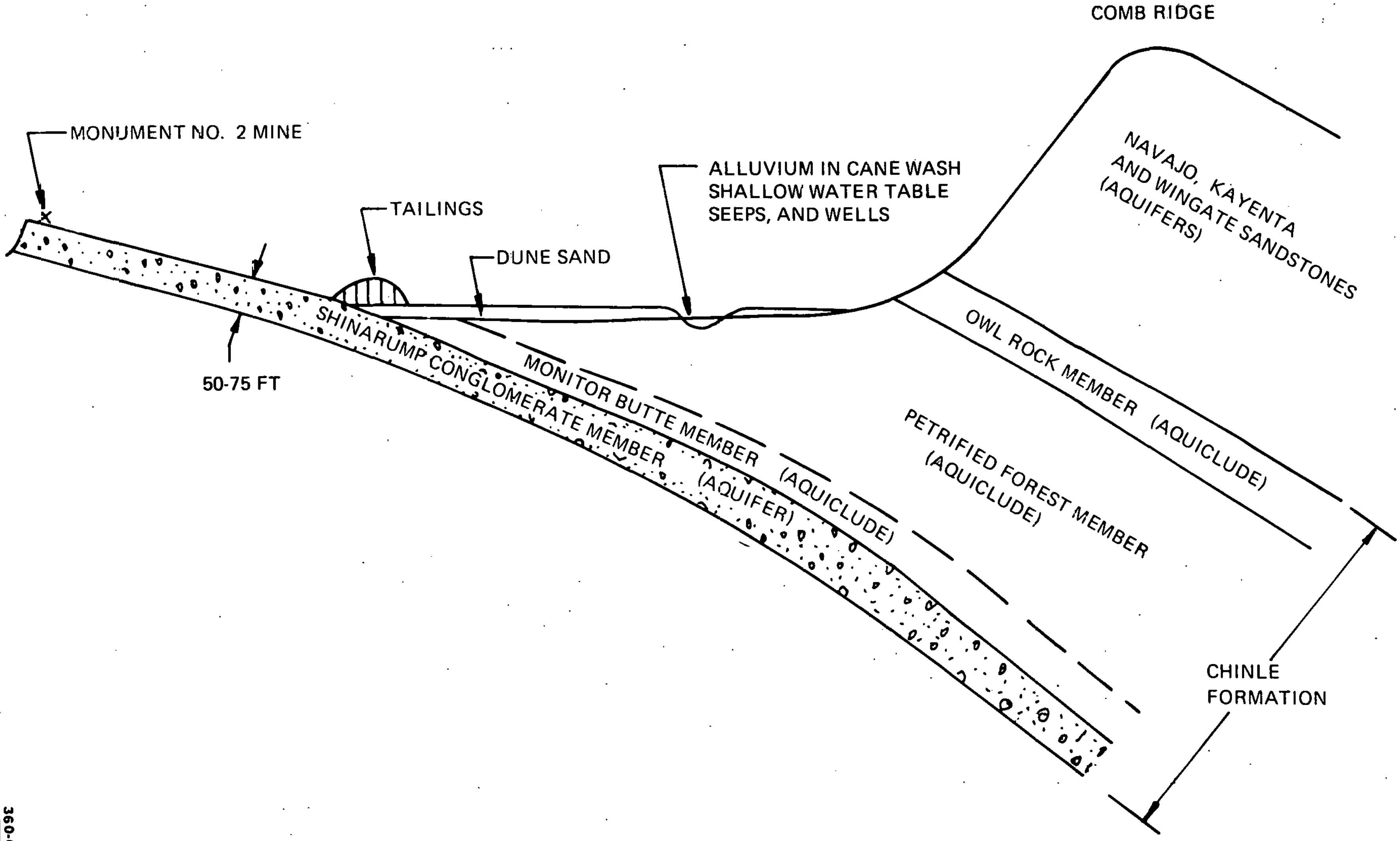

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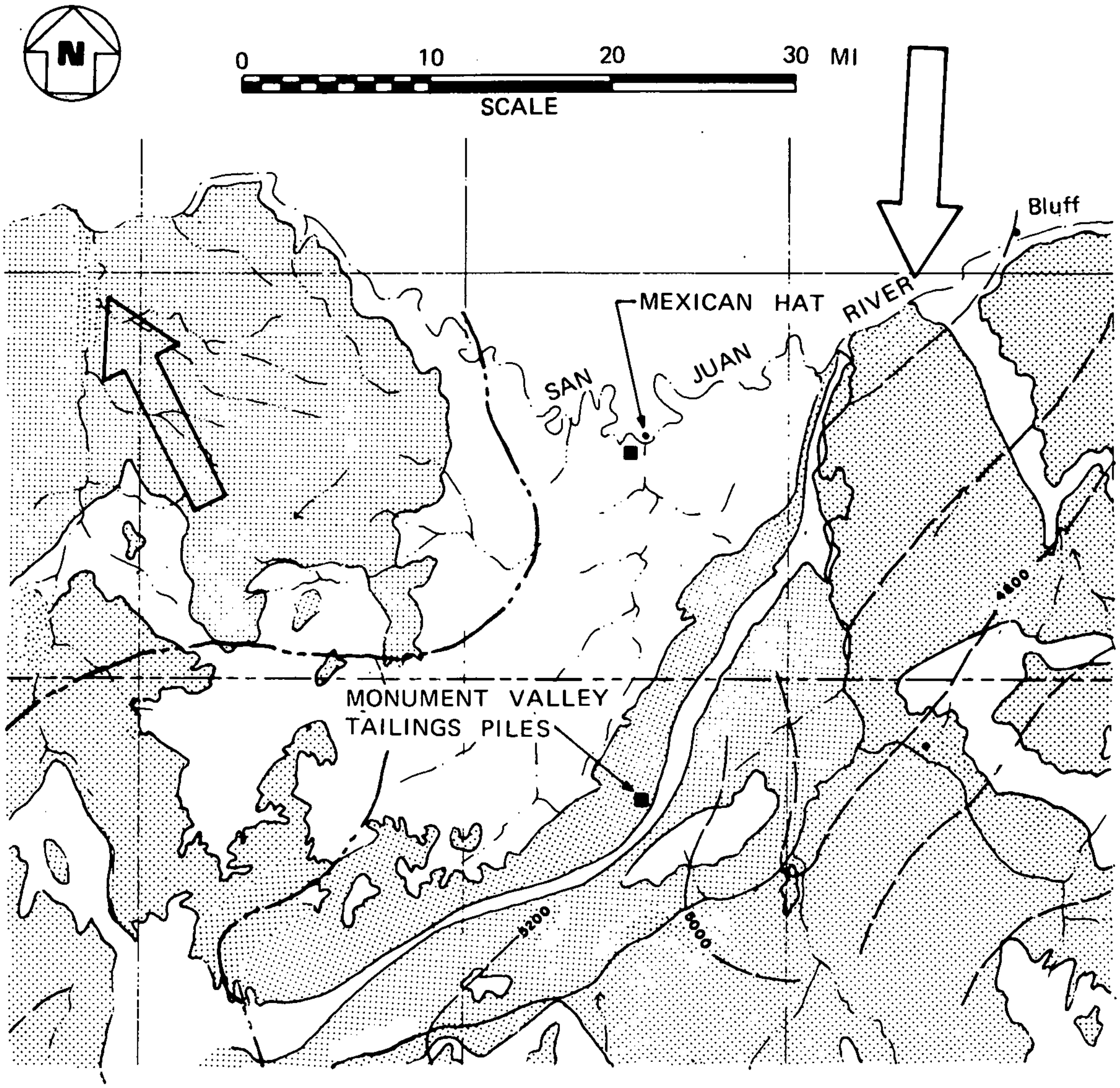
FIGURE 2.8. SIMPLIFIED STRATIGRAPHIC CROSS-SECTION (NOT TO SCALE)



LEGEND

ROCKS RECEIVING RECHARGE

UNSHADED AREAS INDICATE AQUICLUDE (ROCKS RECEIVING LITTLE OR NO RECHARGE)

PROBABLE DIRECTION OF GROUND WATER FLOW

NOTE:
'FROM REFERENCE 11

FIGURE 2-9. GROUND WATER CONDITIONS

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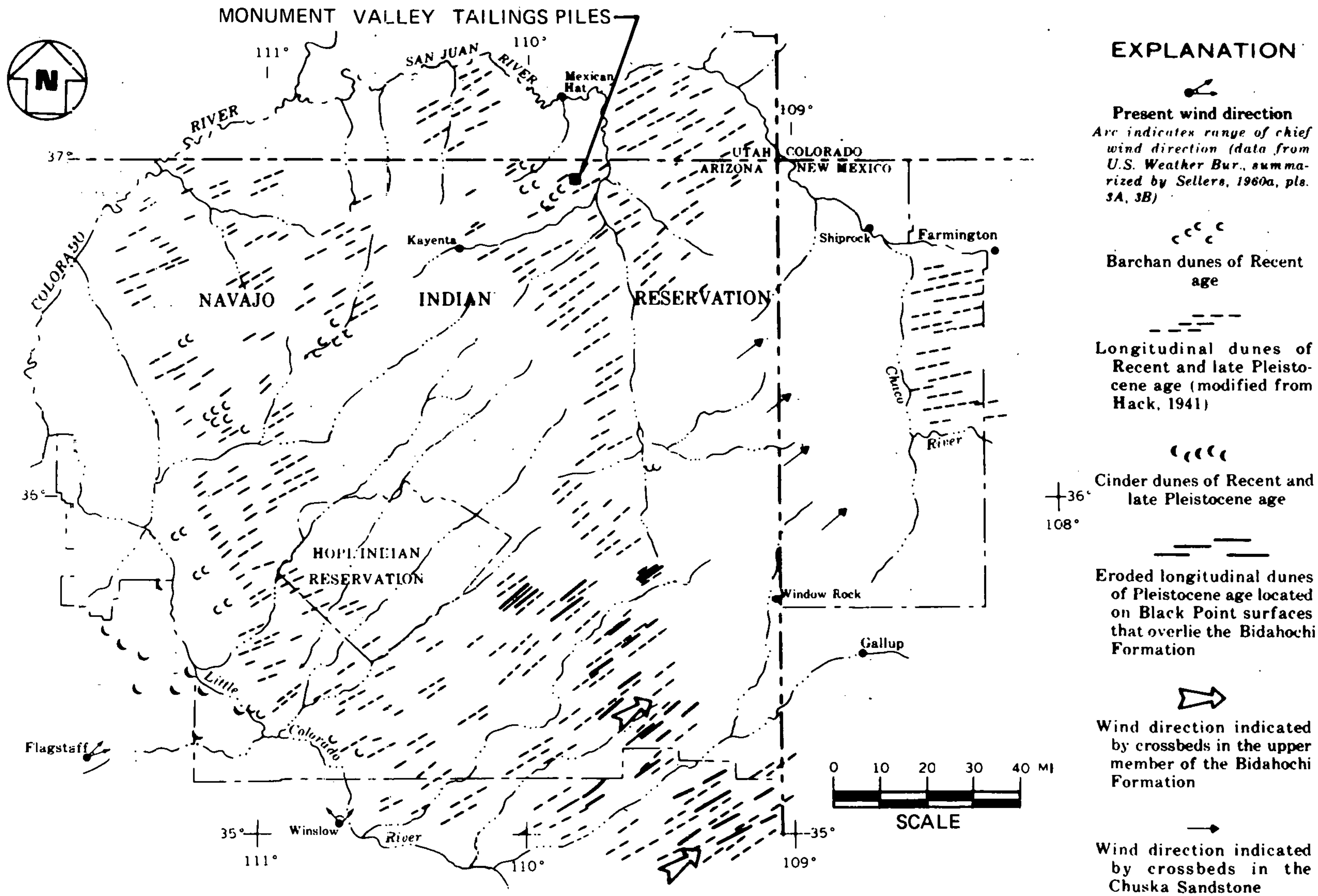

MAP SHOWING PAST AND PRESENT PREVAILING WIND DIRECTIONS

NOTE:
FROM REFERENCE 11

FIGURE 2-10. PREVAILING WIND DIRECTIONS

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TABLE 2-1

CONTAMINATED MATERIALS AT MONUMENT VALLEY SITE

Material	Volume (yd^3)	Weight (tons)
Old Pile Uranium Tailings	123,000	165,000[a]
New Pile Uranium Tailings	698,000	935,000[a]
Contaminated Soil, Former Mill Area	12,000[b]	16,000[g]
Contaminated Subsoil, Old Pile Area	68,000[c]	92,000[g]
Contaminated Subsoil, New Pile Area	105,000[d]	142,000[g]
Off-Site Windblown Contaminated Soil	11,000[e]	14,000[g]
On-Site Windblown Contaminated Soil	37,000[f]	50,000[g]
TOTAL	1,054,000	1,414,000

[a]Except tailings, weight is based on average existing field densities, which includes moisture.

[b]Volume based on 7.4 acres contaminated to an average depth of 1 ft.

[c]Volume based on 10.6 acres contaminated to an average depth of 4 ft.

[d]Volume based on 21.7 acres contaminated to an average depth of 3 ft.

[e]Volume based on 13 acres contaminated to an average depth of 0.5 ft.

[f]Volume based on 46 acres contaminated to an average depth of 0.5 ft.

[g]Weight based on an estimated density of 100 lb/ft^3.

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TABLE 2-2

FREQUENCY OF WIND DIRECTION AND SPEED[16]
FARMINGTON, NEW MEXICO, AIRPORT
(PERIOD: 1960-1964)

	Wind Speed Range (mi/hr)						
Direction	0-3 (calm)	4-7	8-12	13-18	19-24	25-47	Total
N	--	1.52	0.41	0.16	0.05	0.03	2.17
NNE	--	1.25	0.39	0.11	0.03	0.01	1.79
NE	--	4.20	1.13	0.11	0.02	0.01	5.47
ENE	--	4.68	1.65	0.22	0.02	0.00	6.57
E	--	4.65	1.85	0.23	0.01	0.00	6.74
ESE	--	2.19	1.27	0.20	0.02	0.00	3.68
SE	--	1.31	0.62	0.17	0.02	0.00	2.12
SSE	--	0.42	0.31	0.25	0.06	0.01	1.05
S	--	0.70	0.79	0.58	0.20	0.05	2.32
SSW	--	0.64	0.83	0.56	0.16	0.07	2.26
SW	--	2.45	2.14	0.78	0.15	0.02	5.54
WSW	--	2.22	2.19	0.99	0.15	0.04	5.59
W	--	2.18	2.26	1.69	0.38	0.05	6.56
WNW	--	1.26	1.56	1.60	0.49	0.13	5.03
NW	--	0.65	0.58	0.49	0.16	0.06	1.94
NNW	--	0.44	0.29	0.20	0.08	0.02	1.03
Calm	40.13	---	---	---	---	---	40.13
TOTAL	40.13	30.76	18.27	8.34	2.00	0.50	100.00

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CHAPTER 3

RADIOACTIVITY AND POLLUTANT IMPACT ON THE ENVIRONMENT

CHAPTER 3

RADIOACTIVITY AND POLLUTANT IMPACT ON THE ENVIRONMENT

The principal objective of the assessment in this chapter is to determine the magnitude and characteristics of the radiation emitted from the Monument Valley uranium tailings piles and the resulting potential exposure to the population residing in the vicinity of Monument Valley, Arizona. 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 site was conducted by Oak Ridge National Laboratory (ORNL),[1] concurrently with work performed by FB&DU in 1976. The principal results of that work are included in this engineering assessment.

3.1 RADIOACTIVE MATERIAL CHARACTERISTICS

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

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

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

The activity and the total number of radioactive atoms of a particular type depend upon their creation rates as well as their half life for decay. If left undisturbed, the radioactive components of the decay chain shown in Figure 3-1 all reach the same level of activity, matching that of the longest-lived initiating isotope. This condition is known as secular equilibrium. When the uranium is removed in the milling process, ^{230}Th, which is not removed, becomes the controlling isotope. After processing the ore for uranium, the thorium, radium, and other members of the decay chain remain in the spent ore solids in the form of a waste slurry. The slurry is pumped to a tailings pond. The sands and slimes that remain constitute the tailings 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 x 10^5 MeV of alpha energy. The working level is so defined because it is a single unit of measure, taking into account the relative concentrations of radon daughter products which vary according to factors such as ventilation. One WLM results from exposure to air containing a radon daughter concentration (RDC) of 1 WL for a duration of 170 hr.

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

3.3 NATURAL BACKGROUND RADIATION

There are several sources of radiation that occur naturally in the environment. Natural soils contain trace amounts of uranium, thorium, and radium that give rise to radon gas and to alpha, beta, and gamma radiation. The average background value in 6 off-site soil samples for each member of the uranium decay chain, assuming equilibrium, was 0.95 pCi/g.(1) The samples taken within an 80-mi radius of the Monument Valley site and the corresponding ^{226}Ra concentrations are shown in Figure 3-2. Radium concentrations in samples taken during the EPA gamma survey(2) tend to agree with these values. Another natural source of radiation in the environment arises from the decay of ^{232}Th, the predominant thorium isotope. The half-life of ^{232}Th is 1.4×10^{10} yr. It is also the parent of a decay chain containing isotopes of radium and radon. The average background value in the same off-site samples for each member of the thorium decay chain, assuming equilibrium, is about 0.67 pCi/g of soil.(1) Table 3-2 lists the major background radioactive sources and their concentrations. Background values of the radium and thorium chains vary with locations by factors of 6 to 7. In addition, soils in the general area contain about 20 pCi/g of ^{40}K, a beta and gamma emitter.(2)

Soil samples were collected in 1980 from the topmost 12 in. of earth at three locations at an average distance of 700 ft from the site. The sample locations are shown in Figure 3-3, along with the corresponding concentrations of ^{226}Ra. One sample contained 9 pCi/g of ^{226}Ra and is not considered to be indicative of background radium concentrations. The average background concentration of ^{226}Ra in the other two samples is about 2.1 pCi/g.

Background values of radon concentrations were measured at four locations ranging from 0.8 to 2 mi from the tailings using continuous radon monitors supplied by ERDA.(3) An average outdoor value of 0.6 pCi/l was obtained from the 24-hr samples. However, the range of the 24-hr average concentrations extends from 0.4 to 0.7 pCi/l. A previous background measurement(3) taken during midday yielded a value of 0.2 pCi/l. A more detailed presentation of radon measurement data is given in Paragraph 3.4.1.

Background gamma ray levels, as measured 3 ft above the ground, also were determined at several locations within 450 yd from the site by using a calibrated and energy-compensated Geiger Mueller detector.[1] A value of 9 μR/hr was determined as the average background level, but the values ranged from 7 to 11 μR/hr. Previous measurements of the gamma background radiation in 1974 at nine locations using a pressurized ion chamber indicated an average value of 9.4 μR/hr, with a high of 12 μR/hr and a low of 7 μR/hr.[2] Cosmic rays contribute to background radiation levels. The contribution from cosmic rays is generally dependent upon the altitude and is approximately 5 μR/hr in the Monument Valley area.[4] The gamma survey is treated in more detail in Paragraph 3.4.2.

3.4 RADIATION EXPOSURE PATHWAYS AND CONTAMINATION MECHANISMS

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

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

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

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

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

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

(f) Physical removal from the tailings piles 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

Field measurements of the radon exhalation flux from the tailings using the charcoal canister technique[5] are shown in Figure 3-4. The values range from 14 to 29 pCi/m^2-s. Radon flux depends principally on radium content of the tailings and the thickness of any cover material. In general, the radon flux varies considerably from time to time at a single sampling location, partly as a result of differing moisture, soil, climatological factors, and major changes in pile configuration between different locations, and partly because of the difficulty of performing such measurements. At Monument Valley, the area-weighted radon exhalation flux is only about 20 pCi/m^2-s.

Radon gas concentration was found to be 4.3 pCi/l at a distance of 0.6 mi north of the site where tailings may have been used for an airstrip. At 1 mi north, the concentration dropped to 0.5 pCi/l. Measurement locations and corresponding 24-hr average radon concentrations are illustrated in Figure 3-5. The only other measurements known[6] do not indicate radon concentrations above background at this distance; however, they were grab sample measurements taken in the late morning and early afternoon hours under lapse conditions, when radon has been dispersed.

The variations of radon concentration during the measurement period and the existing weather conditions are shown in Figures 3-6 and 3-7. The sample location for Figure 3-6 is between the old and new tailings piles and the sample location for Figure 3-7 is 0.6 mi north of the tailings piles. Even though the present data are 24-hr averages, the values were obtained during atmospheric conditions normal at that time of year. Data were not recorded during wind or rainstorms.

Radon concentration measurements taken during this program generally indicated increased concentrations during the night hours, reverting to background values during the daylight hours.

This is probably the result of a nighttime inversion condition and reduced wind velocities. High winds tend to disperse the radon and generally do not result in higher measurements of radon concentration downwind from the tailings piles.

The radon concentration measurements are plotted in Figure 3-8 as a function of distance from the edge of a tailings pile. Also shown in this figure is the predicted concentration calculated with the FB&DU model for radon diffusion from the Monument Valley tailings.

3.4.2 Direct Gamma Radiation

Background gamma radiation in the Cane Valley area is about 9 μR/hr. The external gamma radiation (EGR) levels measured on the old and new tailings piles are shown in Figure 3-9.(1) The gamma levels measured in the area surrounding the piles are shown in Figure 3-10. Data were taken with a calibrated and energy-compensated Geiger Mueller detector.

The highest gamma radiation (137 μR/hr) was measured on the old tailings pile at the edge of the dry wash that intersects that pile. The next highest reading (95 μR/hr) was found in the mill area directly west of the old pile. All other gamma measurements on the tailings piles and in the mill and ore storage areas were below 80 μR/hr.

Gamma measurements away from the piles reached background levels of 9 μR/hr within 300 yd to the north, east, and south of the site. To the west, the gamma radiation approached background levels 400 yd west of the site, but then the radiation increased in the direction of the Monument No. 2 mine. This is due, in part, to ore scattered throughout the area. The gamma survey was terminated at that point since the mine is not part of the assessment program.

The reduction of gamma radiation as a function of distance from the piles is shown in Figure 3-11. The gamma radiation decreases to background range at less than 0.1 mi from the edges, except to the west. In that direction, the gamma radiation was high at the millsite, dropped to the background range at 0.2 mi, and then increased rapidly toward the mine. There are no inhabitants between the piles and the mine.

In general, gamma radiation levels on and in the vicinity of the Monument Valley site are lower than most other inactive sites. With one exception, gamma radiation rate measurements were all less than 10 times the background value.

3.4.3 Windblown Contaminants

Another pathway results from windblown tailings. The prevailing winds are from the west and southwest. Windblown tailings were observed adjacent to the northeastern edge of the new pile, but the coarse-grained character of the sand has limited the extent of contamination to a few hundred feet in most directions from the pile. Figure 3-12 indicates an iso-exposure line due to the residual windblown tailings as determined by the EPA.[7] If scattered tailings and ore are removed from inside the 10 μR/hr line (toward the pile), and if all direct gamma radiation from the pile could be completely shielded, then the remeaning tailings outside the line (away from the pile) would produce a new gamma exposure rate, 3 ft above ground, approximately equal to 10 μR/hr.

Surface soil samples were taken in the area surrounding the site. The sample locations and ^{226}Ra concentrations are shown in Figure 3-13. In the northerly direction, ^{226}Ra concentration is three times the average background value at a distance of 600 yd from the piles. A surface sample 200 yd northeast of the new pile contained 20 times the average background concentration of ^{226}Ra.[1] Ore, overburden, and possibly tailings may have been used for roads in the area and in the construction of the airstrip.

Measurements and data analyses were performed in 1980 to establish the boundary of that region around the site contaminated in excess of 5 pCi/g of ^{226}Ra. A lead-shielded scintillometer, NAI(Tl), was used. The scintillometer had one unshielded end directed toward the ground and was held about 1 in. above the ground surface. After obtaining an unshielded reading, a 0.5-in.-thick lead shield was placed over the unshielded end and a second reading was obtained. The difference between the unshielded and shielded readings, called "delta", represents the exposure from the surface at that location. A difference of about 400 counts/min between the unshielded and shielded count rates with the meter used has been estimated to indicate an area with a soil concentration of about 5 pCi/g of ^{226}Ra.

Traverses with the scintillometer were conducted across open lands adjacent to the tailings piles and were continued until a soil contamination of 5 pCi/g of ^{226}Ra was indicated. Figure 3-14 shows the traverses and the location of the 5 pCi/g of ^{226}Ra level on each traverse. These points are connected to indicate the area surrounding the site contaminated in excess of 5 pCi/g of ^{226}Ra. In most instances the traverses extended well beyond the 10 μR/hr contour of the 1975 EPA gamma survey,[7] and surface contamination readings remained at or near background levels. It is readily apparent from Figure 3-14 that the extent of windblown contamination is greatest to the north and west of the old tailings pile, where the ^{226}Ra concentration does not fall below 5 pCi/g for a distance of 800 ft from the edge of the pile. In all directions around the new tailings pile, the 5-pCi/g boundary is reached within 200 to 400 ft from the edge of the pile.

Previous measurements of airborne particulate concentrations[6] are shown in Table 3-3. At the time of the measurements, the airborne concentrations of ^{226}Ra and ^{230}Th were below the maximum permissible concentrations at all four locations including one on top of the new tailings pile. Concentrations off the piles were at least an order of magnitude below the concentration limits given in 10 CFR 20.

3.4.4 Ground and Surface Water Contamination

Water samples were taken from drill hole MVA-1 (Figure 2-5) and from a well east of the tailings site. Water from the well, used by livestock, had a dissolved ^{226}Ra concentration of 2.9 pCi/l.[1] In 1967, the same well was sampled[6] and the analysis indicated a dissolved radon content of 1.5 pCi/l. The difference in indicated radon content of the well water may be due to sampling and analysis errors. It would be appropriate to periodically monitor the radon content of this well water even though the radon content is less than the EPA Interim Primary Drinking Water Regulations, which allow a combined contamination level of 5 pCi/l for ^{226}Ra and ^{228}Ra. Other samples were taken 7 mi north and 5 mi south of the site from wells near the Cane Valley Wash along Comb Ridge. The ^{226}Ra concentration in these samples ranged from 0.05 to 0.6 pCi/l.[1] (The 0.05 value is unexplainably low.) These values are well below the EPA Interim Primary Drinking Water Regulations. These concentrations and locations are shown in Figure 3-13. Previous measurements of ^{226}Ra concentration in water from five wells in Cane Valley yielded activities that ranged from 0.11 to 0.36 pCi/l.[8]

3.4.5 Soil Contamination

The amount of ^{226}Ra activity in the tailings and the extent of leaching of radium from the tailings into the soil were determined by drilling holes through the tailings and into the soil beneath both the old and the new piles. The radioactivity profile was measured in these holes with a collimated Geiger Mueller detector. Soil samples were taken with a Shelby tube sampler from selected holes for radiometric analysis. Two additional holes were drilled off the tailings piles, one to measure a background gamma radiation value and one to check for contamination close to the new pile. The locations of the boreholes are shown in Figure 2-5.

Typical ^{226}Ra radium activity profiles in the Monument Valley tailings and subsoil are shown in Figures 3-15 and 3-16. Figure 3-15 illustrates the radium activity in borehole MVA-7 drilled through the new tailings pile on the eastern portion of the site. These tailings had been reprocessed by leaching after first being processed by sand-slime separation. Measurements of the borehole samples indicated fairly low levels of activity, less than 100 pCi/g of ^{226}Ra. This hole was drilled to a depth of 8 ft below the tailings-soil interface. At the bottom, the ^{226}Ra concentration in the soil from the gamma long was about 5 times the background value. Another hole on the eastern edge of the new pile (hole MVA-5) reached the background value of ^{226}Ra concentration 2 ft below the tailings interface.

The radium activity profile in hole MVA-4 is shown in Figure 3-16. As shown in Figure 2-5, this hole is located in the old tailings area in a dry wash just east of a sandstone outcrop. About 2 ft of the subsoil has been contaminated by the tailings. The original surface beneath the old pile is a fairly hard but porous sandstone. At 1.5 ft below the interface, the ^{226}Ra concentration was about twice background. Soil samples were taken from all three of the holes mentioned above.

Radium concentrations in the old tailings pile were measured as high as 180 pCi/g. The variations in the radioactivity of the tailings noted in the profiles are due to variations in the methods of milling and tailings deposition. At hole MVA-8, between the new tailings pile and the dike to the east, ^{226}Ra concentrations reached 1,300 pCi/g within 1 ft of the soil surface. Typical tailings slimes were found in this area below the new tailings pile; consequently, the activity was considerably higher than for the leached piles. Holes drilled previously in this area established contour lines for removal of contaminated subsoil.(8)

The mill area west of the old pile is underlain by sandstone. No holes were drilled in this area but the gamma survey indicated contaminated areas where data ranged from 60 to 95 μR/hr.

3.4.6 Off-Site Tailings Use

Some of the uranium tailings have been moved physically from the site and used in structures in the area. These locations have been identified and are discussed in Chapter 7.

3.5 REMEDIAL ACTION CRITERIA

The criteria for remedial action that 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, applied to: (a) the cleanup of structures(9) where tailings are present, and (b) the cleanup of open land.

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

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

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

3.5.1 EPA Interim and Proposed Standards

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

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

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

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

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

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

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

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

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

3.5.2 NRC Regulations on Uranium Mill Tailings

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

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

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

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

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^2-s above natural background levels. Direct gamma exposure from the tailings or wastes should be reduced to background levels.

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

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

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

3.6 POTENTIAL HEALTH IMPACT

An assessment has been made of the potential health impact of the tailings 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.[10]

(b) External Gamma Radiation - Gamma radiation above background is measurable to distances of 0.1 mi from the piles, 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 reduce the gamma radiation.

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

(d) Water Contamination - The low ^{226}Ra activity in surface water away from the piles indicates little, if any, contamination from the tailings piles.

(e) Subsoil Contamination - The minimal amount of leaching of radioactive materials into the ground beneath the piles measured during this project indicates this pathway results in negligible health effects.

(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. The off-site remedial action is described in 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.(11,12) Furthermore, the uncertainty in the estimates of the potential health effects from this pathway far exceeds the magnitude of the health effects from the other pathways.

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

3.6.1 Assumptions and Uncertainties in Estimating Health Effects

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

The risk estimator used for continual exposure to gamma radiation is expressed as:[18]

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

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

3.6.2 Health Effects

The health effects were estimated using a ^{222}Rn flux of 75 pCi/m^2-s for the piles, which was calculated using diffusion theory and the tailings physical properties. Even though the calculated value for radon flux appears much larger than the measured values, it is considered a more defensible estimate of the radon release rate since measurements of radon flux to date have been made only at a few points in time and give no suggestion of the magnitude of annual variations. In the absence of this information, the conservative estimate was chosen as the basis for health effect calculations.

The transport of radon from the tailings piles was modeled using a Gaussian plume model, meteorology characteristics of the area, and population distribution surrounding the tailings piles as a function of the radius and direction from the center of the piles. The piles were modeled as vertical cylinders with area and volume equal to the total area and volume of the piles.

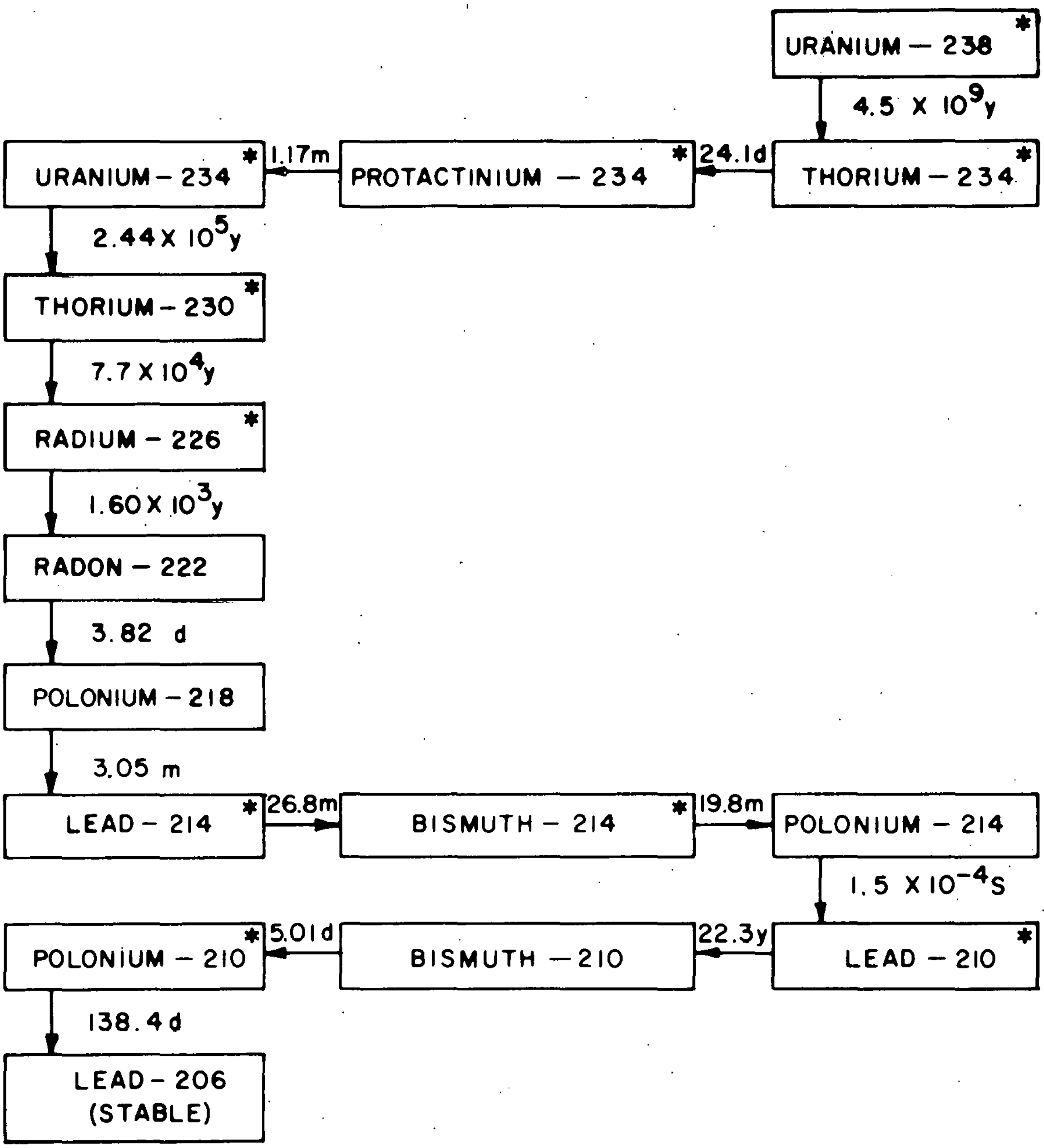
Total predicted outdoor ^{222}Rn concentration (resulting from radon release from the piles) is shown as a function of distance from the edge of the piles in a westerly direction in Figure 3-8. The predicted ^{222}Rn concentration at 0.1 mi from the edge of the piles is about 1.2 times the background level. The fact that there are two unexpectedly high measurements of radon in air at two distances from the piles may be explained in two ways. First, it is possible that sources of radon, such as uranium-rich outcroppings, are located near the measurement points. Second, it is possible that during the measurement periods the winds were predominantly from the piles in the direction of the measurement point. By contrast, the predicted concentrations are based on an annual average wind rose, which shows winds in the maximum direction less than 7% of the time.

Figure 3-17 shows the lung cancer risk per year from continuous exposure to radon as a function of distance east of the tailings piles. The curve shows that the risk for developing lung cancer from radon emanating from the piles is only about 5% greater than the natural occurrence from all causes at a distance of 0.2 mi from the edge of the piles and declines to the natural occurrence within 0.4 mi.

The population distribution within 4 mi of the edge of the piles was developed based on 1980 field observations of the area. This distribution includes virtually all residents close enough to the piles to be noticeably exposed to radon exhalation from the piles, as described in Chapter 4.

The three population projections used to estimate the cumulative health impacts attributable to the tailings piles were the 0.8% constant growth rate and the 2.5% and 4% declining growth rates, as discussed in Chapter 4. All three growth projections assume that the population is distributed in the same proportions as that reflected in Table 4-1.

Table 3-4 presents the estimated health impacts from the tailings piles for 0 to 4 mi from the edge of the piles, based on the estimated 1980 population distribution presented in Table 4-1. The cumulative health effects for the three growth scenarios considered for Monument Valley are also included. In Table 3-4, the health effects from the pile radon are shown to be about 1% of those caused by background radon for the vicinity within 4 mi of the edge of the piles.



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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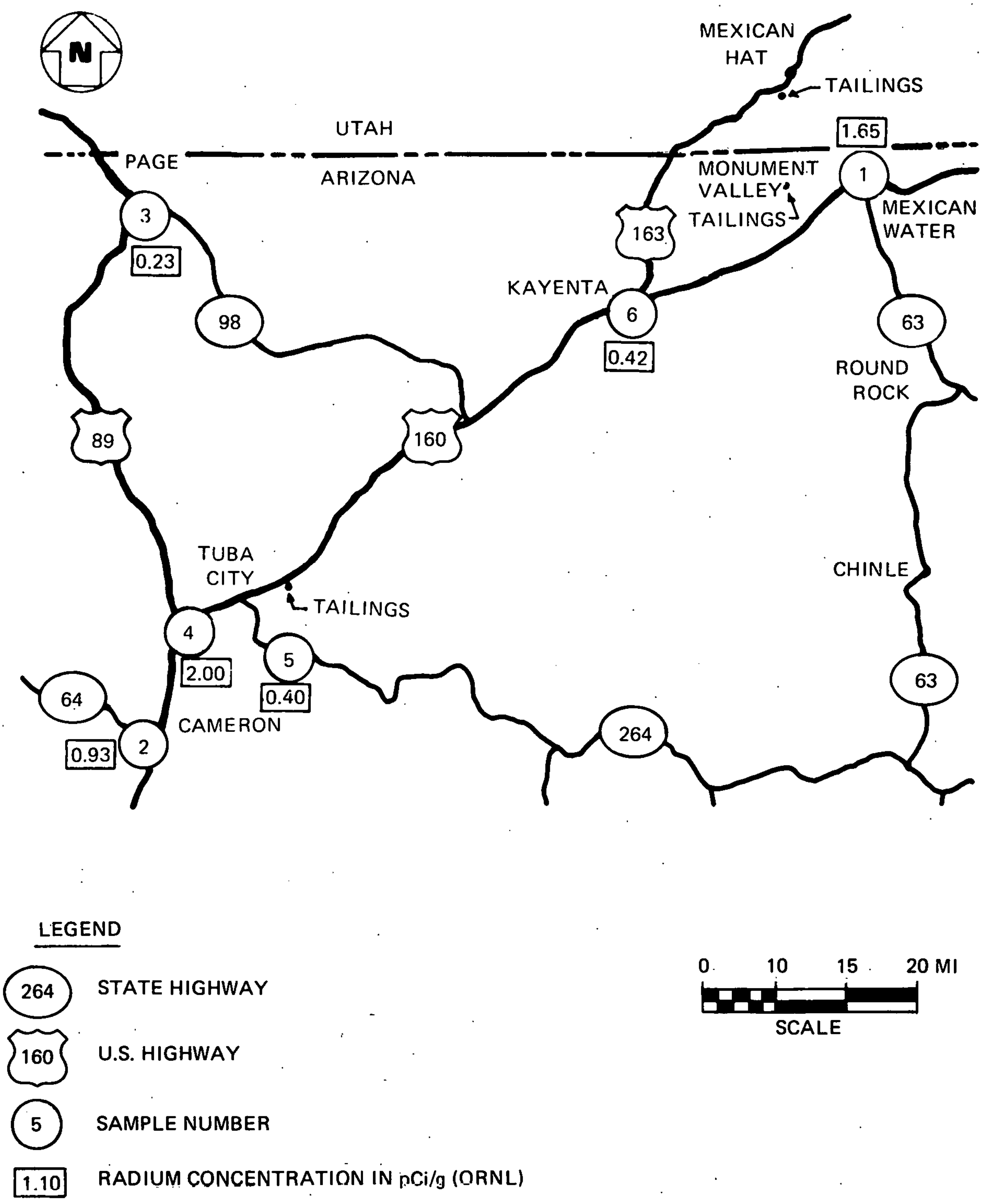

FIGURE 3-2. LOCATIONS FOR ^{226}Ra BACKGROUND SAMPLES

360-04 3/77

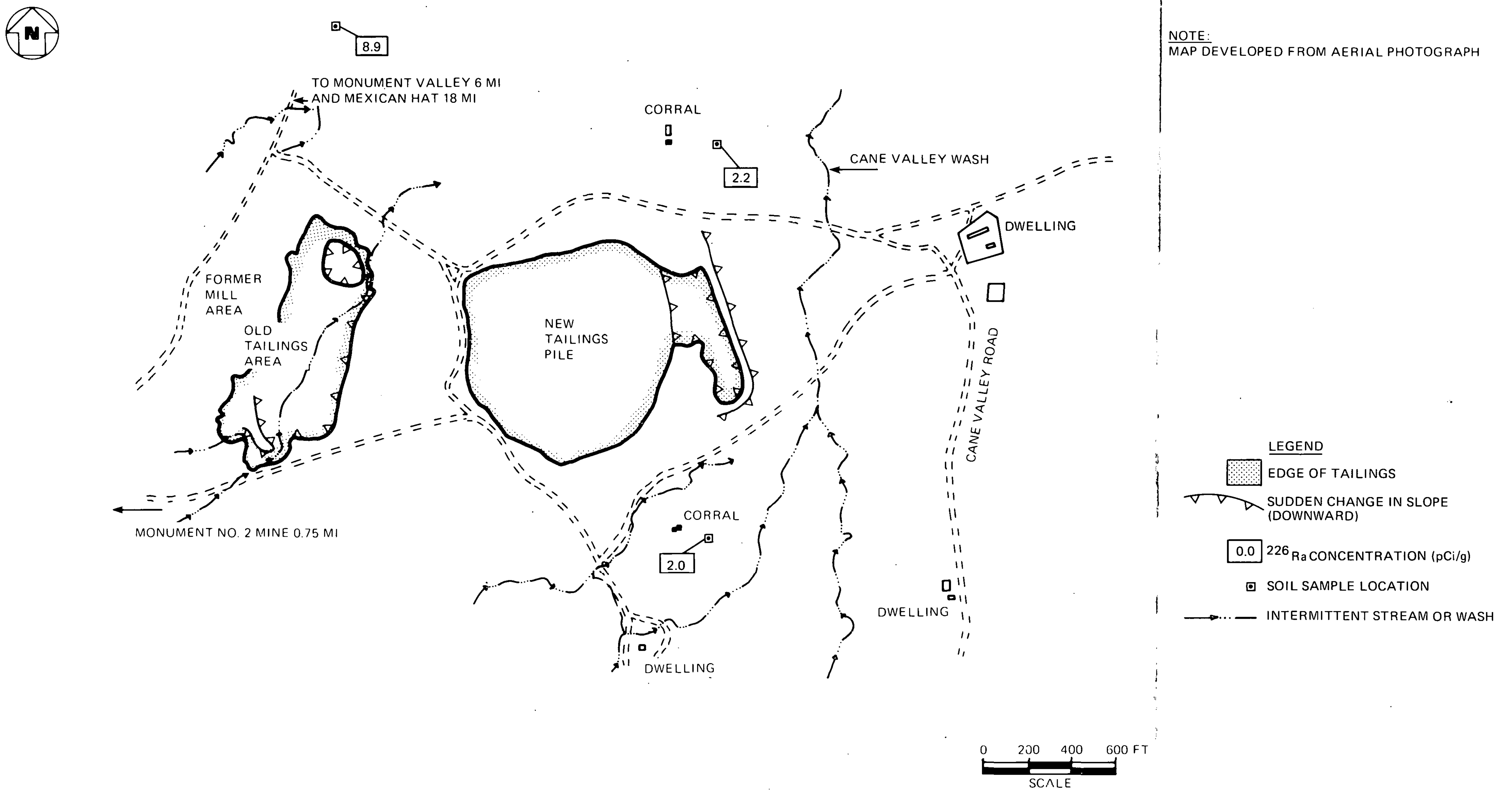

FIGURE 3-3. BACKGROUND SOIL SAMPLE LOCATIONS

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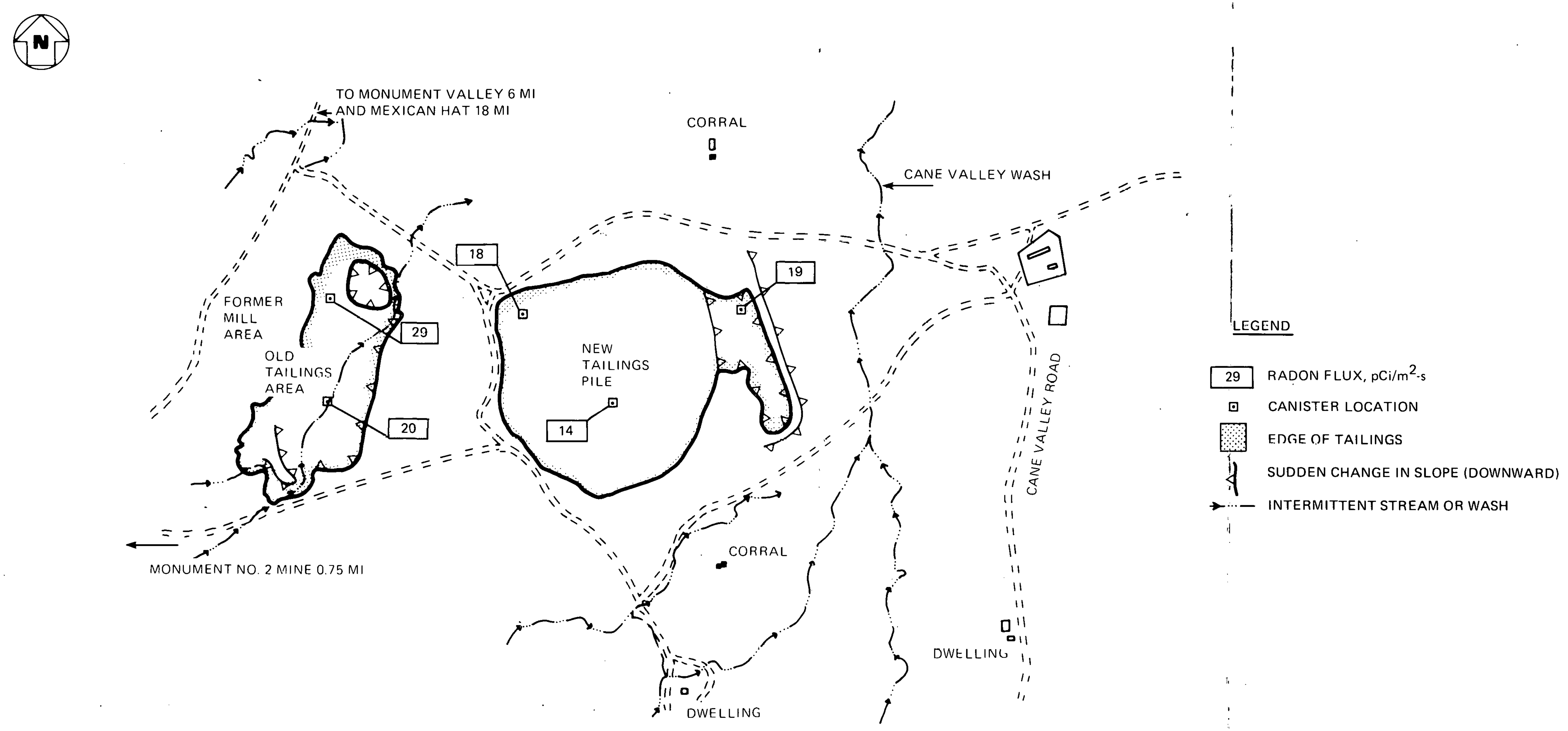

FIGURE 3-4. RADON CANISTER LOCATIONS AND FLUX VALUES

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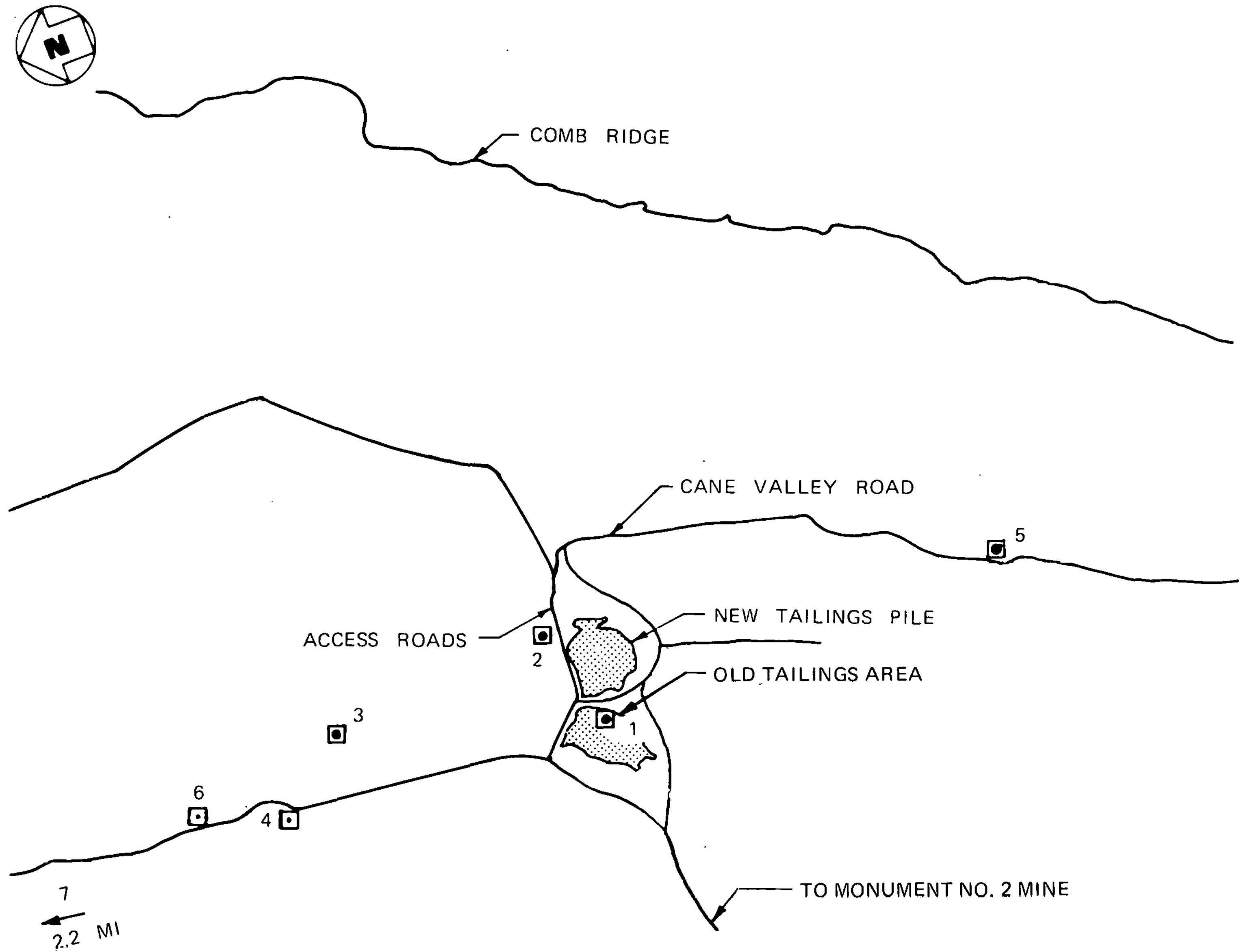

SITE NO.	24 HR OUTDOOR (pCi/l)	LOCATION
1	6.8	BETWEEN OLD AND NEW PILES
2	3.2	0.11 MI N E CORRAL
3	4.3	0.60 MI NORTH
4	0.7	0.83 MI NORTH
5	0.4	1.0 MI SOUTH
6	0.5	1.0 MI NORTH
7	0.6	2.2 MI NORTH

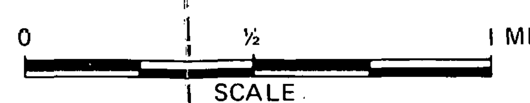

FIGURE 3-5. RADON CONCENTRATION IN VICINITY OF PILES

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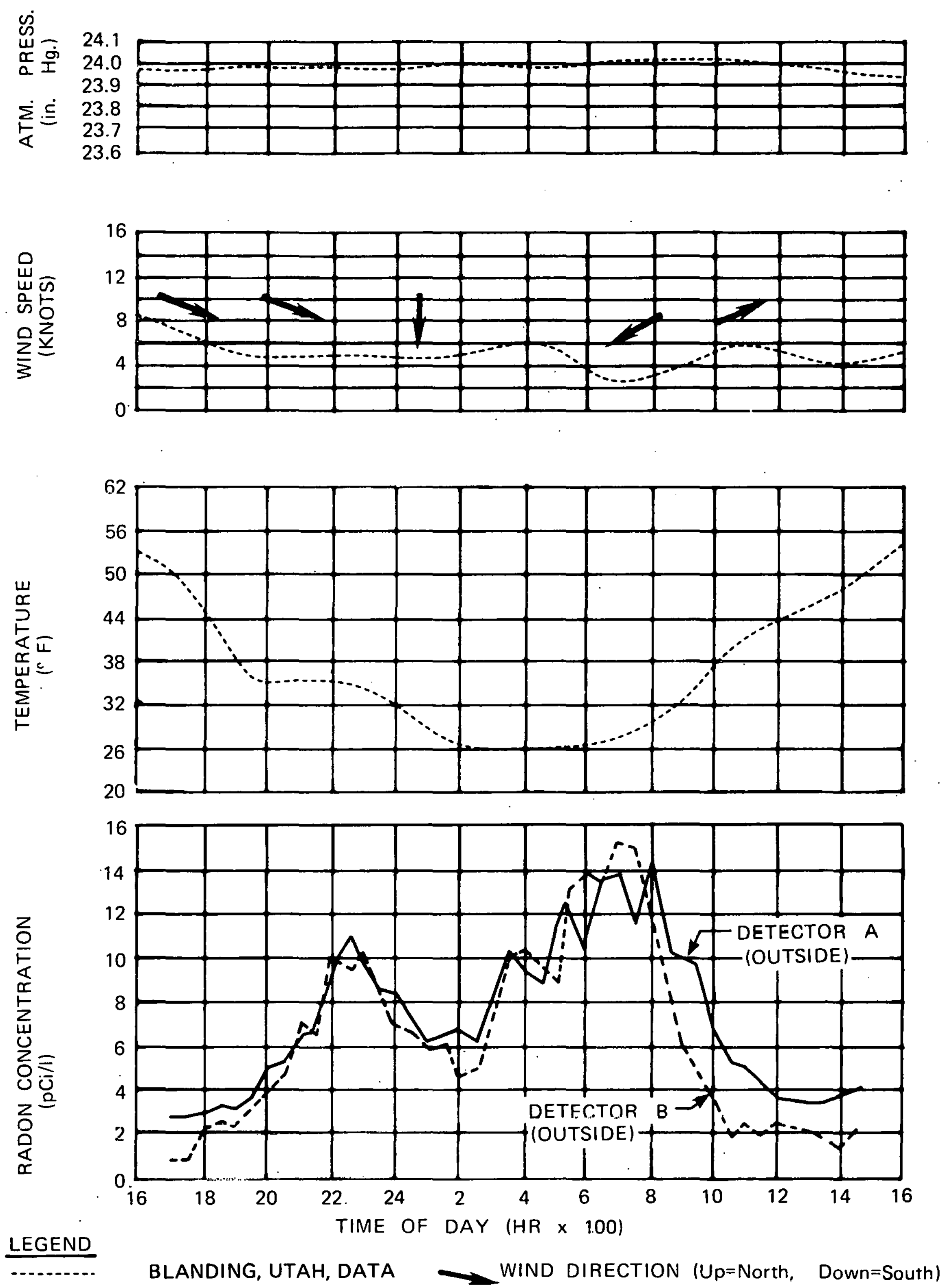

FIGURE 3-6. ^{222}Rn AND ATMOSPHERIC TRANSIENTS AT TAILINGS PILES ON MARCH 8-9, 1976

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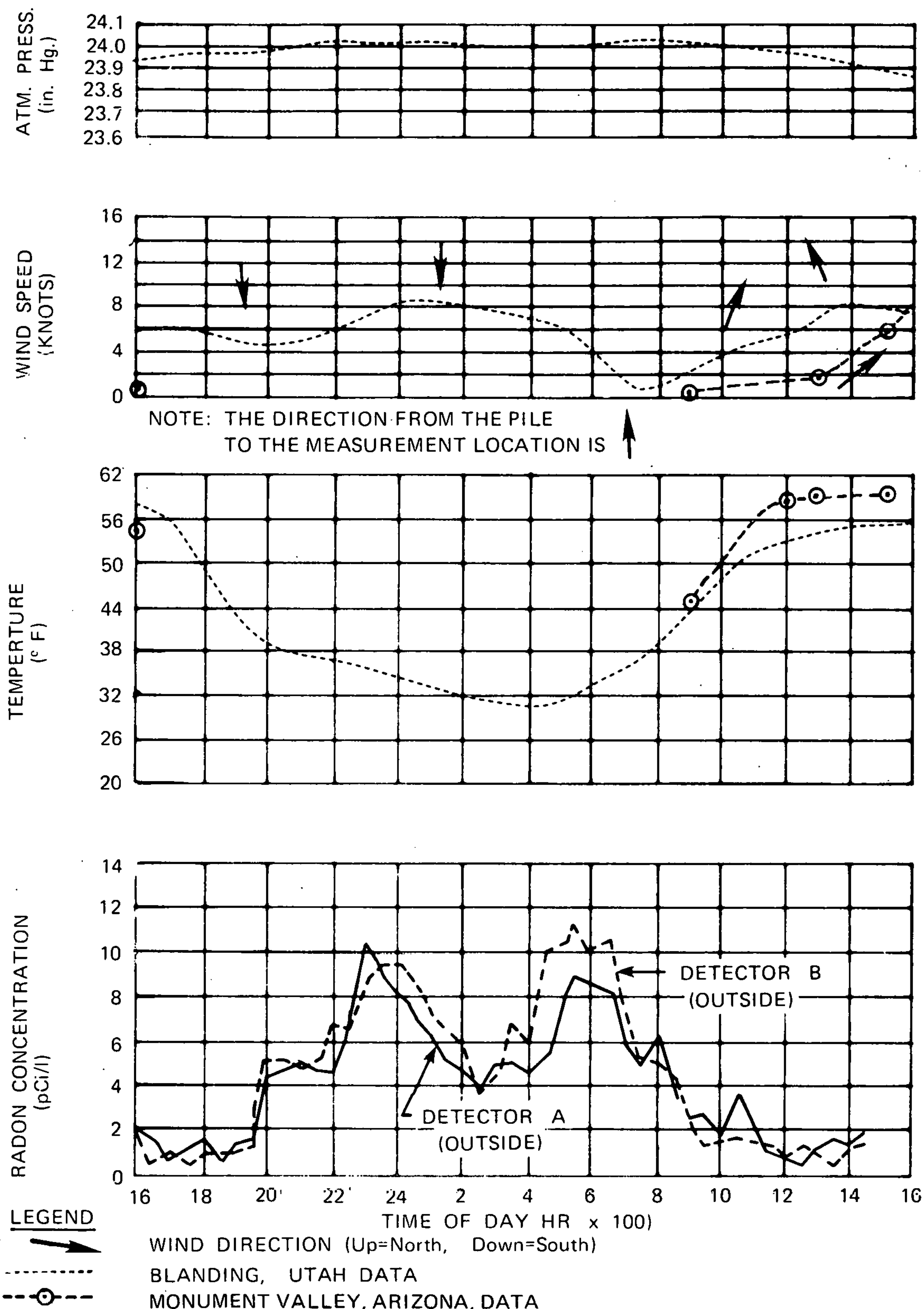

FIGURE 3-7. ^{222}Rn AND ATMOSPHERIC TRANSIENTS AT 0.6 MI NORTH OF PILES ON MARCH 9-10, 1976

360-04 3/77

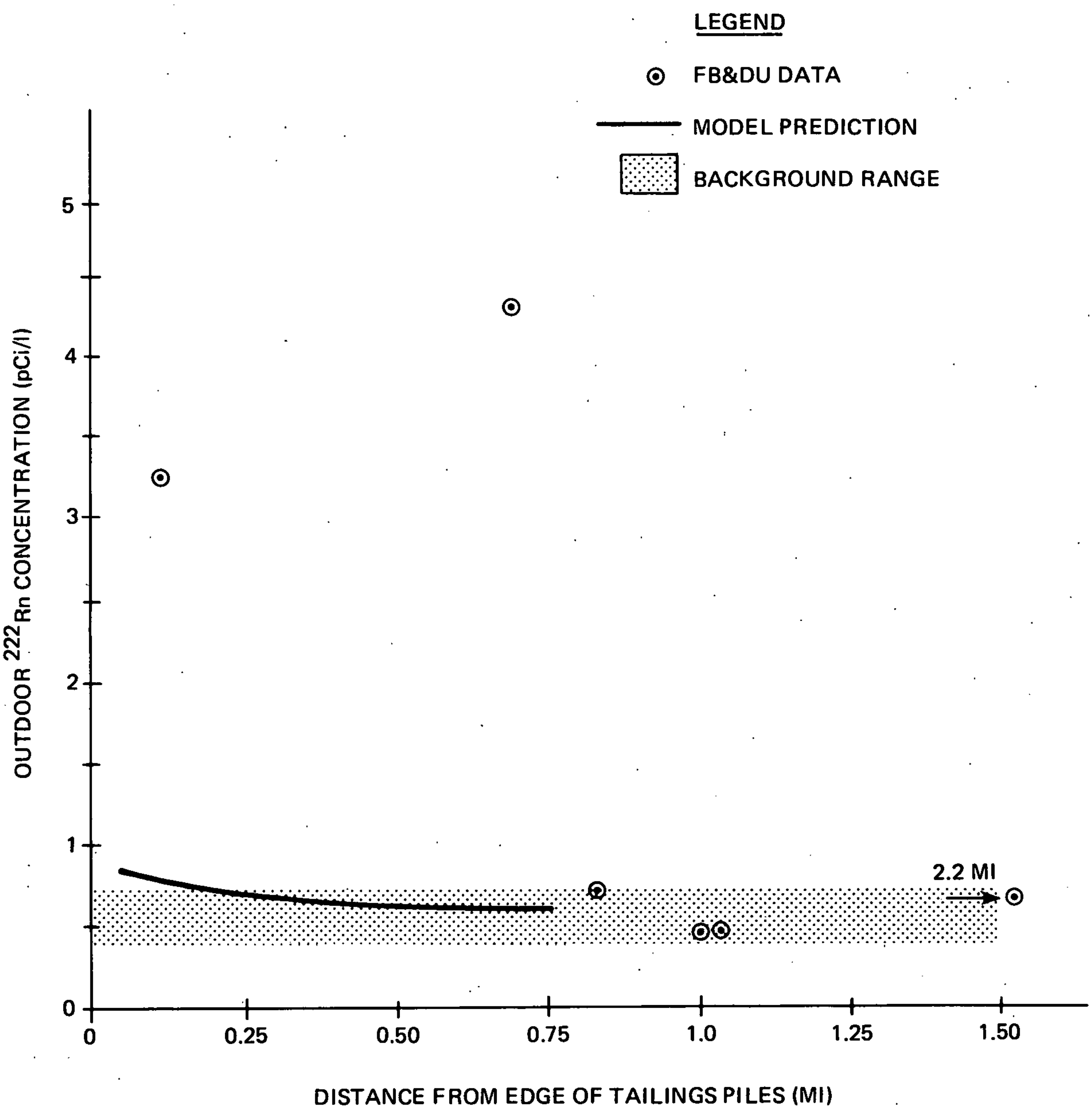

FIGURE 3-8. REDUCTION OF OUTDOOR ^{222}Rn CONCENTRATION WITH DISTANCE FROM THE TAILINGS PILES

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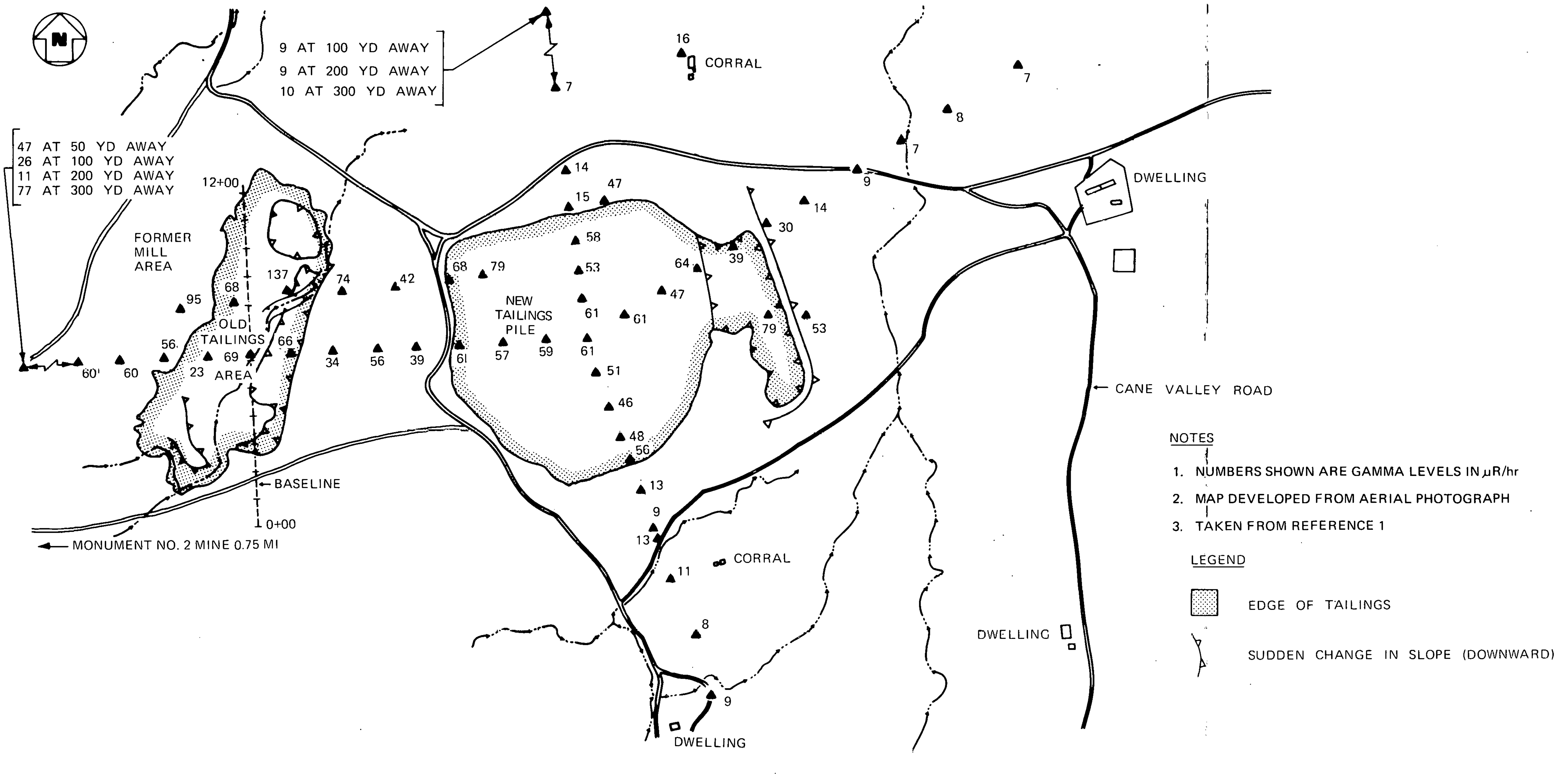
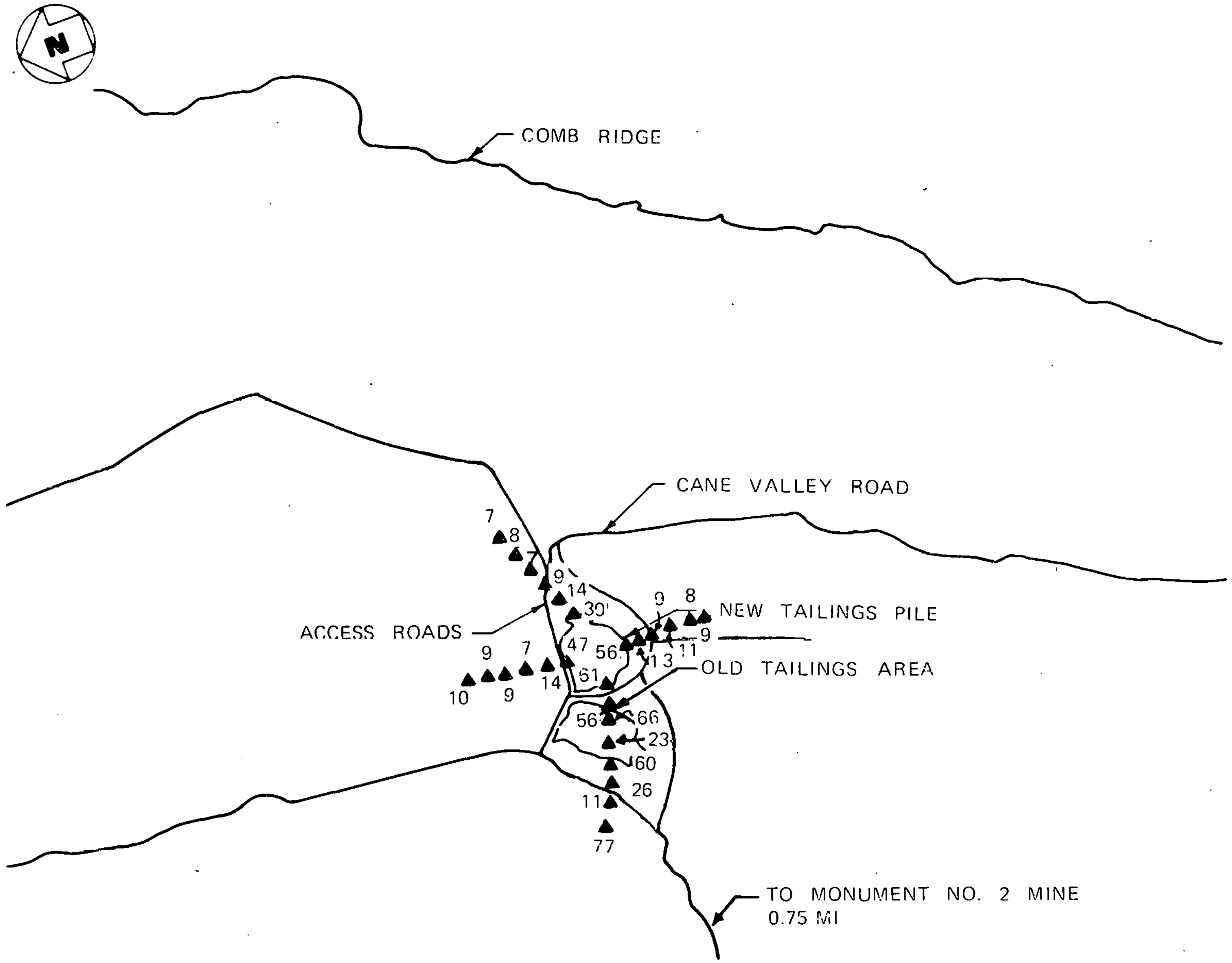


FIGURE 3-9. GAMMA LEVELS 3 FT ABOVE GROUND



NOTES

1. NUMBERS SHOWN ARE GAMMA LEVELS IN μR/hr
2. MAP DEVELOPED FROM AERIAL PHOTOGRAPH
3. TAKEN FROM REFERENCE 1

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

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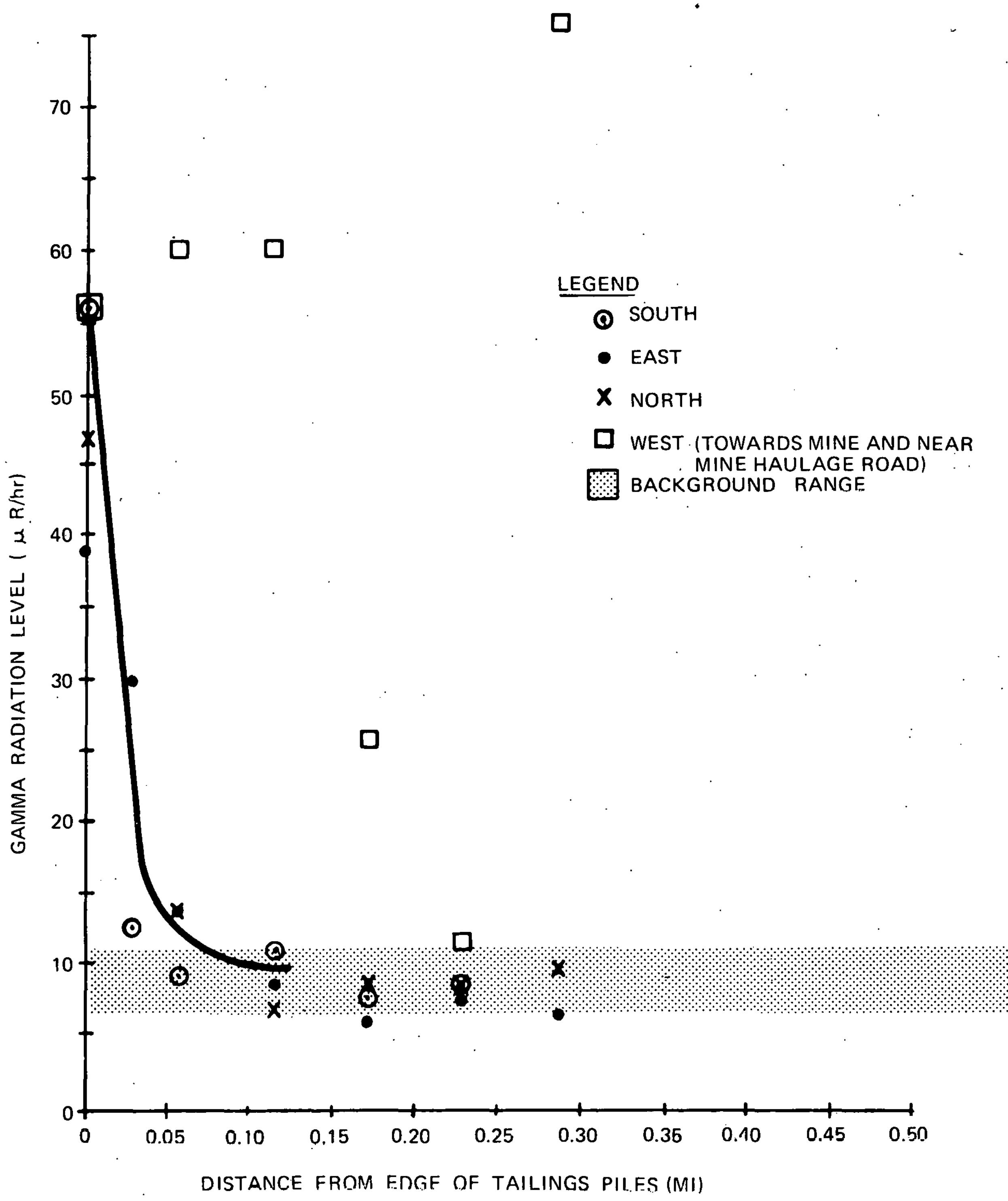

FIGURE 3-11. REDUCTION OF EXTERNAL GAMMA RADIATION LEVELS WITH DISTANCE FROM THE TAILINGS PILES

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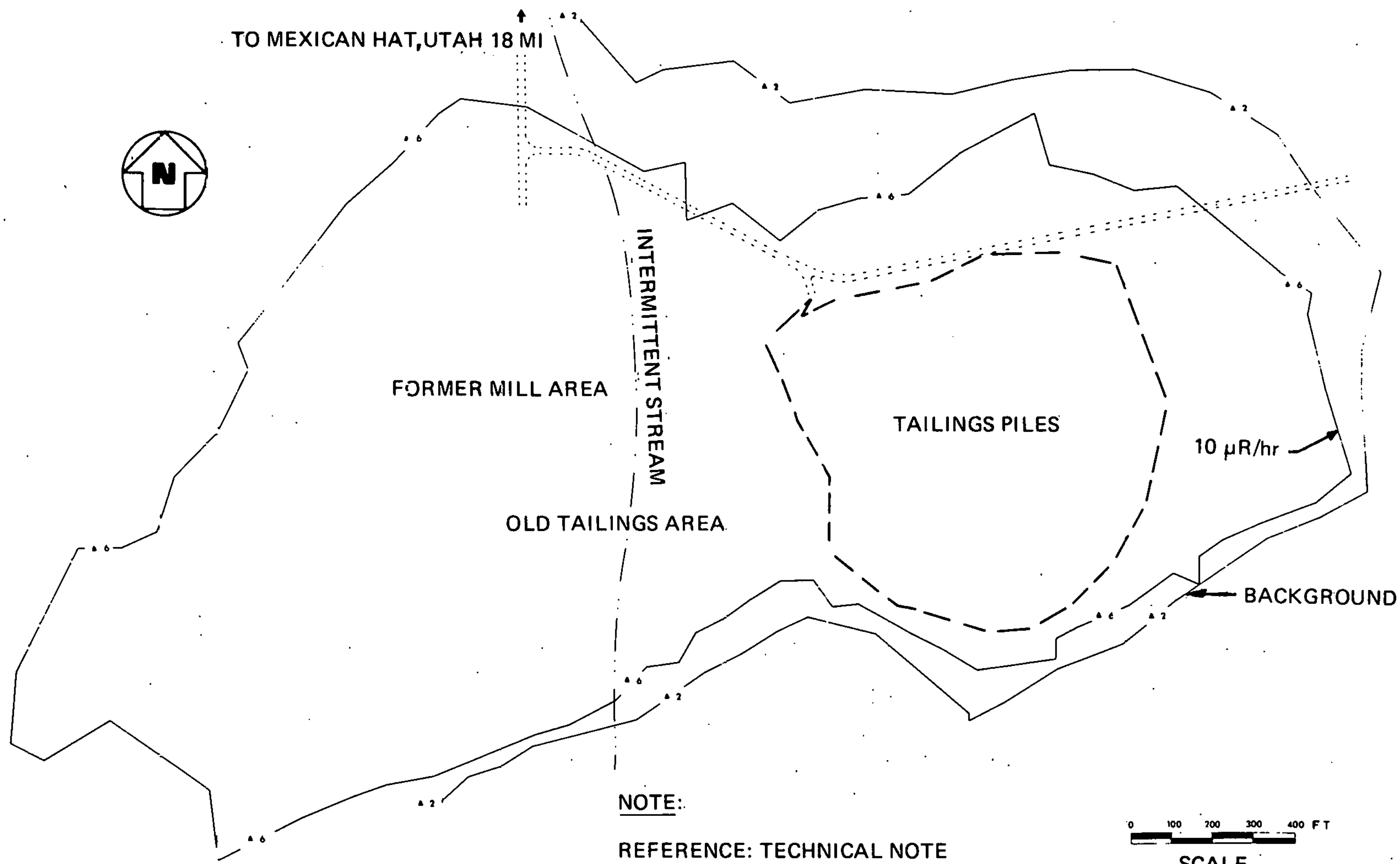

NOTE:

REFERENCE: TECHNICAL NOTE ORP/LV-75-5 "GAMMA RADIATION SURVEYS AT INACTIVE URANIUM MILLSITES," USEPA, LAS VEGAS, NEVADA, AUG 1975.
FIGURE 2 PAGE 39

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FIGURE 3-12. EPA GAMMA SURVEY SURROUNDINGS MILLSITE

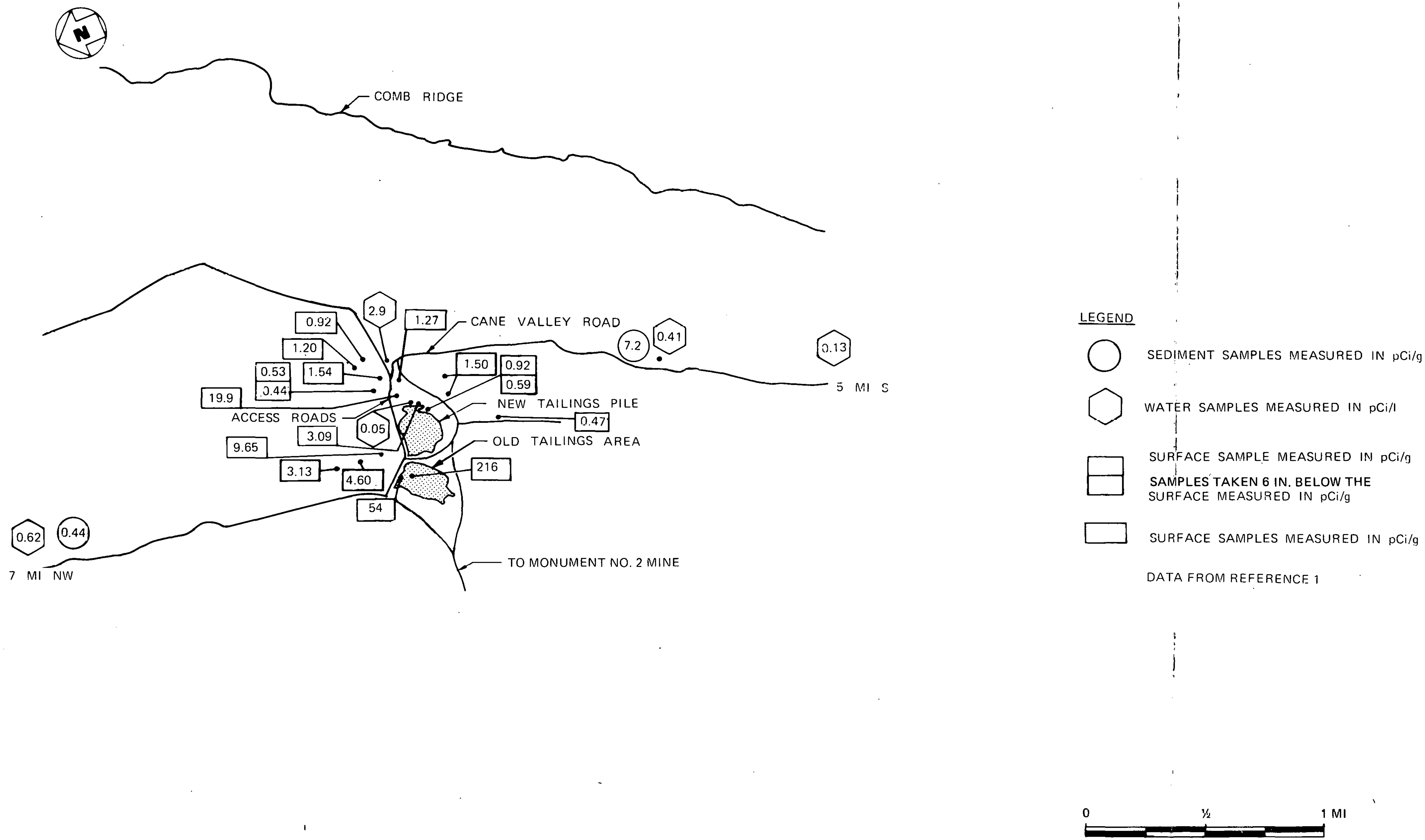

FIGURE 3-13. SURFACE AND SUBSURFACE RADIUM CONCENTRATIONS

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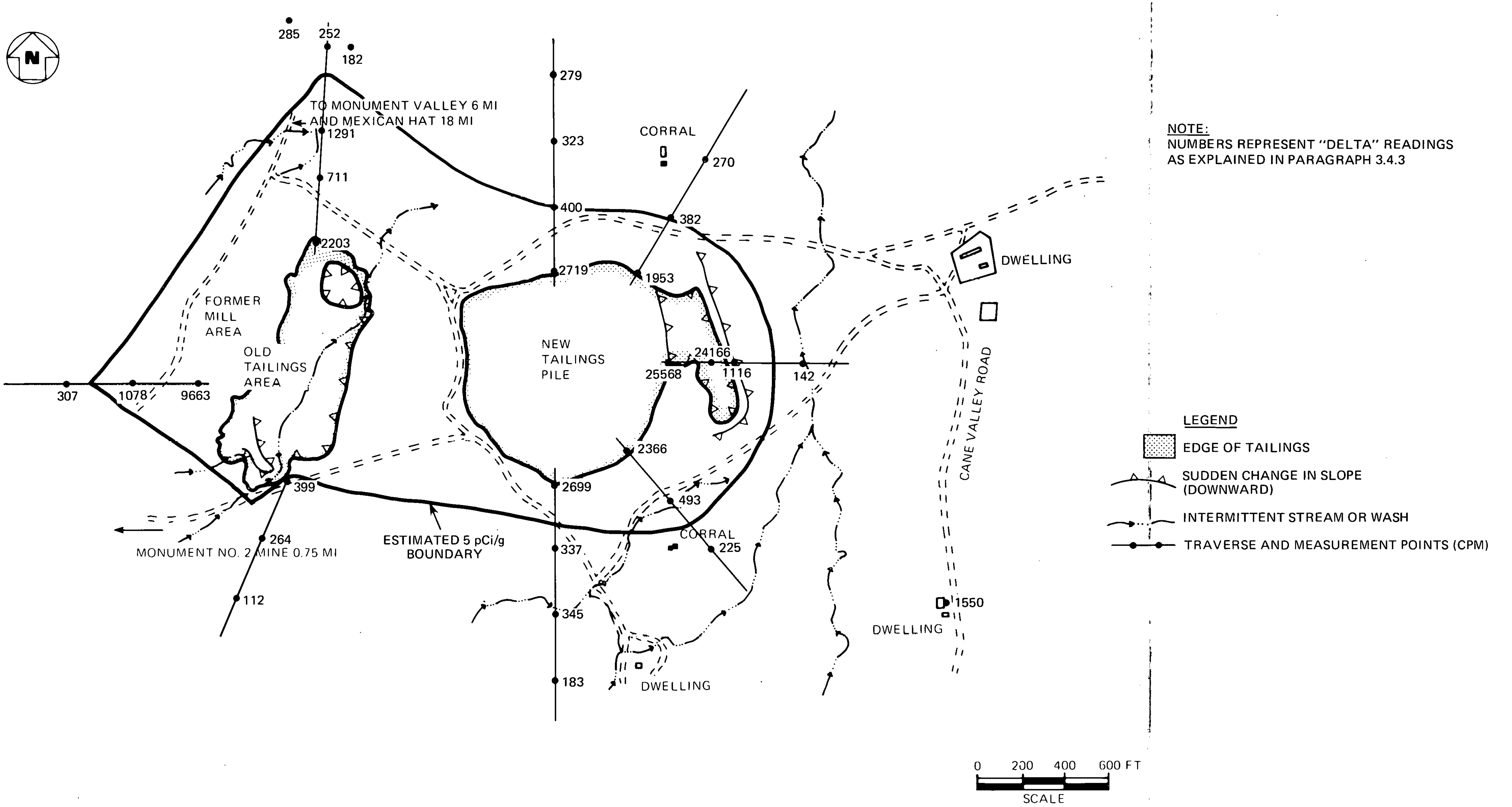

FIGURE 3-14. WINDBLOWN CONTAMINATION SURVEY

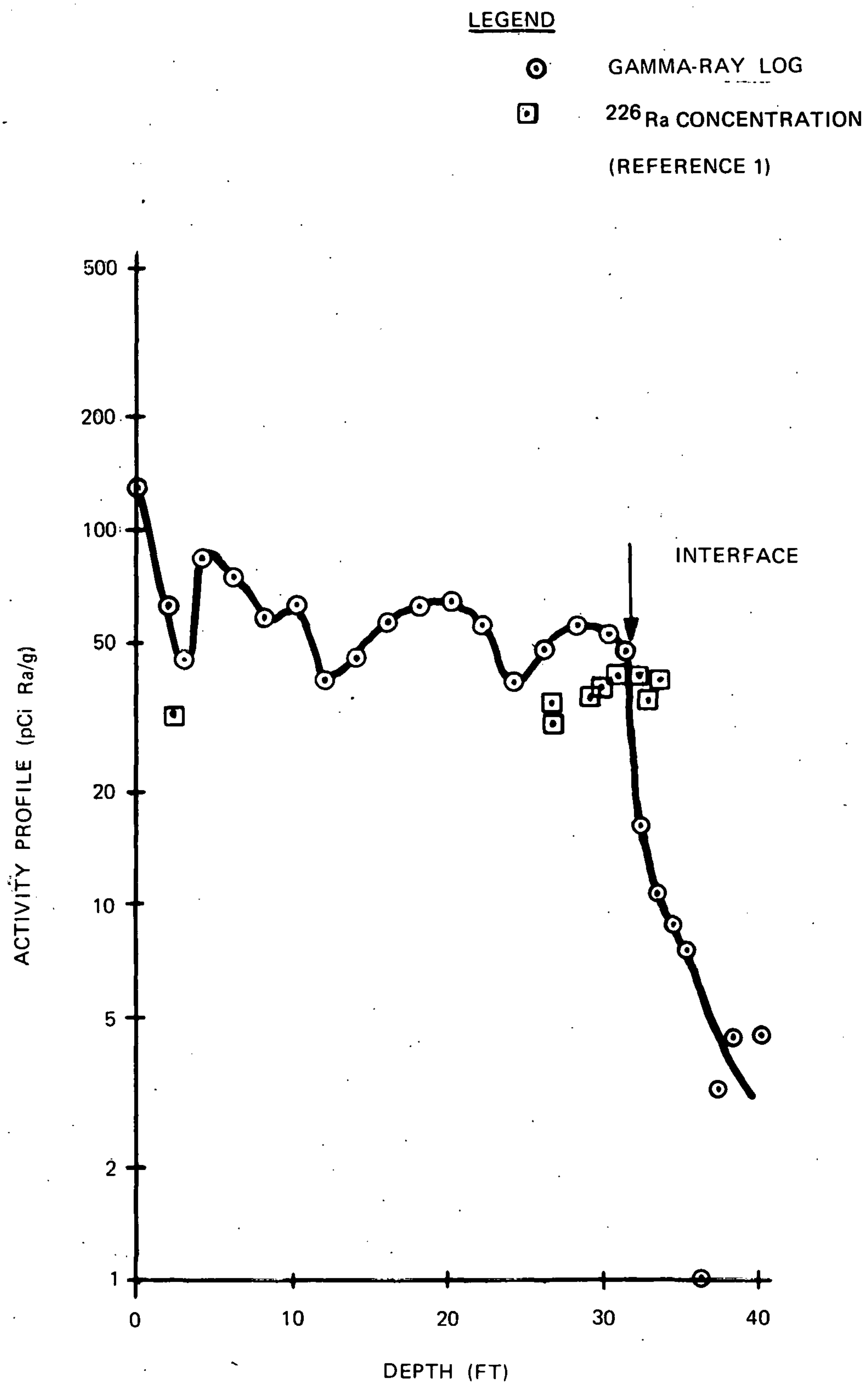

FIGURE 3-15. RADIOACTIVE PROFILE AT DRILL HOLE MVA-7

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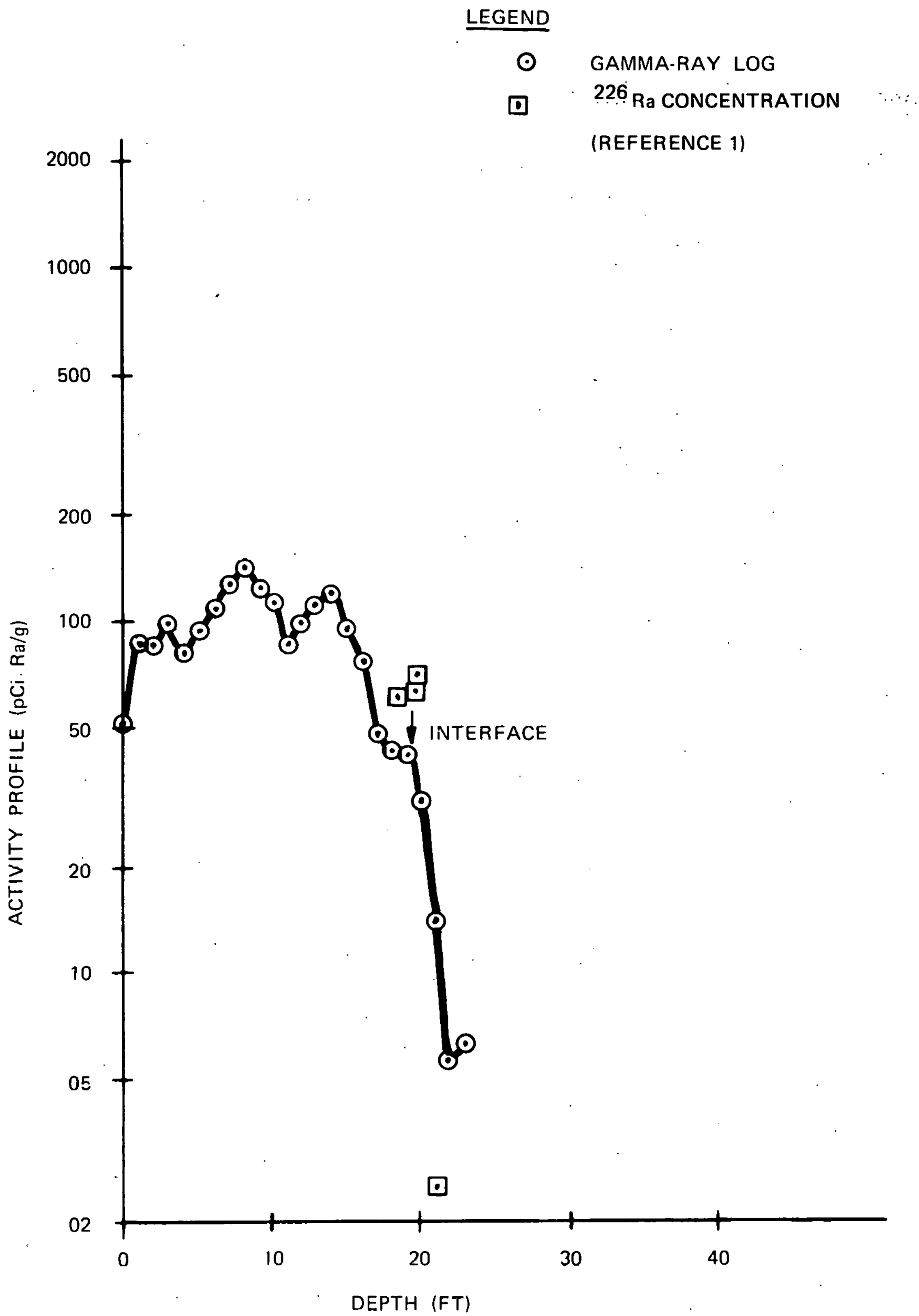

FIGURE 3-16. RADIOMETRIC PROFILE AT DRILL HOLE MVA-4

360-04 3/77

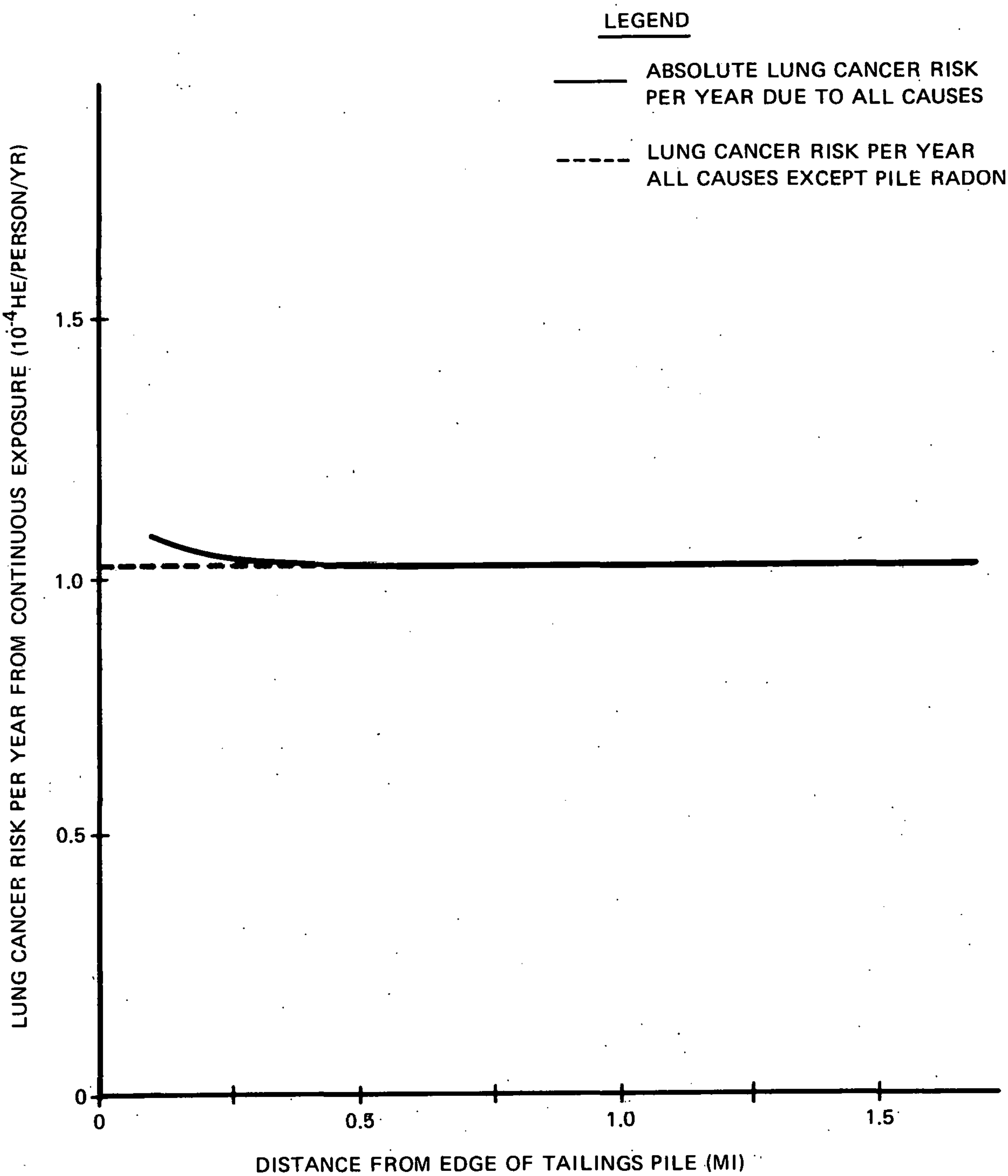

FIGURE 3-17. LUNG CANCER RISK FROM CONTINUOUS EXPOSURE TO RADON

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TABLE 3-1

NOTATIONS AND ABBREVIATIONS USED IN CHAPTER 3

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

Isotope Abbreviations:

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

Radiations:

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

TABLE 3-1 (Cont)

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

Note: Also see definitions of terms in Glossary.

TABLE 3-2

BACKGROUND RADIATION SOURCES IN SOIL FROM NORTHEAST ARIZONA[1]

Isotope (Decay Chain)	Average Value (pCi/g)	Range (pCi/g)
^{226}Ra (^{238}U)	0.95 ± 0.73	0.23 - 2.00
^{232}Th (^{232}Th)	0.67 ± 0.46	0.20 - 1.29
^{40}K (2)	19.8	10.7 - 21.5

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TABLE 3-3

RADIOACTIVE AIRBORNE PARTICULATE CONCENTRATIONS NEAR THE SITE[6]

Isotope	Maximum[a] Permissible Concentration pCi/l x 10^{-5}	New Pile[b] pCi/l x 10^{-5}	250 Ft North[b] of New Pile pCi/l x 10^{-5}	200 Ft South[b] of Old Pile pCi/l x 10^{-5}	Millsite[c] pCi/l x 10^{-5}
^{226}Ra	200	2.3	0.5	0.1	0.6
^{230}Th	8	4.5	0.7	0.6	1.1
Gross Alpha	--	10.3	7.0	1.6	10.3
Uranium	--	62	12	14	40

[a] 10 CFR 12, Maximum exposure to an individual in an unrestricted area.

[b] Continuous 24-hr samples on 10 consecutive days in May 1968.

[c] 16-hr samples on 10 consecutive days in May 1968.

TABLE 3-4

ESTIMATED HEALTH IMPACT FROM MONUMENT VALLEY TAILINGS
FOR AN AREA 0 TO 4 MILES FROM TAILINGS EDGE

Time Period	Population (Persons)	Total Pile-Induced RDC Health Effects/Yr	Background RDC Health Effects/Yr
1980	80	0.000018	0.0018
2005 (0.8% constant growth rate)	98	0.000023	0.0022
2005 (2.5% declining growth rate)*	110	0.000025	0.0025
2005 (4% declining growth rate)*	134	0.000031	0.0030

Growth Projection	25-Yr Cumulative RDC Health Effects: Pile-Induced	25-Yr Cumulative RDC Health Effects: Background
0.8% constant growth rate	0.00050	0.050
2.5% declining growth rate*	0.00056	0.056
4% declining growth rate*	0.00064	0.064

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

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CHAPTER 3 REFERENCES

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2. J.M. Hans, Jr.; EPA, ORP/LV; personal communication of preliminary data; Sep 1976.

3. 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.

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

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

6. R.N. Snelling; "Environmental Survey of Uranium Mill Tailings Pile, Monument Valley, Arizona"; Radiological Health Data and Reports; Oct 1970.

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

8. J.M. Hans, Jr., and R.L. Douglas; "Radiation Survey of Dwellings in Cane Valley, Arizona and Utah, for Use of Uranium Mill Tailings"; ORP/LV-75-2; EPA, Office of Radiation Programs; Las Vegas, Nevada; Aug 1975.

9. "Radiological Criteria for Decontamination of Inactive Uranium Mill Sites, Phase I"; USEPA/ORP; Washington, D.C.; Dec 1974; (See Reference 1, Appendix 1).

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

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

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

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

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

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

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

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

CHAPTER 4

SOCIOECONOMIC AND LAND USE IMPACTS

CHAPTER 4

SOCIOECONOMIC AND LAND USE IMPACTS

The Navajo Nation is divided into political divisions called "agencies" and subdivisions called "districts", which in turn are divided into "chapters", also known as "units". Cane Valley and the Monument Valley site are in the Tuba City Agency, which is divided into five districts, as shown in Figure 4-1. The tailings are in District 8, the most northeastern district in the agency. District 8 is further divided into four chapters. The Monument Valley tailings are in the northern part of the Kayenta Chapter, which is headquartered in Kayenta, Arizona. There are no villages within 10 mi of the site.

4.1 SOCIOECONOMIC BACKGROUND

Social and economic conditions of District 8 have been studied by several researchers.[1,2] Compared with the Navajo Nation as a whole, the mean education levels of District 8 are higher but the per capita income is lower. The Cane Valley area does not contribute significantly to employment of the Navajo Nation and the labor force is concentrated in the crafts, agricultural, and household categories.

4.2 POPULATION ESTIMATES

Based on the 1980 site visit, there are approximately 14 occupied dwellings in Cane Valley, of which four are located within 0.5 mi of the tailings. The locations of these four dwellings are shown in Figure 4-2. Assuming that there are 5.6 people per Navajo household, a total of approximately 80 people are estimated to reside in Cane Valley (within 4 mi of the site). The estimated 1980 population distribution as a function of distance and direction from the Monument Valley tailings piles is presented in Table 4-1.

Three possible growth rates for the area are shown in Figure 4-3. The smallest growth rate projects that the population of the area will increase at an annual rate of 0.8%/yr. This growth rate is typical of the United States as a whole and is presented as a lower bound on the projected population growth near the site. If this projection is realized, the population of the area will increase from 80 to about 100 people by the year 2005.

The highest growth rate projects that the population growth rate will decline linearly from the initial rate of 4%/yr to zero growth over a period of 25 yr. This growth rate is typical of areas with limited resources of water and irrigable land, which characterize this region. The 4% declining annual growth rate has been suggested as a likely upper bound on the population growth rates of areas such as Monument Valley.(1) If this growth projection is experienced, the population of the area will reach a static figure of about 134 people by the year 2005.

As shown in Figure 4-3, a 2.5% declining annual growth rate has been suggested as a probable growth rate for the area.(1) This projection estimates that the growth rate of the area will decrease linearly from its initial rate of 2.5%/yr to zero growth over a period of 25 yr. If this growth scenario is accurate, the population of the area will reach a static figure of 110 people by the year 2005.

4.3 LAND USE

The current land use in the Monument Valley tailings site area is best characterized as grazing land. Four dwellings are located close to the tailings. The remainder of the surrounding area, on which a dwelling or camp is occasionally visible, is used for very low density grazing.

Land use patterns are not likely to change in the area. There is a possibility of an increase in recreation and tourism in Monument Valley. Even an influx of tourism, however, would not involve the immediate vicinity of the tailings. In addition, the city of Kayenta to the south, not the tailings site area, will be the focal point of development in the chapter.

4.4 IMPACT OF THE TAILINGS ON LAND VALUES

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

All land is owned commonly by the Navajo Tribe. Individuals and families enjoy primary use rights to certain lands that have been established through historic grazing or other use. Such lands are called "assignments".(3)

Very few of the total assigned lands of the reservation have legally described boundaries; i.e., no specified boundary line has been agreed upon by adjoining neighbors, and overlaps of grazing use are common. However, severe violations of the generally acknowledged boundaries are seldom tolerated.(3) Since no fee ownership exists within the reservation boundaries, assignees do not hold titles to the land that they use.(3)

This lack of a traditional monetary market for land exchanges on the Navajo Reservation makes it difficult to calculate the dollar value of the site and its environs. However, recent land exchanges by the Navajo Tribal Council whereby they purchased off-reservation land and exchanged it for tribal land is one indication. Another indication is the recent lease payments for Navajo lands projected onto land values. Comparisons with land values off the reservation near Mexican Hat, Utah, might be an indication of the worth of the Monument Valley site. Also, by assigning a monetary value to sheep production per acre of land, and by translating this value into capital-valued land, another cash valuation may be determined. Considering the aforementioned methods, the distance of the site from a paved highway, and the absence of utilities (e.g., water, electricity, sewage, natural gas), the probable zoning of the site would be for agriculture.

The Navajo Land Administration estimated a value of \$55 to \$65/acre on the grazing land in the tailings site area. These figures could increase to \$300 to \$350/acre if a mineral inventory currently being conducted establishes that there are useful minerals on or near the site.

The presence of the tailings limits the use of the actual site for grazing or other purposes. However, the substantial amount of neighboring grazing land keeps demand for grazing on the site low. The lack of buildings at the site, the inaccessibility by rail, air, or paved road, and the competition from more populated areas contribute to a continuing low demand for use of the tailings area.

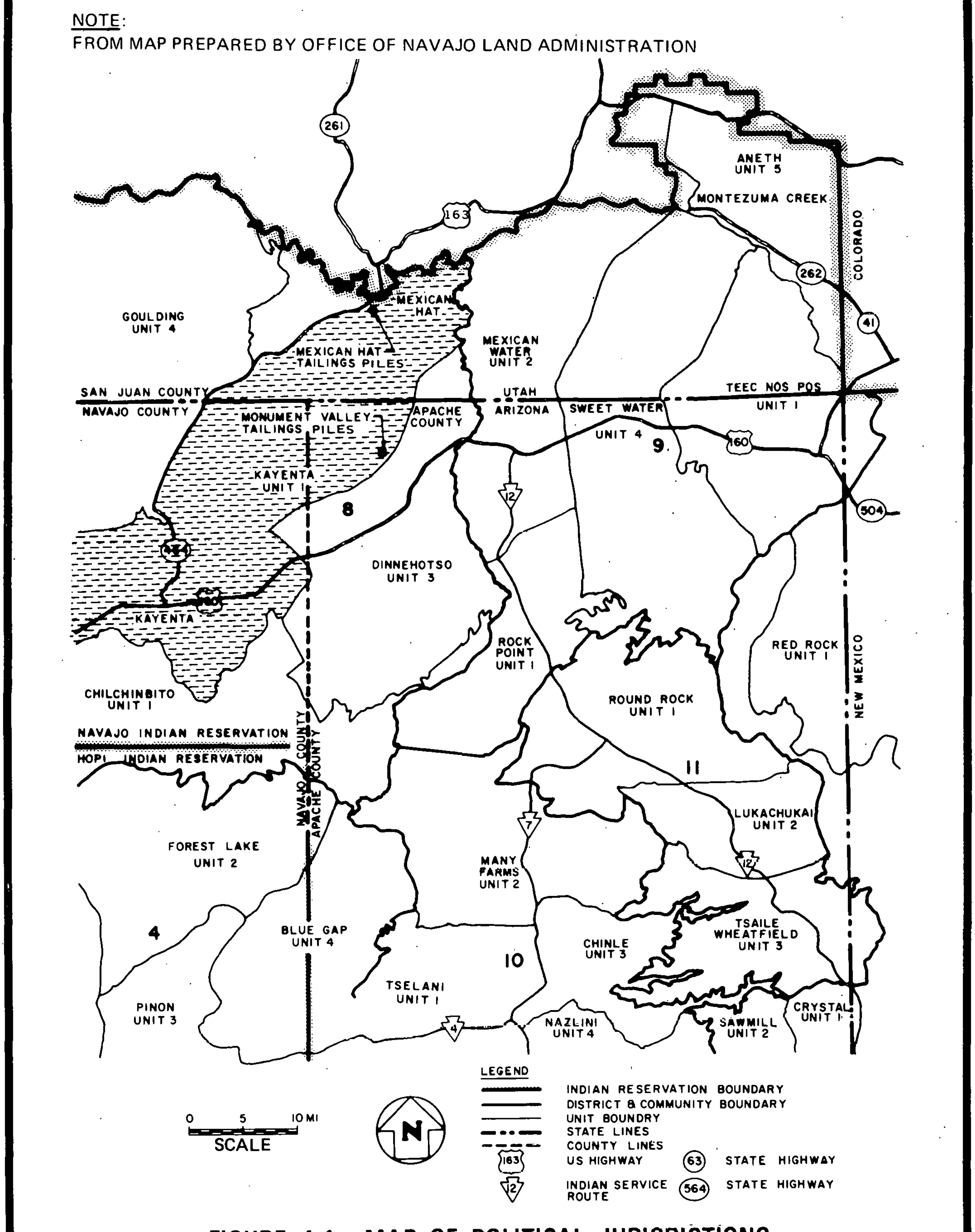

FIGURE 4-1. MAP OF POLITICAL JURISDICTIONS

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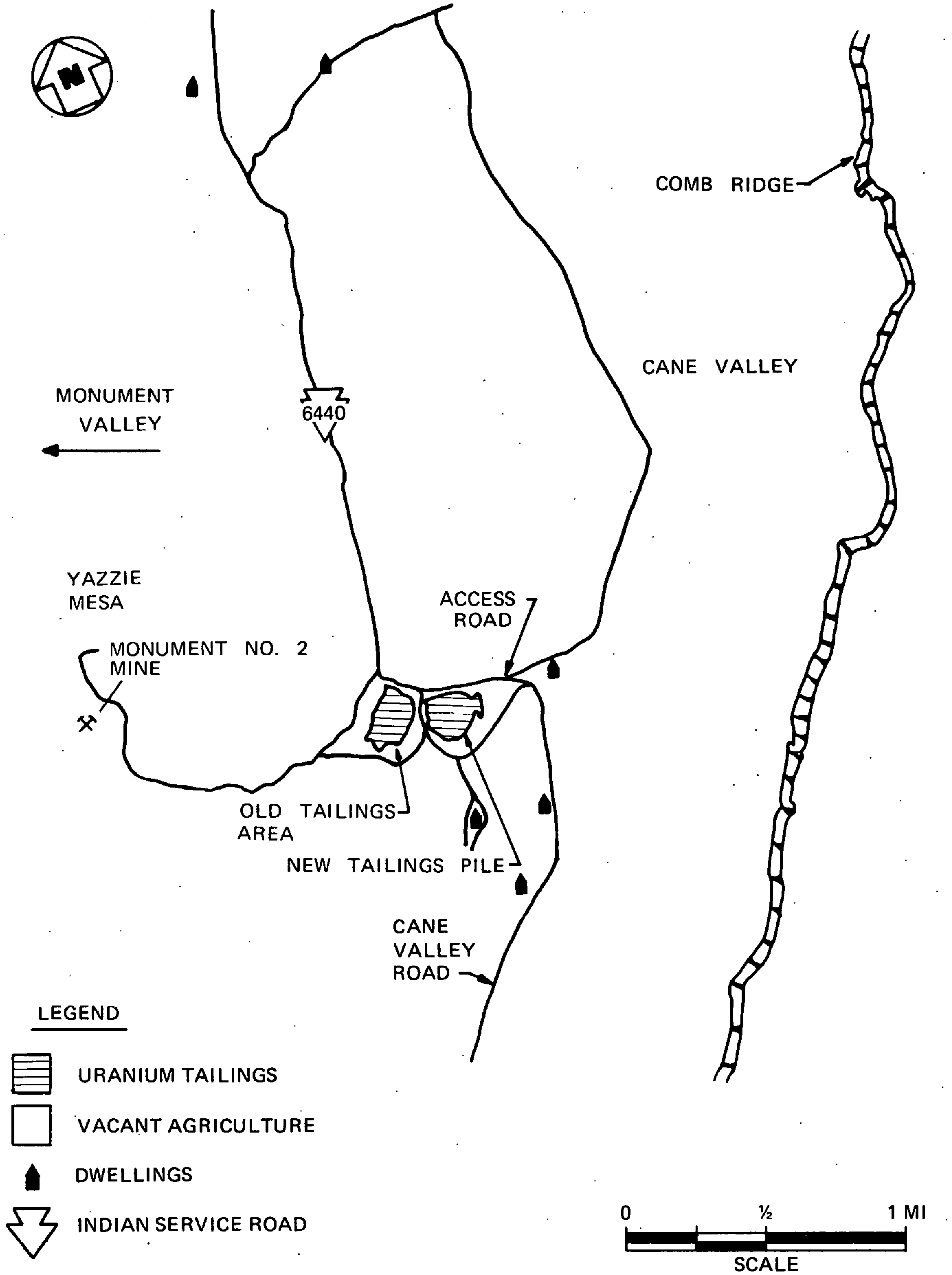

FIGURE 4-2. VICINITY LAND USE

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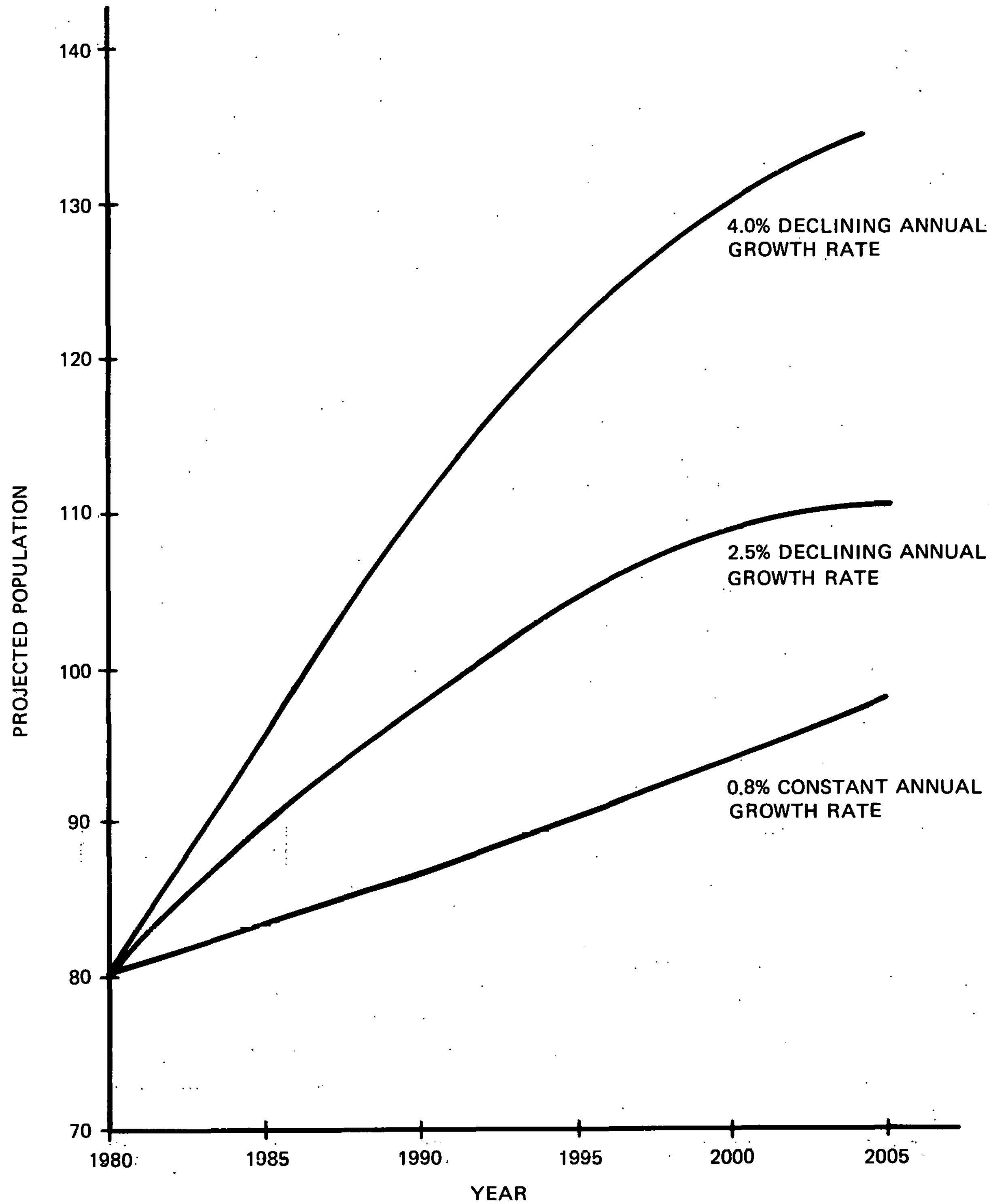

FIGURE 4-3. POPULATION PROJECTIONS

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TABLE 4-1

ESTIMATED 1980 POPULATION DISTRIBUTION

Number of People	Direction and Radial Distance from Tailings Piles
6	South, 0.25 mi
6	East, 0.5 mi
6	Southeast, 0.5 mi
6	South-southeast, 0.5 mi
6	North, 0.75 mi
6	Southwest, 0.75 mi
17	South, 1 mi
5	North, 3 mi
5	North, 3.5 mi
17	North-northeast, 4 mi
80 Total	

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CHAPTER 4 REFERENCES

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CHAPTER 5

RECOVERY OF RESIDUAL VALUES

The tailings at the Monument Valley site are the waste products of heap leach and upgrader operations. High grade ore was shipped directly from the Monument No. 2 mine to the mill at Durango, Colorado, and later to the mill at Shiprock, New Mexico. Ore that was too low grade to bear the cost of shipment was upgraded in a small plant near the mine. At first the process was a sand-slime separation, the coarse sands being rejected to waste and the higher grade slimes being shipped to the mill. Subsequently, equipment was installed to batch leach the previously discarded sands, and additional low grade ore was treated by heap leaching in shallow beds. The tailings that now remain on the site have a low uranium content, averaging about 0.006% U_3O_8 based on assays of composite samples of the two tailings piles on the site. Table 5-1 gives the complete analyses of these samples. The "old tailings pile" sample is the residue from heap leach operations. There are about 100,000 tons of this material. The "new tailings pile", comprising about 1,100,000 tons, is the product of the batch leaching of the sands. The vanadium content of the combined tailings averages 0.19% V_2O_5. There are no other metals present in significant concentrations. A more comprehensive sampling would be necessary if reprocessing were under serious consideration.

No amenability testing has been performed on Monument Valley tailings to determine the recovery of uranium and other metals that could be achieved in a reprocessing operation. In the absence of specific testing, the uranium recovery from retreatment of the tailings is estimated from the graph provided by the DOE Grand Junction Office, as shown in Figure 5-1. For the purpose of this chapter it is assumed that the uranium content of 0.0062% U_3O_8 and vanadium content of 0.19% V_2O_5 indicated by the composite samples are correct. The uranium recovery that can be achieved using a conventional milling process is about 33%, or 0.041 lb U_3O_8/ton of tailings. If the tailings are pelletized with acid and heap leached, the recovery would be about 25%, or 0.031 lb U_3O_8/ton. By normal heap leaching the recovery would be about 18% or 0.022 lb. At November 1980 prices of $28/lb of U_3O_8, the value of the uranium recovered would be $0.56 to $1.15/ton of tailings processed. The vanadium in the Monument Valley tailings, assuming a recovery of 40% and a price of $3/lb of V_2O_5, would be worth about $4.60/ton of tailings. As will be shown in the following analysis, the prospects for profitably reprocessing the Monument Valley tailings are poor.

5.1 PROCESS ALTERNATIVES

There are three principal alternatives for the reprocessing of tailings:

(a) Heap leaching

(b) Treatment at an existing mill

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

5.1.1 Heap Leaching

There are two process variations in use for heap leaching. In the first method, which has been used successfully to treat low-grade ore that otherwise would not warrant treatment, a pad is prepared with an impermeable layer at the bottom. A pipe drainage system is laid down and covered with gravel and sand. The tailings are deposited on this base in a layer up to about 20 ft thick. The surface of the tailings is then contoured into shallow basins to contain the leach solution. An acid solution, sometimes with added oxidant, is allowed to flow into the surface basins and to percolate through the bed. The solution collected is treated, usually by ion exchange or solvent extraction, to recover the uranium. When present, vanadium can be recovered in a second solvent extraction circuit. The metal 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 uranium is considerably lower (roughly half) than by conventional plant processes, as shown in Figure 5-1.

In the second method, 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 other values. 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 by leachate. 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. Due to the coarse particle sizes of the Monument Valley tailings, percolation rates would be expected to be good, but amenability testing would be necessary to determine whether or not any heap-leaching method can be used on this material, in view of its very low grade.

5.1.2 Treating in an Existing Plant

For reprocessing in an existing conventional plant to be economically feasible, a mill with significant excess capacity must be located reasonably close to the present tailings site. The mill also must 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 1,100,000 tons of tailings, there are large quantities of contaminated waste at the Monument Valley site, including contaminated soils that will be removed in the cleanup of land in the vicinity of the site.

The site has only fair access, and the dirt roads near the site cannot handle much traffic. Trucks could remove material from the site at a rate of about 1,000 tons/day. At this rate, all tailings and contaminated materials could be removed from the site in about 4.5 yr. The nearest operating mill is about 60 mi north, near Blanding, Utah. The transportation costs would far exceed the value of the metals that could be recovered from the Monument Valley tailings.

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 Monument Valley tailings would feed a 1,000 ton/day plant for about 4 yr. Normally, amortization of a plant is based on planned operation for 10 to 20 yr. The immediate area in which this millsite is located is not a favorable one for development of new reserves. Thus, it is unlikely that new reserves will be found to provide additional feed to such a mill.

5.2 MONUMENT VALLEY RECOVERY ECONOMICS

The subjects 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[2] rose from $30/lb of U_3O_8 in November 1975 to $43/lb in November 1977 and essentially held constant until the end of 1979. The price dropped precipitously to $28.50/lb of U_3O_8 by September 1980 and to $25/lb early in 1981. Prices in individual long-term uranium sales contracts have varied over a broad range.

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

5.2.2 Escalation of Plant Construction Costs

The estimated construction costs of both heap-leach plants and conventional mills without crushing and grinding facilities, as provided by the DOE Grand Junction, Colorado Office, were included as figures in the Phase II - Title I Engineering Assessment report.[1] The costs were adjusted to January 1977. Since that time, 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.[4] 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[5] publishes reports quarterly on various construction cost indexes. The following data are derived from this source:

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

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

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

From the above indexes, an increase in plant construction cost of 25% from January 1977 to mid-1980 has been applied as a conservative estimate. As indicated in Figure 5-2, the capital cost of a 1,000 ton/day heap-leach facility would be about $7.7 million. As indicated in Figure 5-3, the cost for a conventional mill of similar capacity would be about $9.7 million. If these capital costs were to be amortized on the Monument Valley tailings only, the unit costs would be $6.40 to $8.10/ton, or from $200 to $210/lb of U_3O_8 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 March 1977 Engineering Assessment report(1) the direct operating costs of a 1,000 ton/day facility were estimated at $3.20 and $5.60/ton for heap leach and conventional acid leach mills, respectively. However, R.B. Coleman(4) reports that 1980 operating costs of conventional mills are in the range of $8.70 to $18.40/ton.

Ranchers Exploration and Development Corporation reported their operating costs for heap leaching at Naturita, approximately a 1,200 ton/day facility, at about $34/lb of U_3O_8

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

Considering the differences in plant designs, it is estimated that average mill operating costs have increased by a factor of 2.5 from the January 1977 costs to mid-1980. This would result in operating costs for Monument Valley tailings in a 1,000 ton/day conventional mill of about \$14/ton, or \$340/lb of U_3O_8 recovered (assuming 0.041 lb recovered/ton). For a heap-leach plant of the same size, the corresponding figures would be \$11/ton and \$355/lb recovered. In view of these operating costs, which far exceed the market price, no detailed analysis of optimum plant size is warranted.

5.2.4 Competitive Market Factors

The average grade of ore processed in conventional mills has decreased from 0.15% U_3O_8 in 1977 to 0.11% in 1979. The average recovery rate for the industry has been 91 ± 1% during this period.(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 Monument Valley 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 the tailings.

5.3 CONCLUSION

It is concluded that the processing of Monument Valley 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 attractive at present market prices for these metals, nor is it likely to be practicable for the foreseeable future. A substantial improvement in metal recoveries over those used as a basis for this analysis and an improvement in prices by a factor of 20 or more would be needed to make the reprocessing economically attractive. For processing this material, assuming a plant of about 1,000 tons/day capacity, the cost of the uranium recovered would be about \$550/lb of U_3O_8. A comparison of costs by process method is given below. Coincidentally, at the assumed recovery rates for uranium, the two processes appear to have nearly the same cost per lb of U_3O_8 recovered.

	Conventional Plant		Heap Leach	
	\$/ton	\$/lb U_3O_8	\$/ton	\$/lb U_3O_8
Capital Cost	18.10	200	6.40	210
Operating Cost	14.00	340	11.00	355
Total	32.10	540	17.40	565

The cost is, of course, very sensitive to the percent recovery of metal values, which can only be roughly estimated in the absence of amenability tests on representative samples. Capital costs might be lowered if another source of feedstock could be provided for the plant, but prospects for development of new ore sources near the site are not considered favorable.

Vanadium recovery will not aid reprocessing economics, as the cost to recover vanadium is about the same as its price. At an estimated cost of \$4.50/ton to process the tailings for vanadium and an expected recovery of 1.5 lb/ton treated, the cost would be \$3/lb of V_2O_5. The market price is also about \$3/lb of V_2O_5.

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

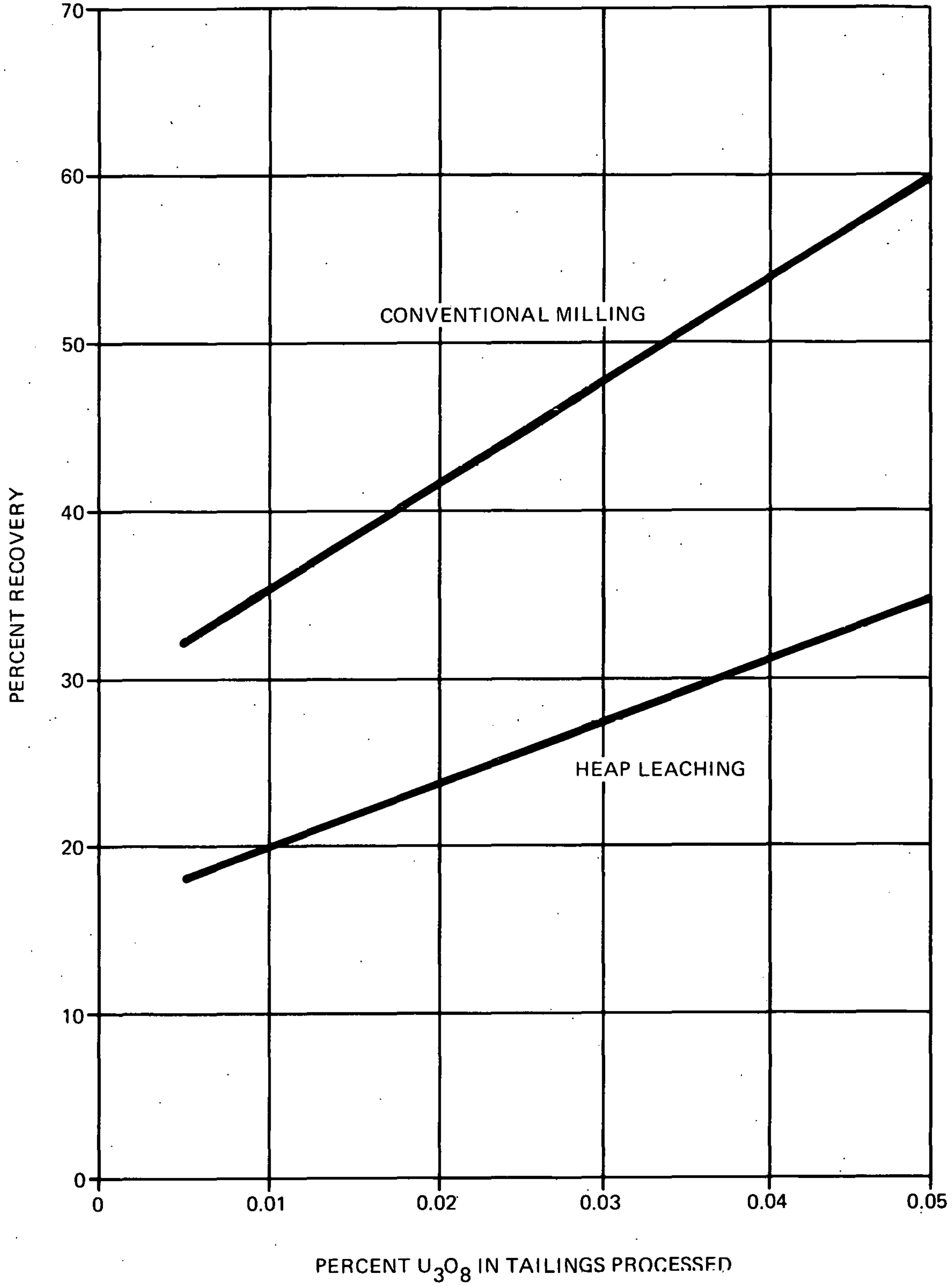

FIGURE 5-1. URANIUM RECOVERY FROM MILL TAILINGS AS A FUNCTION OF U_3O_8 CONTENT IN TAILINGS

360-04 2/81

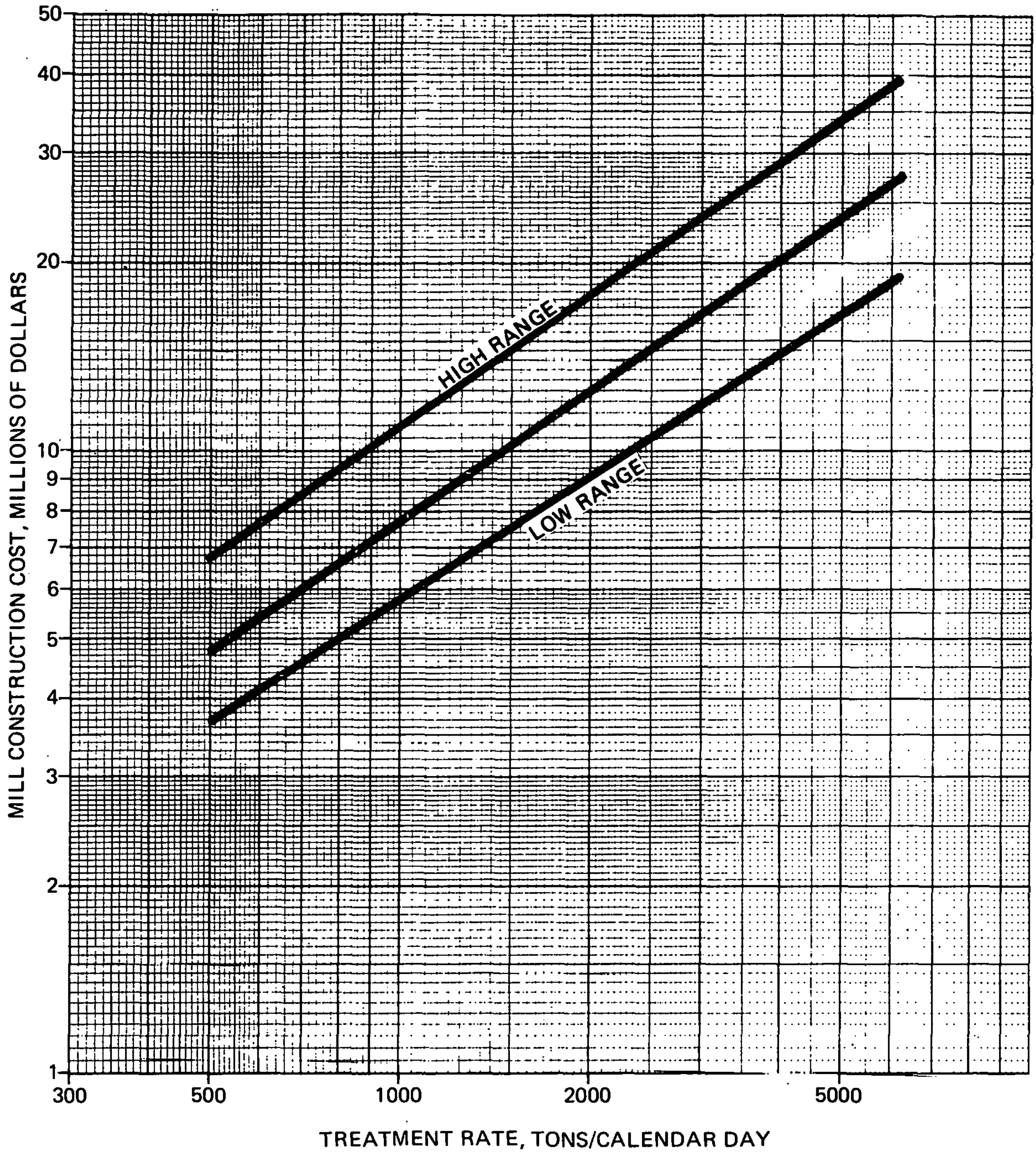

FIGURE 5-2. CONSTRUCTION COSTS OF HEAP LEACHING PLANT TO REPROCESS URANIUM MILL TAILINGS (COST ADJUSTED TO JULY 1980)

360-04 2/81

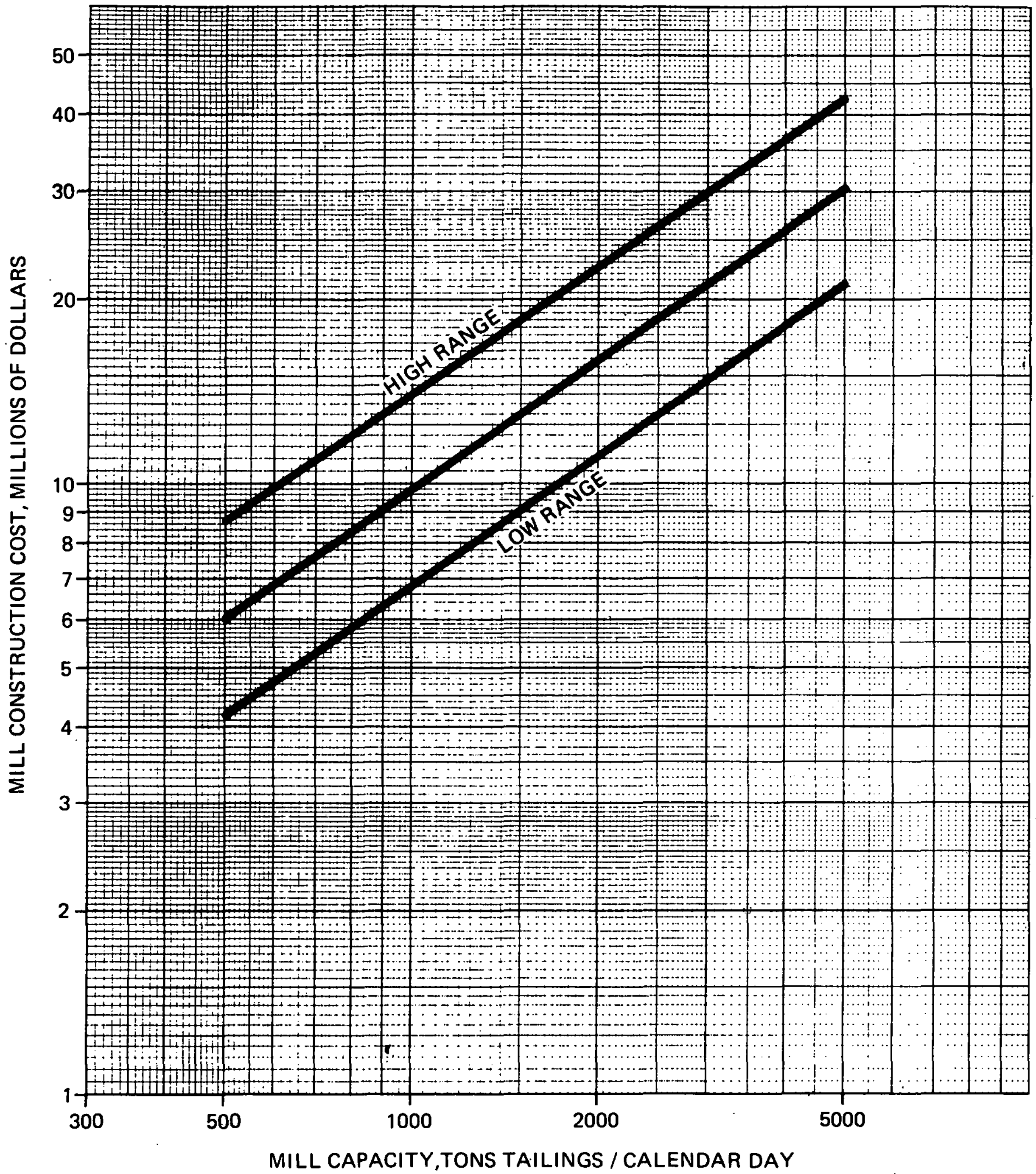

FIGURE 5-3. CONSTRUCTION COSTS OF A CONVENTIONAL URANIUM MILL TO REPROCESS TAILINGS W/O CRUSHING AND GRINDING FACILITIES OR TAILINGS STABILIZATION COSTS (COST ADJUSTED TO JULY 1980)

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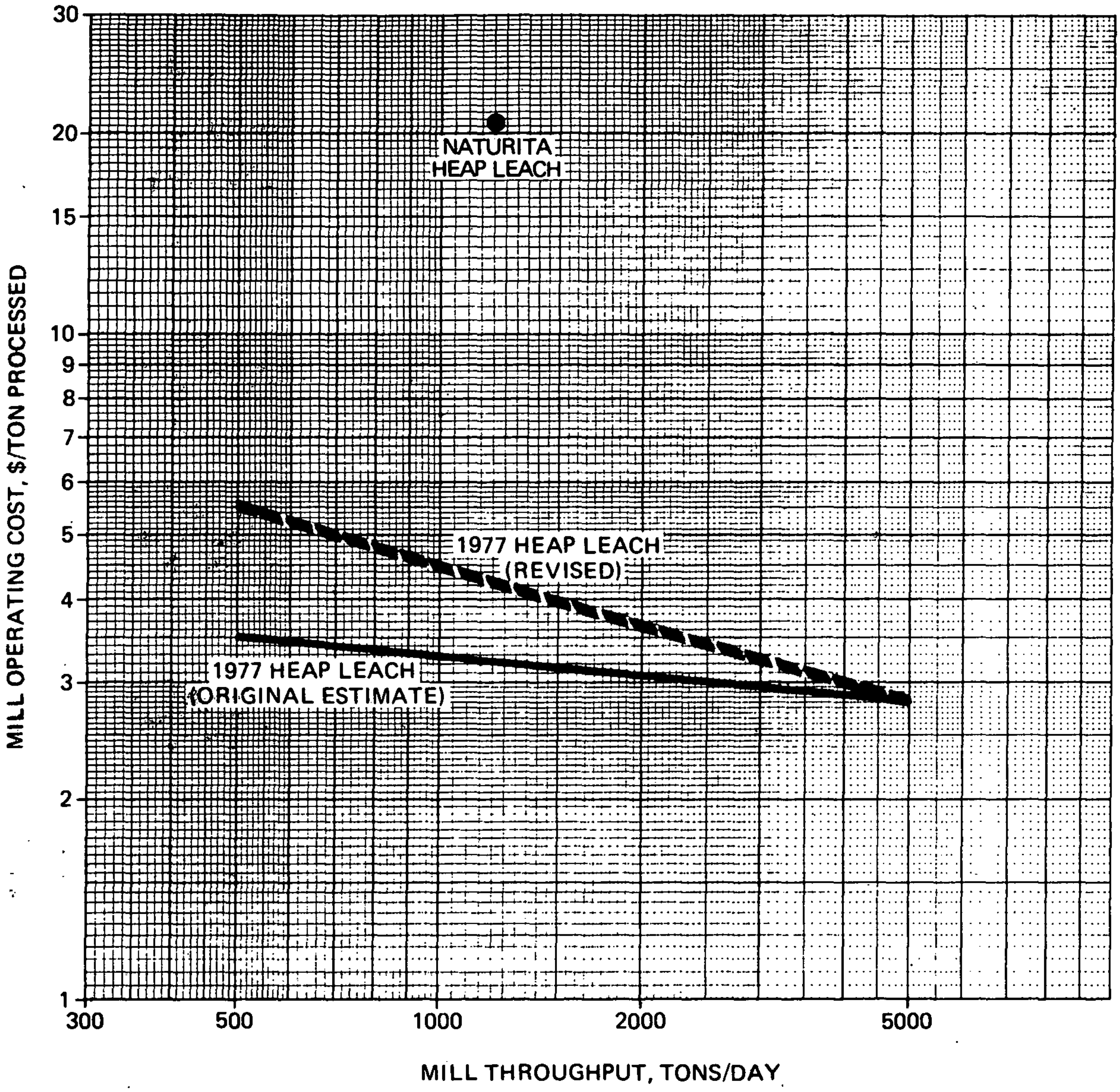

FIGURE 5-4. OPERATING COSTS OF HEAP LEACHING OF URANIUM MILL TAILINGS

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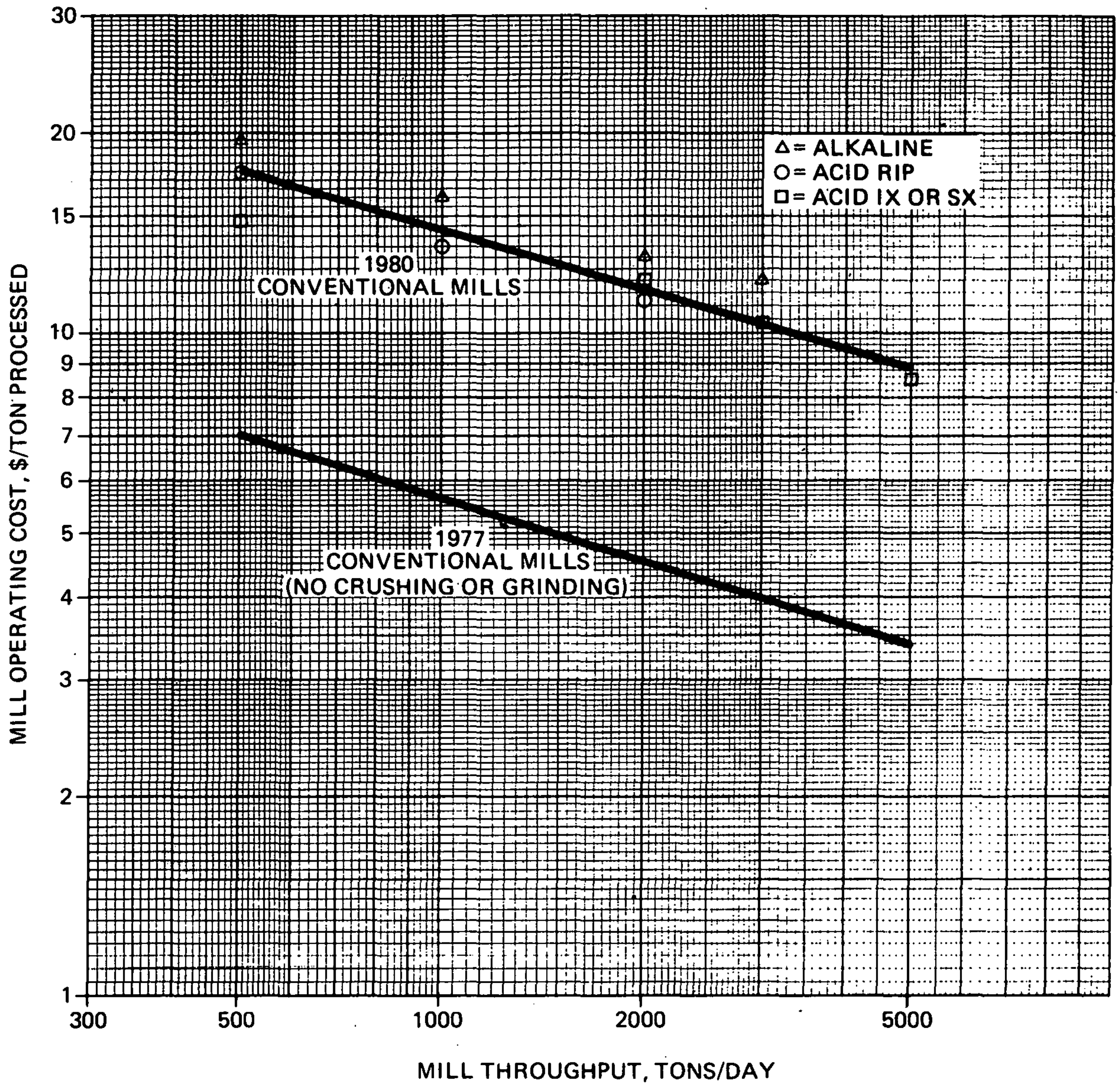

FIGURE 5-5. OPERATING COSTS OF CONVENTIONAL MILLING W/O CRUSHING AND GRINDING FACILITIES TO REPROCESS TAILINGS (COST ADJUSTED TO JULY 1980)

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TABLE 5-1

ASSAY RESULTS OF COMPOSITE TAILINGS SAMPLES

Element	Composite Old Tailings Pile Sample (%)	Composite New Tailings Pile Sample (%)
	Spectrographic Analysis	
Aluminum	1.0-0.01	1.0-0.01
Arsenic	0.00020	0.000138
Calcium	<0.01	<0.01
Cobalt	<0.01	<0.01
Boron	<0.01	<0.01
Copper	<0.01	<0.01
Gallium	<0.01	--
Iron	>1.0	>1.0
Lead	<0.01	<0.01
Magnesium	0.01-1.0	0.01-1.0
Manganese	<0.01	<0.01
Molybdenum	<0.01	<0.01
Nickel	<0.01	<0.01
Selenium	0.0000073	0.0000064
Silicon	>1.0	>1.0
Titanium	<0.01	<0.01
	Chemical Analysis	
Uranium U_3O_8)	0.008	0.006
Vanadium (V_2O_5)	0.235	0.185

TABLE 5-2

U.S. URANIUM SUPPLY AND MARKET SUMMARY

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

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

CHAPTER 5 REFERENCES

1. "Phase II - Title I Engineering Assessment of Inactive Uranium Mill Tailings, Monument Valley Site, Monument Valley, Arizona"; GJT-4; Ford, Bacon & Davis Utah Inc.; Mar 1977.

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CHAPTER 6

MILL TAILINGS STABILIZATION

CHAPTER 6

MILL TAILINGS STABILIZATION

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

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

(a) Wind and water erosion

(b) Leaching of radioactive materials and other chemicals

(c) Radon exhalation from the tailings

(d) Gamma radiation emitted from the tailings

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

6.1 PREVENTION OF WIND AND WATER EROSION

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

6.1.1 Surface Stabilization

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

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

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

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

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

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

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

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

6.1.2 Volumetric Stabilization

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

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

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

6.1.3 Physical Stabilization

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

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

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

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

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

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

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

6.1.4 Vegetative Stabilization

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

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

(a) Be tolerant of local environmental conditions.

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

(c) Have propagules that are readily available.

(d) Be relatively easy to establish.

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

(f) Have minimal rooting depth requirements.

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

(h) Have low value as habitat for wildlife.

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

(a) Evapotranspiration is not excessive.

(b) Landscapes are properly shaped.

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

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

Growth of vegetation at sites receiving less than 10 in. of annual precipitation and with high evapotranspiration rates requires initial irrigation and fertilization. At Monument Valley, precipitation is estimated to be about 8 in. annually.

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

6.2 PREVENTION OF LEACHING

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

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

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

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

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

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

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

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

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

*Registered trademark.

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

(d) Rubberized asphalt membrane

(e) Hydraulic asphalt concrete

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

(g) Bentonite, sand and gravel mixture

(h) Catalytic airblown asphalt membrane

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

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

6.3 REDUCTION OF RADON EXHALATION

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

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

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

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*Registered trademark.

stabilizing inactive mill tailings require a minimum of 3 m of cover over the tailings.[1]

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

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

6.4 REDUCTION OF GAMMA RADIATION

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

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

6.5 ASSESSMENT OF APPLICABILITY

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

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

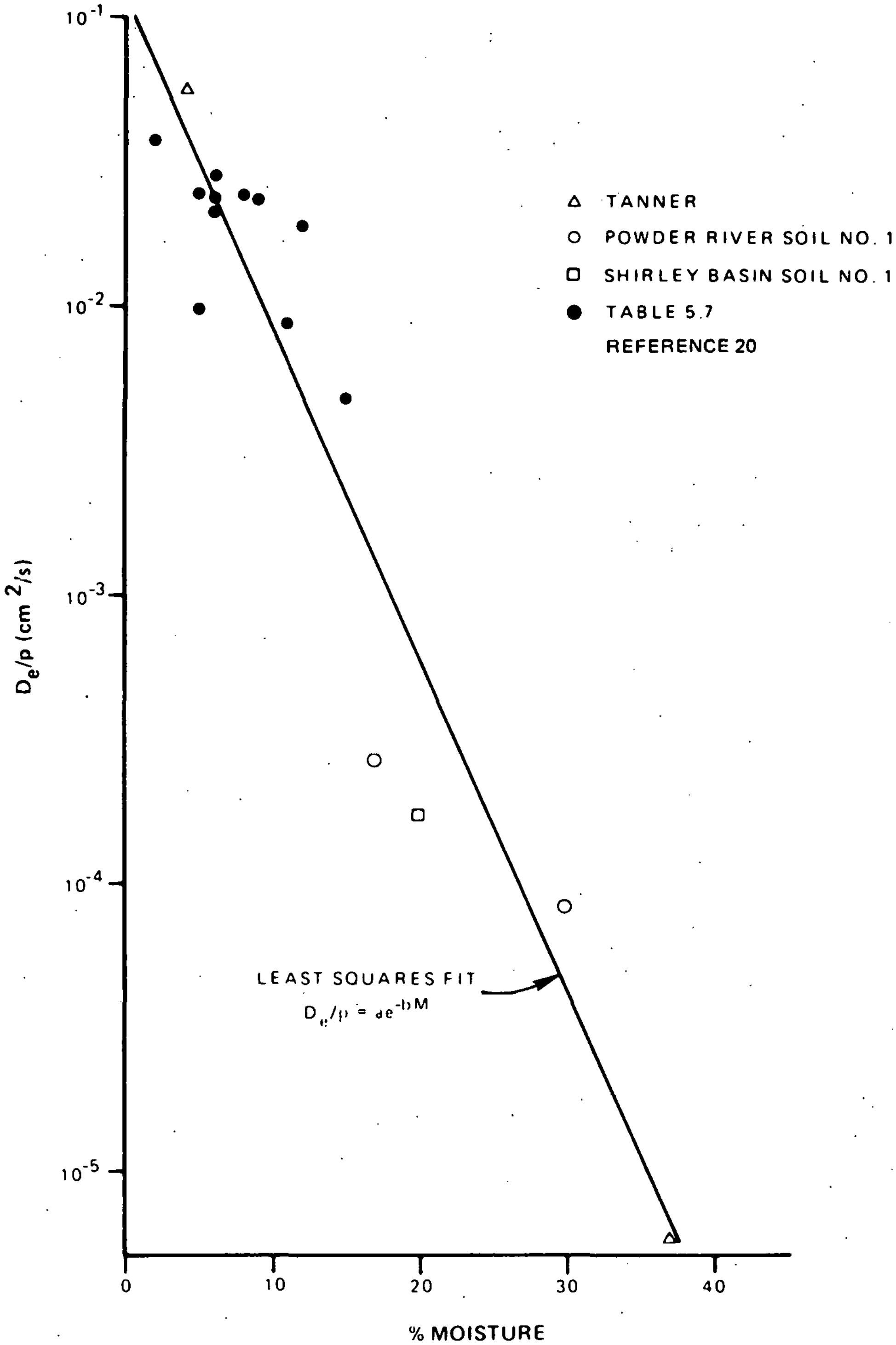

FIGURE 6-1. EXPONENTIAL MOISTURE DEPENDENCE OF THE DIFFUSION COEFFICIENT

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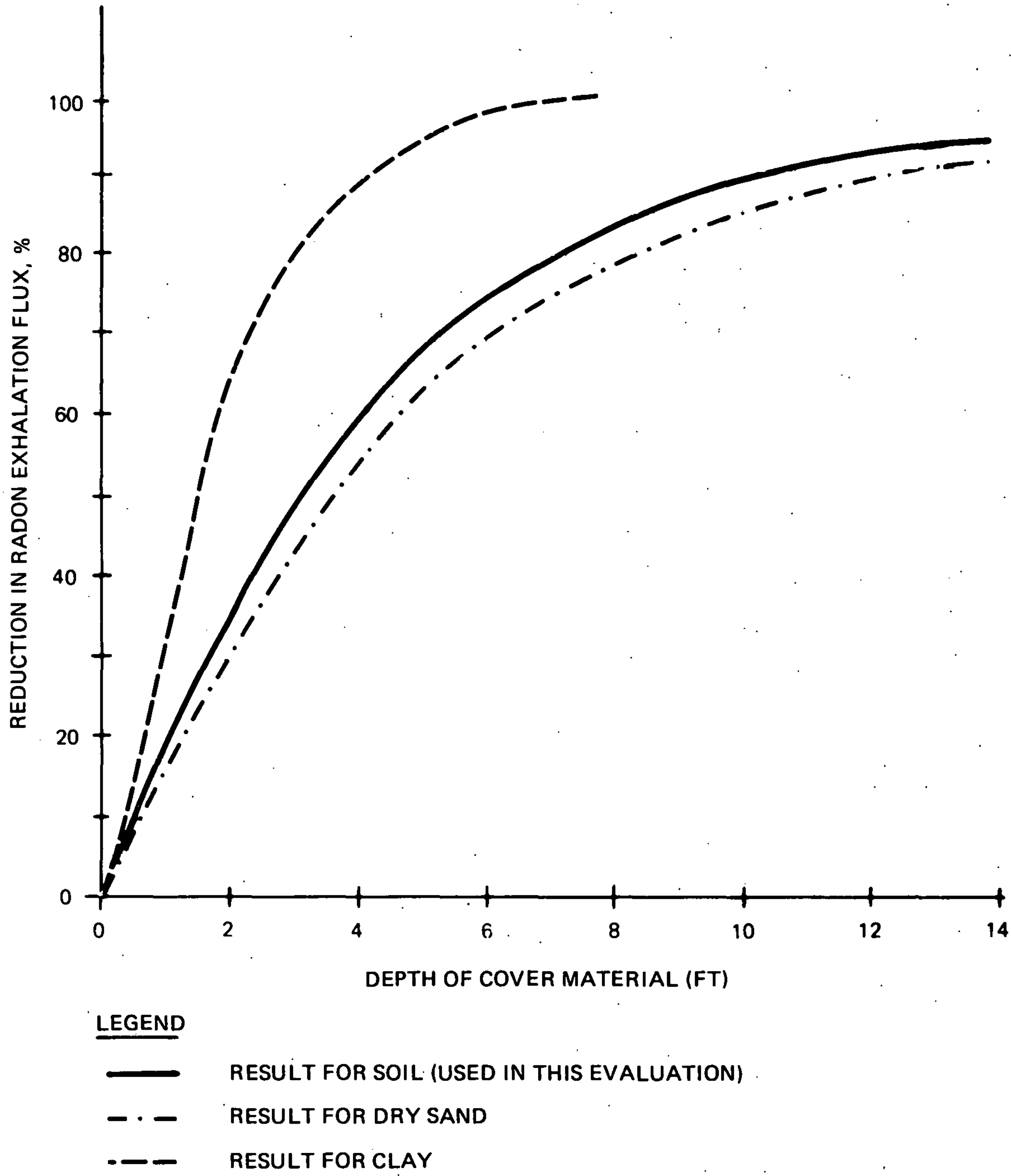

FIGURE 6-2. REDUCTION OF RADON EXHALATION FLUX WITH DEPTH OF COVER

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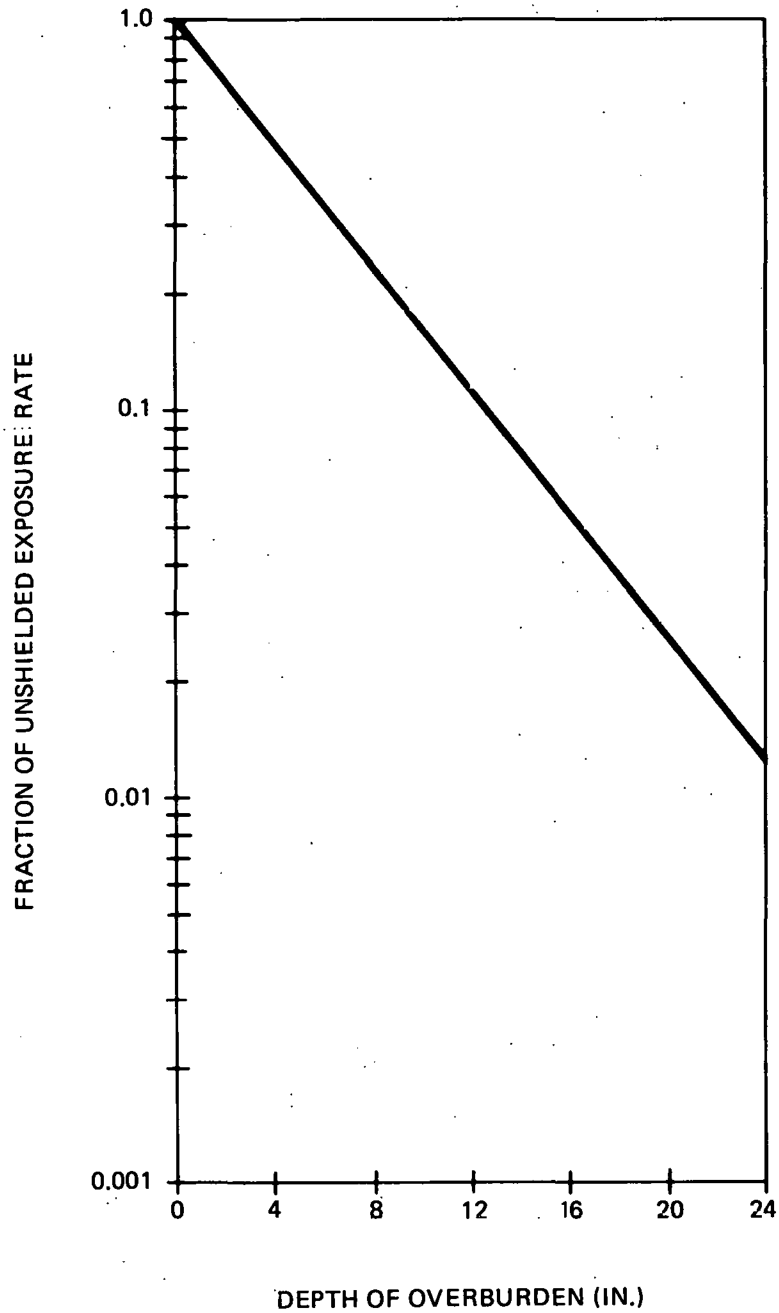

FIGURE 6-3. REDUCTION OF GAMMA EXPOSURE RATE RESULTING FROM PACKED EARTH SHIELDING

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CHAPTER 7

OFF-SITE REMEDIAL ACTION

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OFF-SITE REMEDIAL ACTION

An important objective of this engineering assessment is to estimate the cost of appropriate remedial action for those off-site properties contaminated with tailings. Those locations where tailings have been transported off site are discussed in this chapter. Such off-site locations are classified as off-site windblown properties and off-site properties other than windblown. Costs associated with the cleanup of on-site contaminated areas, i.e., windblown, tailings piles, millsite, and ore storage, are considered in Chapter 9.

7.1 DATA SOURCES

An initial survey conducted by the Navajo Environmental Protection Commission in February 1975 revealed the use of uranium mill tailings and uranium ore in the construction of several dwellings in the Monument Valley area. In August 1975 a follow-up radiation survey was conducted(1) to specifically identify those dwellings in which uranium mill tailings had been used and to assess the resulting radiation exposures. Among the 37 structures scanned, 16 dwellings with radiation significantly above background levels were discovered. A joint team composed of representatives of the EPA Office of Radiation Programs, Las Vegas, Nevada (EPA-ORP-LVF), the Arizona Atomic Energy Commission, and the Navajo Environmental Protection Commission performed individual gamma surveys of the 16 locations to determine the source of the anomalies and, if tailings, how they had been used. If the use of tailings was indicated in the dwelling, a gamma map was drawn, pressurized ion chamber measurements were made to determine the ambient exposure rate at 3 ft above the floors, and the indoor radon progeny was sampled for a 24-hr period.

The ^{226}Ra 5-pCi/g boundary mentioned in Paragraph 3.4.3 was the data source for consideration of remedial action for windblown areas.

7.2 REMEDIAL ACTION FOR OFF-SITE PROPERTIES OTHER THAN WINDBLOWN

A total of 16 dwellings for which remedial action may be expected was identified in the radiation survey.(1) The tailings were used as fill material under the floors and in the cement, mortar, and stucco of the buildings.

Of the residential locations surveyed, five had average total gamma exposure rates below the background rate inside the structures. The rates inside structures at eight of the residential locations ranged from 0 to 10 μR/hr above background, and at two other residential locations they ranged from 10 to 20 μR/hr above background. The highest average total gamma exposure rate inside the structures evaluated in the survey was 38 μR/hr.

In most residences where tailings were confirmed, 24-hr radon daughter measurements were made. The radon daughter concentrations detected ranged from background to 0.046 WL, with 12 of the 14 measurements being less than 0.01 WL.

The use of tailings in the construction of several wells was also confirmed. Water samples taken from four such wells indicated that the maximum ^{226}Ra concentration of any sample was 0.36 pCi/l. These well structures were substantial distances from dwellings and have not been included in the determination of remedial action costs.

The cost for remedial action at off-site properties other than windblown has been estimated to be $1,140,000, exclusive of engineering and contingency allowances, based on available information and adjusted Grand Junction off-site remedial action costs. This cost includes cleanup, backfill, restoration, and health physics and monitoring services. The estimated cost includes remedial action for the 16 locations where tailings use has been identified and remedial action is possible.

7.3 REMEDIAL ACTION FOR OFF-SITE WINDBLOWN PROPERTIES

The extent of windblown tailings is indicated by the 5-pCi/g line in Figure 3-14. Decontamination of the area containing windblown tailings consists of removing 6 in. of soil. This action is assumed to satisfy remedial action criteria as discussed in Paragraph 3.5.

The cost for cleanup and restoration of approximately 13 acres of off-site land contaminated by windblown tailings is estimated to be $180,000, exclusive of engineering and contingency allowances.

CHAPTER 7 REFERENCES

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CHAPTER 8

DISPOSAL SITE SELECTION

CHAPTER 8

DISPOSAL SITE SELECTION

It was assumed in the 1977 engineering assessment that the tailings and contaminated materials at the Monument Valley site could be stabilized in place as opposed to being transported to an off-site disposal location; therefore, no disposal sites were identified in the 1977 report. Furthermore, no effort was made to identify disposal sites during the 1980 field work.

However, in order to provide an understanding of the magnitude of remedial action costs if off-site disposal were elected, three unspecified disposal sites have been postulated. It is assumed that three sites that can meet the existing criteria for disposal are available at distances of 5, 10, and 15 mi from the present tailings locations.

The costs associated with remedial action (decontamination of the present site and disposal of the tailings and contaminated residues) were estimated for each unspecified site using typical disposal site preparation and haul costs. These cost estimates are presented in detail in Chapter 9. Care must be exercised in the use of these cost estimates because specific characteristics of actual disposal sites are not available and may differ substantially from those assumed in this report.

CHAPTER 9

REMEDIAL ACTIONS AND COST-BENEFIT ANALYSES

CHAPTER 9

REMEDIAL ACTIONS AND COST-BENEFIT ANALYSES

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

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

Remedial actions designed to meet the EPA interim remedial action criteria were investigated. As outlined in Chapter 8, no specific disposal sites have been identified for the Monument Valley tailings. However, in order to provide an understanding of the magnitude of the costs involved with disposal of the tailings at typical disposal sites in the Monument Valley area, it was assumed that three unspecified sites that can meet the present criteria for disposal sites are available at distances of 5, 10, and 15 mi from the tailings site. Costs for disposal of the tailings and contaminated materials at these unspecified sites have been estimated using typical disposal site preparation and haul costs and are presented in this chapter. Care must be exercised in the use of these typical cost estimates, however, because exact site locations are not identified and actual site characteristics may differ significantly from those assumed for this study. The utility of the estimated costs lies in the perspective they provide in determining the relative costs of possible remedial action alternatives.

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

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

The options for disposal at the unspecified sites would provide for the relocation of all debris and contaminated materials from the site 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}Ra above background.

A discussion of the concepts involved in tailings stabilization and their applicability to the Monument Valley site has been detailed in Chapter 6. It is assumed that either vegetation will be planted or a riprap cap provided if the tailings are stabilized on site. However, for disposal options, a riprap cap of 0.3 m on top of 3-m cover material is assumed to suffice for erosion control in lieu of vegetation.

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

In this section, the conceptual design of the option to stabilize the Monument Valley tailings piles and contaminated residues is discussed, and the estimated cost of the corresponding remedial action is presented.

9.1.1 Conceptual Design

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

Under this option the tailings would remain on site. The tailings site would be leveled, graded, and stabilized with 3 m of cover material, which has been shown under certain conditions to be adequate to reduce radon flux to less than 2 pCi/m^2-s. With the cover material in place, the combined pile would cover about 23 acres and rise about 15 ft above the natural grade of the millsite. Abandoned equipment on the site would be buried in the pile.

If the Monument Valley site were stabilized in place, it would have limited future use.

9.1.2 Costs

As shown in Table 9-1, the cost for stabilization at the Monument Valley site is estimated to be $6,600,000. Costs include cleaning up of off-site locations, covering all contaminated materials with 3 m of cover, contouring the surface, adding 0.3 m of riprap cover, and reclaiming all areas.

9.2 REMOVAL OF TAILINGS AND ALL CONTAMINATED MATERIALS FROM THE SITE (OPTIONS II THROUGH IV)

Options II, III, and IV would provide for the complete removal of all tailings, contaminated soil, materials, and rubble from the tailings site and off-site areas to a disposal site. The amount of soil to be removed depends on the depth of contamination. Figure 9-1 is a decontamination plan for the Monument Valley site and shows the areas of the site that will require cleanup action and the estimated depths of soil removal required in each area to meet cleanup criteria. For example, removal to depths of 3 ft below the interface under the new tailings pile and 4 ft below the interface of the old tailings pile is estimated to be sufficient to reduce residual radium concentration to less than the allowed level of 5 pCi/g above background. The tailings site would be released for unrestricted use.

9.2.1 Excavation and Loading of Tailings and Soils

The roadways presently providing access to the site are not paved and may require upgrading. Different methods of excavation are possible, with a single-bench open-pit method being the most feasible. To eliminate any possible dispersion of tailings during loading and transportation operations, dust control equipment and washdown facilities would be provided.

9.2.2 Transportation of the Materials

Railroad transportation was not considered feasible for tailings transport since there are no rail facilities in the vicinity of the tailings site.

Slurry pipeline technology was evaluated. Water is a precious resource in this region and is not available for this method of transport from any nearby source. 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 many complications involved in the use of conveyors, many of which are difficult to quantify. Public acceptance, acquisition of rights-of-way and permits within a reasonable time frame, and environmental impact are considerations that cloud the evaluation of conveyors.

With all of the factors considered, the quantity of material to be moved does not warrant the use of conveyors, making transportation by truck preferable. At such time as 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 15 mo. 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 costs of hauling all tailings, necessary cover material, and riprap material. No costs are included for repair and maintenance of public roads. Capital costs include development of access roads and maintenance thereof whenever such roads are required.

9.2.3 Disposal at Alternative Sites

No specific locations have been identified for disposal of the contaminated materials at Monument Valley. However, it is assumed that three unspecified sites that can meet the existing criteria for tailings disposal are available at distances of 5, 10, and 15 mi from the present location. The costs associated with disposal of the tailings at typical disposal sites located 5, 10, and 15 mi from the present location are presented in Table 9-1 as Options II, III, and IV, respectively.

It is assumed that all three sites are accessible from 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 the construction of a gravel-based surface sufficient to handle the heavy loads.

It is also assumed that the disposal sites selected can be isolated from drainage basins naturally or by dikes and drainage ditches. Figure 9-2 is a schematic representation of how these disposal sites might be developed.

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 costs for the disposal options are listed in Table 9-1; they range from about $14,300,000 for Option II to about $15,900,000 for Option IV. The range in cost is due to differences in the length of hauls to the disposal sites from the tailings site and from the cover material locations.

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

In Options II through IV the estimated costs include the cleaning up of off-site locations, windblown contaminated areas, the former mill area, and tailings piles; covering all tailings and contaminated materials at the disposal site with 3 m of cover material; contouring the stabilized disposal site; and 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) resulting from the remedial action. In Chapter 3 the estimated number of health effects was determined for the Monument Valley tailings piles in their present conditions. 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 stabilization of uranium mill tailings, radon fluxes were assumed to be reduced from their predicted values under present conditions (as conservatively calculated in Paragraph 3.6.2) to less than 2 pCi/m^2-s for Option I. In all other options, radon flux was assumed to be reduced to zero with the removal of the tailings. Since health effects are proportional to radon flux, the present health effects rate was estimated to be reduced by more than 97% with stabilization in-place and by 100% with 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 9-3. Option I yields the maximum health benefit per unit cost, whereas Option IV yields the minimum benefit per unit cost.

9.3.2 Land Value Benefits

Because all reservation land is owned commonly by the Navajo Tribe, there is no conventional valuation for Navajo properties. The lack of a traditional monetary market for land exchanges on the Navajo Reservation makes it difficult to calculate the dollar value of the site and its environs. However, recent land exchanges by the Navajo Tribal Council, whereby they purchased off-reservation land and exchanged it for tribal land, are one indication. Recent lease payments for Navajo lands are another indication of land values. Comparisons with land values in the Cane and Monument Valley areas give an indication of the worth of the Monument Valley site. Also, by assigning a monetary value to sheep production per acre of land, and by translating this value into capital-valued land, another cash valuation can be determined.

By using the above methods, the Navajo Land Administration estimated the current value of grazing lands around the site at $55 to $65/acre. These values could increase to $300 to $350/acre if a mineral inventory currently under way establishes that there are useful minerals on or near the site.

The presence of the tailings limits the use of the actual site for grazing or other purposes. However, due to the abundance of available grazing land in the area, pressures to use the tailings area are very low. Therefore even though the site would be available for unlimited uses after implementation of Options II, III, or IV, the value of the site would not increase an appreciable amount. Under Option I the site would continue to have restricted use and its value would remain essentially unchanged.

The value of the land surrounding the site is not depressed by the presence of the tailings and would therefore not increase significantly as a result of the remedial actions of any of the options described in this report.

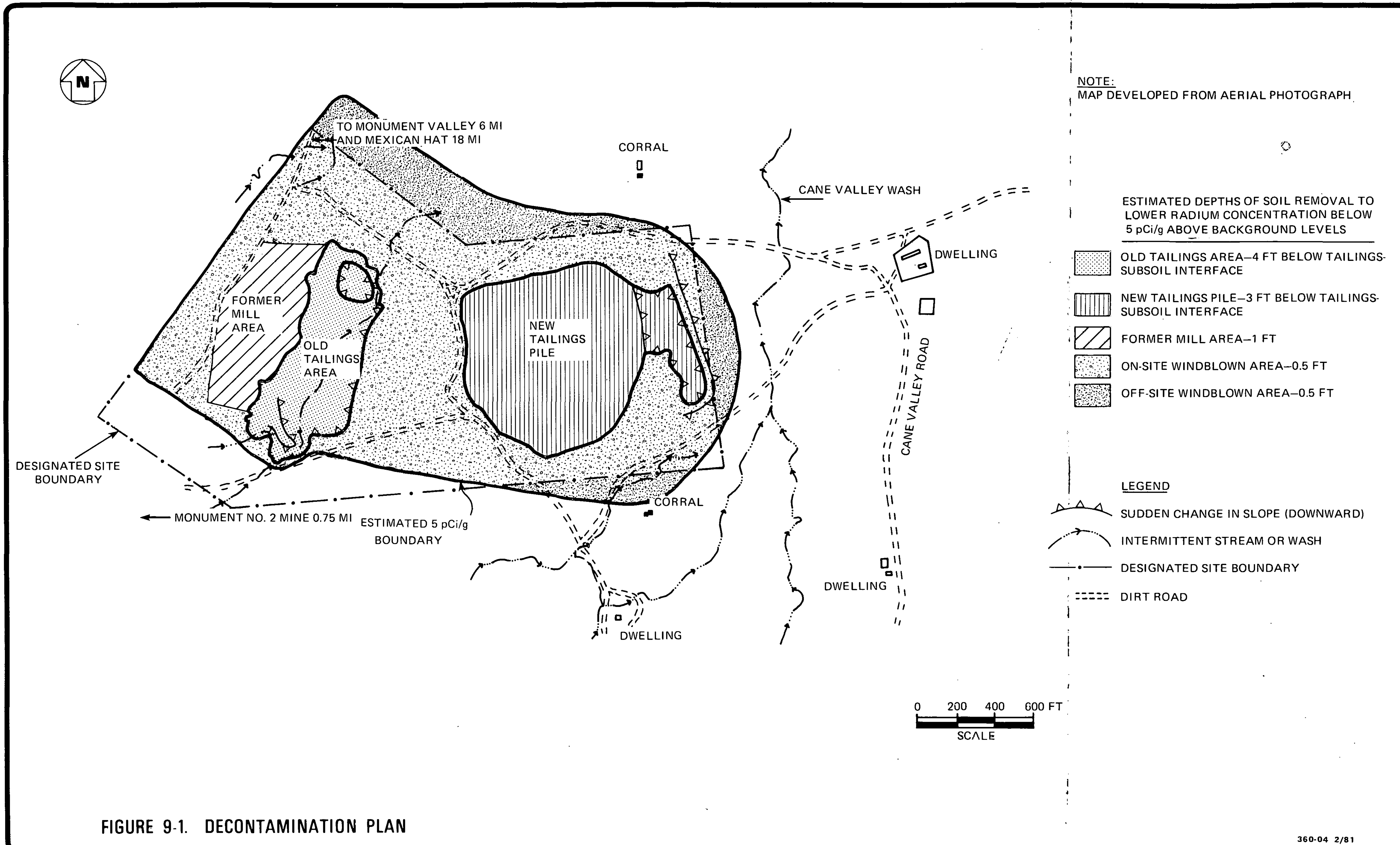

FIGURE 9-1. DECONTAMINATION PLAN

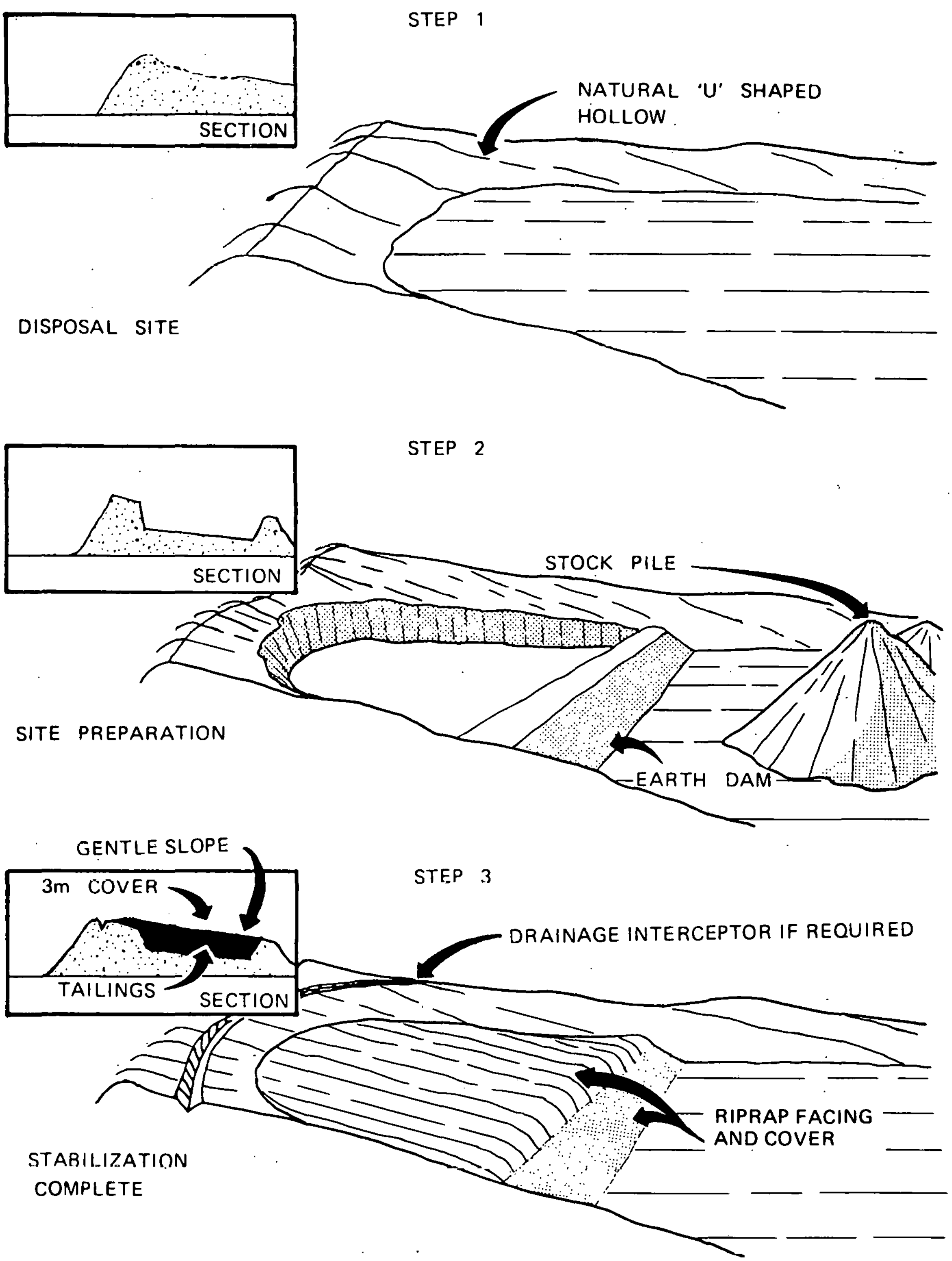

FIGURE 9-2. SCHEMATIC OF TYPICAL TAILINGS DISPOSAL SITE

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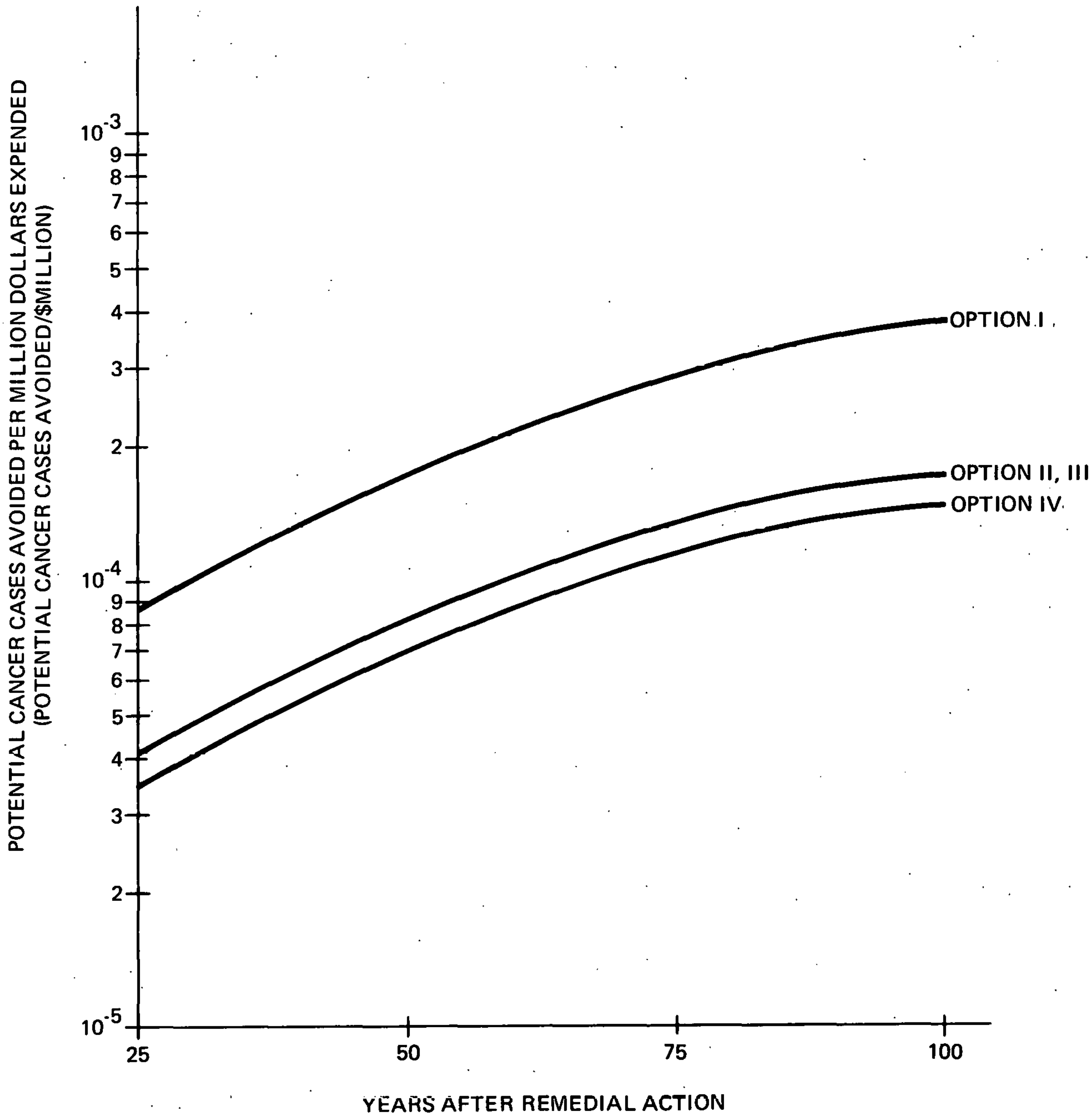

FIGURE 9-3. POTENTIAL CANCER CASES AVOIDED PER MILLION DOLLARS EXPENDED

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TABLE 9-1

SUMMARY OF STABILIZATION AND DISPOSAL COSTS[a]

		Options			
		I	II	III	IV
1.	Tailings Site	2.6	1.8	1.8	1.8
2.	Off-Site Other than Windblown	1.1	1.1	1.1	1.1
3.	Off-Site Windblown	0.2	0.2	0.2	0.2
4.	Transportation				
	a. Capital Costs	--	1.9	1.3	1.2
	b. Haul Costs	--	2.0	3.3	4.2
5.	Disposal Site	--	1.8	1.8	1.8
6.	Total Cleanup[b] (sum of lines 1 through 5)	3.9	8.9	9.6	10.4
7.	Engineering Design and Construction Management (30% of the difference between lines 6 and 4b)	1.2	2.1	1.9	1.8
8.	Total[b] (sum of lines 6 and 7)	5.1	11.0	11.5	12.2
9.	Contingency (30% of line 8)	1.5	3.3	3.4	3.7
10.	GRAND TOTAL[b] (sum of lines 8 and 9)	6.6	14.3	14.9	15.9

[a]Costs are in thousands of year 1980 dollars.

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

TABLE 9-2

POTENTIAL CANCER CASES AVOIDED
AND COST PER POTENTIAL CASE AVOIDED

A. Number of Potential Cancer Cases Avoided

Options:	I	II	III	IV
Option Cost (million $)	6.6	14.3	14.9	15.9
Years After Remedial Action				
25	<0.00056	0.00056	0.00056	0.00056
50	<0.0012	0.0012	0.0012	0.0012
75	<0.0018	0.0018	0.0018	0.0018
100	<0.0024	0.0024	0.0024	0.0024

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

Options:	I	II	III	IV
Option Cost (million $)	6.6	14.3	14.9	15.9
Years After Remedial Action				
25	11,800	24,700	25,700	27,400
50	6,000	11,900	12,400	13,300
75	3,700	7,900	8,300	8,800
100	2,900	6,000	6,200	6,600

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GLOSSARY

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

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

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

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

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

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

radon concentration
: The amount of radon per unit volume. In this assessment, the average value for a 24-hr period of atmospheric radon concentrations, determined by collecting data for each 30-min period of a 24-hr day and averaging these values.

radon daughter
: One of several short-lived radioactive daughter products of radon (several of the daughters emit alpha particles).

radon daughter concentration (RDC)
: The concentration in air of short-lived radon daughters, expressed either in pCi/l or in terms of working level (WL).

radon flux
: The quantity of radon emitted from a surface in a unit time per unit area (typical units are in pCi/m^2-s).

raffinate
: The liquid part remaining after a product has been extracted in a solvent extraction process.

recharge
: The processes by which water is absorbed and added to the zone of saturation of an aquifer, either directly into the formation or indirectly by way of another formation.

rem (roentgen equivalent man)
: The unit of dose equivalent of any ionizing radiation which produces the same biological effect as a unit of absorbed dose of ordinary X-rays, numerically equal to the absorbed dose in rads multiplied by the appropriate quality factor for the type of radiation. The rem is the basic recorded unit of accumulated dose to personnel.

residual value
: The value of minerals in tailings material.

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

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

working level month (WLM) — One WLM is equal to the exposure received from 170 WL-hours.