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ENGINEERING ASSESSMENT OF INACTIVE URANIUM MILL TAILINGS

NATURITA SITE
NATURITA, COLORADO

JULY 1981

PREPARED FOR

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

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CONTRACT NO. DE-AC04-76GJ01658

BY

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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 November 1977, entitled "Phase II - Title I Engineering Assessment of Inactive Uranium Mill Tailings, Naturita Site, Naturita, Colorado," which was authorized by DOE, Grand Junction, Colorado, under Contract No. E(05-1)-1658.

This report has become necessary as a result of changes that have occurred since 1976 which pertain to the Naturita site and associated properties, 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 Bob Anderson of Foote Mineral Company, and A. "Doc" Moore of Ranchers Exploration and Development Corporation. Several local, county, and state agencies contributed information, as did many private individuals.

ABSTRACT

Ford, Bacon & Davis Utah Inc. has reevaluated the Naturita site in order to revise the November 1977 engineering assessment of the problems resulting from the existence of radioactive contamination at the former uranium mill tailings site at Naturita, Colorado. This evaluation has included the preparation of topographic maps, the drilling of boreholes and radiometric measurements sufficient to determine areas and volumes of contaminated materials and radiation exposures of individuals and nearby populations, and the evaluation and costing of alternative remedial actions.

Radon gas released from the estimated 344,000 tons of contaminated materials that remain at the Naturita site constitutes the most significant environmental impact, although external gamma radiation also is a factor. The two alternative actions presented in this engineering assessment are stabilization of the site in its present location with the addition of 3 m of stabilization cover material (Option I), and removal of residual radioactive materials to a disposal site and decontamination of the Naturita site (Option II). Cost estimates for the two options are about $7,200,000 for stabilization in-place, and about $8,200,000 for disposal at the Ranchers Exploration and Development Corporation's reprocessing site. Truck haulage would be used to transport the contaminated materials from the Naturita site to the selected disposal site.

Ranchers Exploration and Development Corporation removed the tailings from the site, reprocessed them, and disposed of them from 1977 to 1979. There is no noteworthy mineral resource remaining at the former tailings site; therefore, recovery of residual mineral values was not considered in this assessment.

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CHAPTER 1

SUMMARY

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SUMMARY

1.1 INTRODUCTION

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

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

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

Evaluations of the following factors have been included in this engineering assessment in order to assess the significance of the radiological conditions that exist today at the Naturita 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 alternatives. The first included only remedial action at off-site structures, and the second included remedial action at off-site structures and cleanup of windblown contamination surrounding the former tailings site. The formulation of these options assumed that the tailings would be removed from the site for reprocessing at a different location and that contaminated soil beneath the pile would also be removed. Since the November 1977 engineering assessment was published, these alternatives have been judged unacceptable because the tailings have already been reprocessed and because of new criteria that have been proposed. In the work performed in the preparation of this report, the remedial action alternatives are revised as follows:

(a) Option I - Stabilization of all remaining contaminated materials and those from cleanup of off-site properties at the former Naturita tailings site.

(b) Option II - Cleanup of the former Naturita tailings site and off-site properties and disposal of resulting contaminated materials at Ranchers Exploration and Development Corporation's reprocessing site.

<u>1.1.1 Background</u>

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

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

terms of a contract with FB&DU. The contract was effective on June 23, 1975. The Salt Lake City Vitro site was assigned as the initial task, and work began immediately. Field work at Naturita included gamma logging of tailings drill holes on March 10 and 11, 1976; field survey work from May 7 to May 11, 1976; additional radon measurements on June 5 and 6, 1976, and October 7 through October 10, 1976. The original Phase II - Title I Engineering Assessment was published in November 1977.[2]

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

In 1979, DOE established the UMTRA Program Office in Albuquerque, New Mexico. Work on the program has since been directed by personnel in that office. The supplementary field work by FB&DU in support of this report was performed during the week of July 13, 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 Naturita site.

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

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

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

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

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

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

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

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

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

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

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

(1) Gamma radiation

(2) Radon

(3) Radon daughter concentrations

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

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

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

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

(n) Evaluation of the alternative corrective actions for each site in order to arrive at recommendations, estimated costs, and socioeconomic impact based on population and land use projections.

(o) Preparation of preliminary plans, specifications, and cost estimates for alternative corrective actions for each site.

Not all of these items received attention at the Naturita site.

1.2 SITE DESCRIPTION

1.2.1 Location and Topography

The former tailings site is located 2 mi northwest of the town of Naturita, Montrose County, Colorado, in the San Miguel River Valley. The valley floor is at an elevation of approximately 5,355 ft above sea level. The locale is arid with canyons, mesas, steep cliffs, and valleys which are typical of the western slope of the Rocky Mountains. The site and its relationship to the surrounding area is shown in the aerial photograph in Figure 2-1. The topography of the site now that the tailings have been removed is shown in Figure 2-2.

1.2.2 Ownership and History of Milling Operations and Processing

The portion of the site formerly occupied by the tailings was purchased by Ranchers Exploration and Development Corporation (Ranchers) of Albuquerque, New Mexico, from Foote Mineral

Company in 1976. The balance of the site is owned by Foote Mineral Company, which has leased a portion to General Electric Company for a uranium ore buying depot. The ore buying operation is still active.

The mill was built in 1930 by the Rare Metals Company. It did not become operational until 1939, when Vanadium Corporation of America (VCA) acquired the mill and converted it to a salt-roast, water-leach process for vanadium recovery. The process was modified again in 1942 so that uranium could be extracted. At the end of World War II the mill was shut down. It reopened under contract to the AEC in 1947. Uranium concentrates were shipped to the AEC until 1958, when the mill was again shut down. From 1961 until 1963 an upgrader was operated at the site by VCA. The mill was dismantled in 1963. In 1967, VCA was merged into Foote Mineral Company and site ownership passed to Foote.

During 1977 through 1979, the tailings were removed by Ranchers from the site area to a new 1,200-ton/day capacity heap leach reprocessing plant located along Colorado State Highway 90, about 3 mi southwest of the intersection of Highways 90 and 141 at Vancorum. After reprocessing, the tailings were placed in new tailings ponds at the new location and were stabilized with 2 to 10 ft of cover.

During its life the mill processed 704,000 tons of ore. Prior to the 1958 shutdown the ore averaged 0.3% U_3O_8 and 1.8% V_2O_5. During the upgrader operation, ore averaging 0.25% U_3O_8 and 1.65% V_2O_5 was processed. Ore was received from throughout the Uravan mineral belt and beyond.

1.2.3 Present Condition of the Site

Figure 2-4 is a descriptive map of the site as it now exists. The tailings have been removed from the site and the present surface of the former tailings area is basically flat. Figure 2-5 shows a typical cross-section of the present site. The old mill building has been removed, although 17 buildings remain which are used for storage, office space, and by those leasing portions of the site as an ore buying station. Native vegetation has begun to establish itself over the former tailings area. The site is fenced with a variety of fence types, and radiation hazard signs have been posted. Maintenance and security are provided.

1.2.4 Tailings and Soil Characteristics

The tailings were removed from the site and reprocessed by Ranchers Exploration and Development Corporation. The estimated volumes of residual tailings material and contamination at and around the former site are given in Table 2-1. The soil beneath the former tailings pile area is composed of alluvial deposits of the San Miguel River.

1.2.5 Geology, Hydrology, and Meteorology

The former Naturita tailings site is located on the west bank of the modern flood plain of the San Miguel River, which flows northwestward through the narrow San Miguel River Valley. The former tailings site is located on approximately 50 ft of alluvium which overlies the shales, sandstones, and conglomerates of the Brushy Basin Member of the Morrison Formation. The bedrock strata dip 2 to 4 deg northeastward. The Brushy Basin Member is 100 to 200 ft thick beneath the former tailings site and is underlain by the sandstones and shales of the Salt Wash Member of the Morrison Formation and the mudstones of the Summerville Formation. A simplified stratigraphic column is shown in Figure 2-6.

The flowing surface waters adjacent to or near the former tailings site consist of the San Miguel River and intermittent streams that drain the neighboring canyons. One of these streams is diverted around the pile, but cloudbursts up the canyon have resulted in the flow of water across the northwestern portion of the former tailings pile area. Waters have flowed onto the former pile area from the diversion ditch along the southwestern border of the site and from drainage at the northwest of the site. The former tailings area has been inundated by flood waters since the tailings were removed.

The unconfined aquifers in the San Miguel River Valley consist of waters within the recent valley alluvium. Except during flooding season, the water table lies 3 to 10 ft below the former tailings-subsoil interface. During an intermediate regional flood or more severe floods, the water table would rise within the alluvium.

Very little work has been done to identify confined ground water aquifers in the Naturita area. Potential aquifers consist of sandstone strata within the Morrison Formation and the sandstone units within the Entrada Formation. The Summerville Formation separates the Morrison Formation from the Entrada Formation and prevents downward migration of water. The Morrison Formation is the host rock for much of the uranium ore in the area and is not tapped as an aquifer. It is recharged in the Naturita area and the hydraulic flow gradient is to the northeast of the former tailings site.

Meteorological records from the Hopkins-Montrose Airport, which lies 2.5 mi east of the site but outside the San Miguel River Valley, show that thunderstorm activity and precipitation in the area can be expected from May through October. Average annual precipitation at Naturita totals about 11 in. Cloudbursts at the site or in the canyons above the site resulted in physical erosion of the tailings before they were moved. The strongest winds at the site are those that are channeled up and down the canyon.

1.3 RADIOACTIVITY AND POLLUTANT IMPACTS ON THE ENVIRONMENT

About 85% of the total radioactivity originally in uranium ore remained in the tailings after removal of the uranium. The principal environmental radiological impact and associated health effects arise from the ^{230}Th, ^{226}Ra, ^{222}Rn, and ^{222}Rn daughters contained in the residual contamination at the site and the tailings that were used off site. 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 they have experienced, they appear to be more soluble and, therefore, more mobile.

1.3.1 Radiation Exposure Pathways, Contamination Mechanisms, and Background Levels

The major potential environmental routes of exposure to man are:

(a) Inhalation of ^{222}Rn and its daughter products, resulting from the continuous radioactive decay of ^{226}Ra in the tailings. Radon is a gas which diffuses from the 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

Measurements of radon exhalation flux from the tailings made in 1980 using the charcoal canister technique[3] ranged from 1 to 124 pCi/m^2-s, with the area-weighted average flux estimated to be about 34 pCi/m^2-s. Radon flux depends principally on radium content of tailings; however, it also varies considerably because of moisture, soil characteristics, and climatological conditions.

Short-term radon measurements were performed by FB&DU in 1976 with continuous radon monitors supplied by ERDA at 11 locations in the vicinity of the Naturita tailings pile. The locations and values of the radon measurements are shown in Figure 3-3. The highest outdoor radon concentration off the pile was measured 0.17 mi north of the Naturita site in the San Miguel River Valley. The radon concentration including background at this location averaged 15.0 pCi/l for a 24-hr period. Indoor radon concentration averaged 7.7 pCi/l at the Foote Mineral Company office 0.11 mi south of the pile.

Five 24-hr measurements of atmospheric radon indicated an average background concentration of about 2.0 pCi/l for the Naturita area.

No new measurements of radon concentrations in the vicinity of the former Naturita tailings pile were made during the 1980 field work since calibrated radon monitors were not available. Presumably, however, radon concentrations in the vicinity are close to the background level determined earlier.

1.3.1.2 Direct Gamma Radiation

The range of natural background values in the Naturita area was between 7 and 12 μR/hr, averaging 10 μR/hr, as measured 3 ft above ground with an energy-compensated Geiger Mueller detector.(4) Above the surface of the former tailings pile area, gross gamma radiation rates were measured with a scintillation detector and ranged from 35 to 850 μR/hr, uncorrected. Across the road (south of Highway 141) at the former ore stockpile area, gamma radiation levels ranged from 36 to 380 μR/hr.

1.3.1.3 Windblown Contaminants

Prevailing winds in the area follow the San Miguel River Valley and therefore tend to be northwest and southeast winds. A gamma measuring technique described in Paragraph 3.4.3 was used to estimate the extent of windblown tailings around the former tailings site. The results of this survey showed windblown tailings as far as 1,800 ft to the northwest and 1,200 ft to the southeast of the site.

1.3.1.4 Ground and Surface Water Contamination

Three water samples taken in the 1976 field work from the San Miguel River contained ^{226}Ra concentrations ranging from 0.4 to 1.7 pCi/l.(4) These samples appeared to indicate a small, localized contamination of the San Miguel River immediately adjacent to the tailings pile; however, these values are less than the limits of the EPA Interim Primary Drinking Water Regulations for radionuclides.[5]

1.3.1.5 Soil Contamination

Results of soil sample analyses and drill holes in the former tailings pile area showed that ^{226}Ra concentrations exceed 5 pCi/g above background down to an average of about 5 ft below ground surface level.

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 (46 FR 2556) standards for structures and open lands. These standards establish the indoor radon daughter concentration, including background, below which no remedial action is indicated at 0.015 WL. The indoor gamma radiation limit is 0.02 mR/hr above background.

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

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

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

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

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

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

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.

*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.

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 provide an earth cover of at least 3-m thickness, sufficient to reduce the radon release 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.

While these standards may undergo further limited revisions, they will not likely experience changes that would significantly alter the nature of the remedial actions or their estimated costs. Therefore, 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 former tailings area and the subsequent inhalation of radon daughters account for a major portion of the total dose to the population resulting from the presence of contaminants at the Naturita site under present conditions. The gamma radiation exposure in the vicinity of the former tailings area is generally the same order of magnitude as the relatively high background of the vicinity.

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 path 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(6) earlier indicated that 13 ft of earth cover would be required to reduce the radon diffusion from the Naturita tailings by 95%. Later experimental work(7) 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).[8] 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[9] 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 former tailings area in the vicinity within 4 mi of the Naturita site is 2.4×10^{-7} per person per year, or less than 0.2% of the average lung cancer risk due to all causes for Colorado residents (1.8×10^{-4}).(10)

The 25-yr health effects were calculated for three population projections using the estimated present population of 2,554 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 Former Tailings Site

Projected Population Growth	Pile-Induced RDC	Background RDC
0.8% constant growth rate	0.018	5.2
2.0% constant growth rate	0.019	6.3
5.0% declining growth rate*	0.023	7.7

As a result of the low population density, the low radiation levels of the residual contamination at the former Naturita tailings site, and the relatively high background radon levels, the potential health impact of this contamination is minimal for persons not working or living directly on or adjacent to the site.

Radon daughter health effects resulting from exhalation of radon from the former tailings site are approximately 0.3% 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.

1.3.4 Nonradioactive Pollutants

There may be other potentially toxic substances in the material below the original tailings-subsurface interface. Chemical analyses of tailing samples from drill holes made in 1976 on the samples from the Naturita tailings pile showed selenium at about 0.5 ppm, lead and arsenic between 40 and

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

60 ppm, and chromium concentration up to 3.5 ppm. Three samples of surface waters in the area surrounding the Naturita tailings pile contained selenium in concentrations above the EPA Interim Primary Drinking Water Regulations. The selenium content of the San Miguel River increased about 30% as it passed the Naturita tailings pile to about 1.2 times the EPA standard of 0.01 mg/l. San Miguel River samples both up and downstream contained chromium at or above the EPA standard for drinking water. However, earlier measurements of standing water which had flowed off the tailings did not indicate measurable chromium. These results may indicate a continuing presence of toxic substances in surface waters, even though the tailings have been removed. This contamination might arise from contaminants that migrated from the tailings to subsurface soils.

1.4 SOCIOECONOMIC AND LAND USE IMPACTS

Based on site inspection and census records, 23,105 persons are estimated to be the 1980 population base of Montrose County, and 2,554 persons are estimated to live within 4 mi of the former tailings area. Population projections could be very optimistic because of the area's small population base and its extreme dependence on mining. The limited water supply, the lack of potential for tourism, and the isolation of the area make sustained population expansion unlikely.

Virtually all the land near the former tailings pile is devoted to low density grazing and other agricultural uses. Four residential communities are within a 5-mi radius of the site, East Vancorum, West Vancorum, Naturita, and Nucla. There are 36 occupied units at West Vancorum, 16 occupied units at East Vancorum, and unoccupied units and trailer sites at West Vancorum. The nearest commercial activity is at Naturita.

The estimated market values of the agricultural properties near the site range from \$6 to \$9/acre, including improvements. The Foote Mineral Company land has a market value of about \$160/acre, and the buildings on the Foote Mineral property are valued at about \$106,300. The former tailings area has a market value of \$200/acre. The presence of contamination restricts the use of the former tailings area itself. However, the loss of grazing or crop land is minimal, and the removal of the tailings has not affected the land use or value of surrounding property.

1.5 RECOVERY OF RESIDUAL VALUES

Since the Naturita tailings have already been reprocessed and disposed of, and since very little uranium-bearing material remains at the former tailings site, there is virtually no further potential for reprocessing material at the Naturita tailings site.

1.6 MILL TAILINGS STABILIZATION

Although most of the tailings have been removed from the former Naturita tailings site and are under new license for disposal, contaminated materials from the cleanup of on- and off-site properties must be disposed of properly. Such contaminated materials meet the definition of "residual radioactive materials" under PL 95-604 and must satisfy the same requirements as uranium mill tailings.

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

The AEC, under interagency agreement with the EPA, used a mobile scanning unit to perform a gamma radiation survey of the Naturita and Nucla, Colorado, areas in 1971. A subsequent field survey identified 13 off-site locations where tailings use was suspected or confirmed to be within 10 ft of a structure. The cost of remedial action for these locations has been estimated to be $217,000. Cleanup of the windblown tailings surrounding the site has been estimated to cost $1,514,000. The total remedial action cost for off-site structures and for decontamination of off-site open lands has been estimated to be $1,731,000, exclusive of engineering costs and contingency.

1.8 DISPOSAL SITE SELECTION

For the purposes of this report, it was assumed that the existing tailings ponds at the Ranchers reprocessing site can be used for disposal of the residual contamination at and around the site and of the tailings at off-site locations. No other disposal sites were identified. The location of this site is shown in Figure 8-1. Since the responsibility for disposal site selection lies with the Federal Government, with input from the State, this site location must be considered only as tentative.

In this option, the residual contamination at the site, windblown tailings, and off-site contamination would be hauled to the reprocessing site by truck, placed, and covered to a depth of 3 m with low-permeability soils. The surface would be gently contoured and covered with 0.3 m of riprap or vegetation established for erosion control and the entire site fenced. Continuing effort might be required to provide maintenance and to assure the integrity of the cover material. The annual maintenance costs have not been included in cost estimates made in this investigation.

1.9 REMEDIAL ACTIONS AND COST-BENEFIT ANALYSES

1.9.1 Remedial Action Options

The remedial action options examined include stabilization of the residual and windblown contamination at the former tailings site, as well as the removal of all radioactive materials to the reprocessing site for disposal where these materials could be isolated from the public. The two options are summarized in Table 1-2.

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

Option I represents remedial action to stabilize the contamination at the former tailings site. All windblown tailings, off-site tailings, and residual contamination would be gathered together and placed on the former site. These materials would be stabilized with the addition of 3 m of cover material and by construction of a dike. 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 site would have limited future use.

Option II represents the hauling of all residual contamination at the site, windblown tailings, and off-site tailings to the Ranchers reprocessing site for stabilization with 3 m of cover material and 0.3 m of riprap for erosion control. This would isolate the materials from the population, and the former site would be available for unrestricted use.

1.9.2 Cost-Benefit Analyses

As summarized in Table 9-1, the estimated costs of remedial action are $7,200,000 for Option I and $8,200,000 for Option II. Each of these options would have associated health and monetary benefits. The options are identified by number in Paragraphs 1.1 and 1.9.1.

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

TABLE 1-1

SUMMARY OF CONDITIONS NOTED AT TIME OF 1980 SITE VISITS

	Condition of Tailings[a]	Condition of Structures On Site[b]	Mill Housing[c]	Adequate Fencing, Posting, Security	Property Close to River or Stream	Houses or Industry within 0.5 Mi	Evidence of Wind or Water Erosion	Possible Water 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 Contam- ination	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	7,200	The contaminated materials would be consolidated and stabilized in place with 3 m of local earth cover. Natural vegetation would be established or a riprap cover provided. Off-site contaminated soil would be cleaned up. Additional protection against erosion by flooding of the river would be provided.	A,B,C,F	X,Y
II	8,200	The contaminated soil and rubble would be removed by truck to Ranchers Exploration reprocessing site, located about 4 mi from the tailings site. The former tailings site and off-site properties would be decontaminated as in Option I and released for unlimited use.	A-F	X

Notes

1. All options include on-site remedial action.

2. For Option II, costs include removal of contaminated earth below the former tailings-soil interface.

TABLE 1-2 (Cont)

Definition of Benefits

A. On-site windblown tailings cleaned up
B. Wind and water erosion controlled
C. Site not used for tailings available for other uses
D. The source of gamma radiation and radon gas removed from site
E. Total tailings site available for unrestricted usage
F. Radon exhalation flux reduced to less than 2 pCi/m^2-s

Definition of Adverse Effects

X. Some security and maintenance required
Y. Restricted use of tailings site

CHAPTER 1 REFERENCES

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

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

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

4. F.F. Haywood, et al.; "Radiological Survey of the Inactive Uranium Mill Tailings at Naturita, Colorado"; ORNL 5454; Oak Ridge National Laboratory, Oak Ridge, Tennessee; Mar 1980.

5. Federal Register, Part II; EPA Interim Primary Drinking Water Regulations; EPA; July 9, 1976.

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

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

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

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

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

CHAPTER 2

SITE DESCRIPTION

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CHAPTER 2

SITE DESCRIPTION

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

2.1 LOCATION

The Naturita mill and former tailings area are located in the narrow San Miguel River Valley 2 mi northwest of the town of Naturita in Montrose County, Colorado, and are shown in Figure 2-1. The former site occupies parts of Sections 14 and 15, Township 46 North, Range 16 West, New Mexico Principal Meridian, at 38 deg 14 min 30 sec north latitude, and 108 deg 36 min 0 sec west longitude.

The tailings, which were located at this site, were transported by Ranchers Exploration and Development Corporation to a new heap leach plant located in Section 34, Township 46 North, Range 16 West, and reprocessed for uranium and vanadium. Following the reprocessing, Ranchers disposed of the tailings on a site adjacent to the heap-leach plant. This site is located approximately 4 road miles south of the former site and is accessed by a gravel road heading south-southwest from Colorado State Highway 90.

2.2 TOPOGRAPHY

The site is located on the San Miguel River Valley floor on the west side of the San Miguel River. This location is within the canyonlands area of the Colorado Plateau on the western slope of the Rocky Mountains. The area is typified by relatively smooth, sloping surfaces broken by canyons with rough and precipitous topographic relief. The canyon floor varies in elevations from 5,350 to 5,360 ft through the site area. Canyon walls and mesas rise on both sides to elevations of 6,250 ft. Vegetation is sparse in the area and varies widely, depending upon elevation and proximity to a water supply. Juniper, piñon pine, and sagebrush grow in the canyon and on the mesas. Willows, native grasses, and cottonwoods grow near the river.

The designated site occupies approximately 50 acres and the tailings cover about 23 acres between Colorado Highway 141 and the San Miguel River. The topography of the site has changed considerably since publication of the November 1977 engineering assessment report because the tailings have been removed from the site. Figure 2-2 is a topographic map of the site as it existed in 1980, subsequent to tailings removal.

2.3 OWNERSHIP

The land ownership at the site is shown in Figure 2-3, which has been adapted from the site description and ownership map prepared for DOE.(1) The 23 acres on which the tailings were formerly located are owned by Ranchers Exploration and Development Corporation of Albuquerque, New Mexico. The mill area and the remainder of the site are owned by the Foote Mineral Company. The mill area is presently being leased to the General Electric Company which is using it as an ore-buying station.

2.4 HISTORY OF MILLING OPERATIONS AND PROCESSING(2)

The Naturita mill was built about 1930, but did not become operational until it was purchased and modified by VCA in 1939 to use a salt-roast water-leach process for vanadium recovery.(3) Process water was obtained from the San Miguel River. In 1942, the plant process was modified again so that uranium as well as vanadium could be extracted. At the end of World War II, the mill was shut down. The VCA at Naturita was the first company awarded a contract by the AEC under the uranium procurement program, and initial shipments of uranium concentrates to the AEC began in 1947. The VCA continued this operation until 1958, when the mill was shut down. From late 1961 to early 1963, VCA operated an upgrader plant at the site.(3) The mill was shut down and dismantled in 1963, and all the equipment was decontaminated. Because of extensive contamination, the tailings launder? was buried within the tailings pile. During the period 1947 to 1963, the Naturita mill processed 704,000 tons of uranium-vanadium ore.

The ore processed at the Naturita mill until shutdown in 1958 averages 0.30% U_3O_8 and 1.80% V_2O_5. Ores averaging 0.25% U_3O_8 and 1.65% V_2O_5 were processed at the upgrader from 1961 to 1963 and the upgraded material was shipped to Durango, Colorado, for further processing. These ores came from within the Uravan Mineral Belt and from as far west as the Cottonwood Wash in Utah. The mill owners processed ore from independent operators as well as from company-controlled properties. All ore was trucked to the Naturita mill.

From 1977 to 1979, the tailings were removed from the site area to a new 1,200-ton/day-capacity heap-leach reprocessing plant located along State Highway 90, about 3 mi southwest of the intersection of Highways 90 and 141 at Vancorum. According to information from Ranchers Exploration and Development Corporation, the tailings were stabilized at the new location with 2 to 10 ft of cover after they were reprocessed.

2.5 PRESENT CONDITION OF THE SITE

Seventeen buildings remain on the old millsite. Most could be classified as sheds although there is an office building, a garage, and a warehouse. All the buildings are used either for storage purposes by Foote Mineral Company or by General Electric Company, which leases some of the facilities to accommodate an ore buying activity. The most significant change at the site is the absence of the tailings pile as explained above. The present surface of the former tailings area is basically flat; the current general layout of the site, facilities, and former tailings area is shown in Figure 2-4, and the current cross-sectional profile of the former tailings pile is shown in Figure 2-5.

Native vegetation, mostly grasses and weeds, has re-established itself over approximately 60% of the former tailings area.

2.6 TAILINGS AND SOIL CHARACTERISTICS

Table 2-1 is a summary of the types, weights, and volumes of contaminated materials remaining on and around the site. The total estimated volume of contaminated materials is 344,000 tons, including field moisture.

2.7 GEOLOGY, HYDROLOGY, AND METEOROLOGY

2.7.1 Geology

The Naturita site is located on the west bank of the modern flood plain of the San Miguel River which flows north-westward through the narrow San Miguel Canyon. The river-run alluvium of the flood plain overlies the shales, sandstones, and conglomerates of the Brushy Basin Member of the Morrison Formation. The surrounding cliffs and mesas are formed by the sandstones and conglomerates of the Burro Canyon Formation. The strata of the Brushy Basin Member were laid down by rivers and in lakes during Jurassic time. The shale beds within the formation act as partial barriers to the upward and downward migration of ground waters, but the sandstones and conglomerates are aquifers and are recharged by the flow of surface waters across them.

At the millsite the strata dip 2 to 5 deg northeast. The Brushy Basin Member is 100 to 200 ft thick beneath the tailings and underlain by the sandstones and shales of the Salt Wash Member of the Morrison Formation and the mudstones of the Summerville Formation. A simplified stratigraphic column of the rock formation is shown in Figure 2-6.

2.7.2 Surface Water Hydrology

While no opportunity was provided for FB&DU to conduct field evaluations of site hydrology, existing information was examined to characterize general hydrologic conditions in the vicinity of the site. The results of this survey are contained in this and Paragraph 2.7.3. Apparently no further hydrologic characterization of the Naturita tailings site is contemplated at this time.

As shown in Figure 2-7, the flowing surface waters near the site consist of the San Miguel River to the northeast and an intermittent stream which drains the watershed west and northwest of the former trailings area. This stream enters the river 200 ft downstream of the former tailings area. Another intermittent stream drains the canyon south of the former tailings area, and crosses beneath Colorado Highway 141 via a 30-in. corrugated metal culvert. This stream is directed to the west by an earthen dike which intersects an old irrigation ditch. This ditch proceeds to the west, crosses back under the highway, and then parallels the highway to where it intersects a natural drainage channel immediately northwest of the pile. During severe runoff conditions, such as after a thunderstorm, canyon drainage is not diverted to the west at Highway 141 but crosses onto the millsite and flows northeast across the property into the San Miguel River.

The San Miguel River originates in the San Juan Mountains near Telluride and drops rapidly to its confluence with the Dolores River 20 mi downstream from Naturita. In the vicinity of the site, the river is contained within a relatively narrow canyon on a 400-ft-wide flood plain. There is no flood plain along the eastern bank of the river. The entire former tailings area is subject to flooding from the San Miguel River and no dike is present to protect the area. Spreading of the residual contamination at the site could occur through this mechanism.

2.7.3 Ground Water Hydrology

The site lies on alluvium of the San Miguel flood plain separated by approximately 50 ft from the strata of the Brushy Basin Member of the Morrison Formation. Very little work has been done to identify confined ground water aquifers in the Naturita area. Potential aquifers consist of the sandstone lenses within the Brushy Basin and Salt Wash Members of the Morrison Formation, and the sandstones of the Entrada Formation which are approximately 500 ft below the surface. These aquifers are recharged by precipitation and by surface waters as they flow across outcrops. The general gradient of confined ground water flow is to the northeast of the site. Thus, the aquifers of the Morrison Formation are recharged in the Naturita area. The Summerville Formation separates the Morrison Formation from the Entrada Formation and prevents downward migration of waters. The Morrison Formation is the host rock for much of the uranium mining in the area and is not tapped as an aquifer.

Within a 2-mi radius of the site there are four wells, as shown in Figure 2-8. The three alluvial wells are all hydraulically upgradient of the pile and there is no potential for contaminating these wells or the bedrock well. Any migration of contaminants would be downstream and downgradient from the site or in confined aquifers northeast of the site. The Naturita sewage plant is located adjacent to the San Miguel River between the town and the site and would further discourage use of water at the site for domestic purposes. Downstream from the site, river water is used for irrigation; further downstream, river water is used for culinary purposes at isolated farm houses.

Recent(4,5) and ongoing research by the Research Institute for Geochemical and Environmental Chemistry suggests that the presence of soluble sulfate salts in the tailings greatly modifies the hydrologic environment of the pile. The principal investigator(4) states that "the general trend of material transfer within the piles is from the interior to the surface where salts with the contaminants precipitate." It is not yet known how significant the observed migration of salts will be for tailings stabilization. Since the tailings have been removed from the former site, it appears that there should be no further concern over this phenomenon. Furthermore, it is presumed that the Ranchers disposal site does not have such poor hydrologic conditions that this phenomenon would be significant.

2.7.4 Meteorology

High-intensity rainfall, such as thunderstorms, can be expected in the Naturita area. Average annual precipitation at Naturita totals about 11 in. Large rainstorms occur usually from May through October. A rainfall of 6-hr duration totalling 1.1 in. has a probability of occurring once in five seasons.(6)

Very little direct information exists regarding the frequency, duration, and intensities of winds in the immediate vicinity of the tailings. The weather data for the area have been gathered at the Hopkins-Montrose County Airport 2.5 mi west of the site and north of the narrow valley which controls the winds at Naturita. The strongest winds are those which blow up or down the valley, as depicted in Figure 2-9. A wind rose from the Hopkins-Montrose County Airport is given in Figure 2-10. The wind records from the airport indicate a predominance of winds from the southwest quadrant. Valley winds tend toward the northwest and, to a lesser extent, southeast of the site.

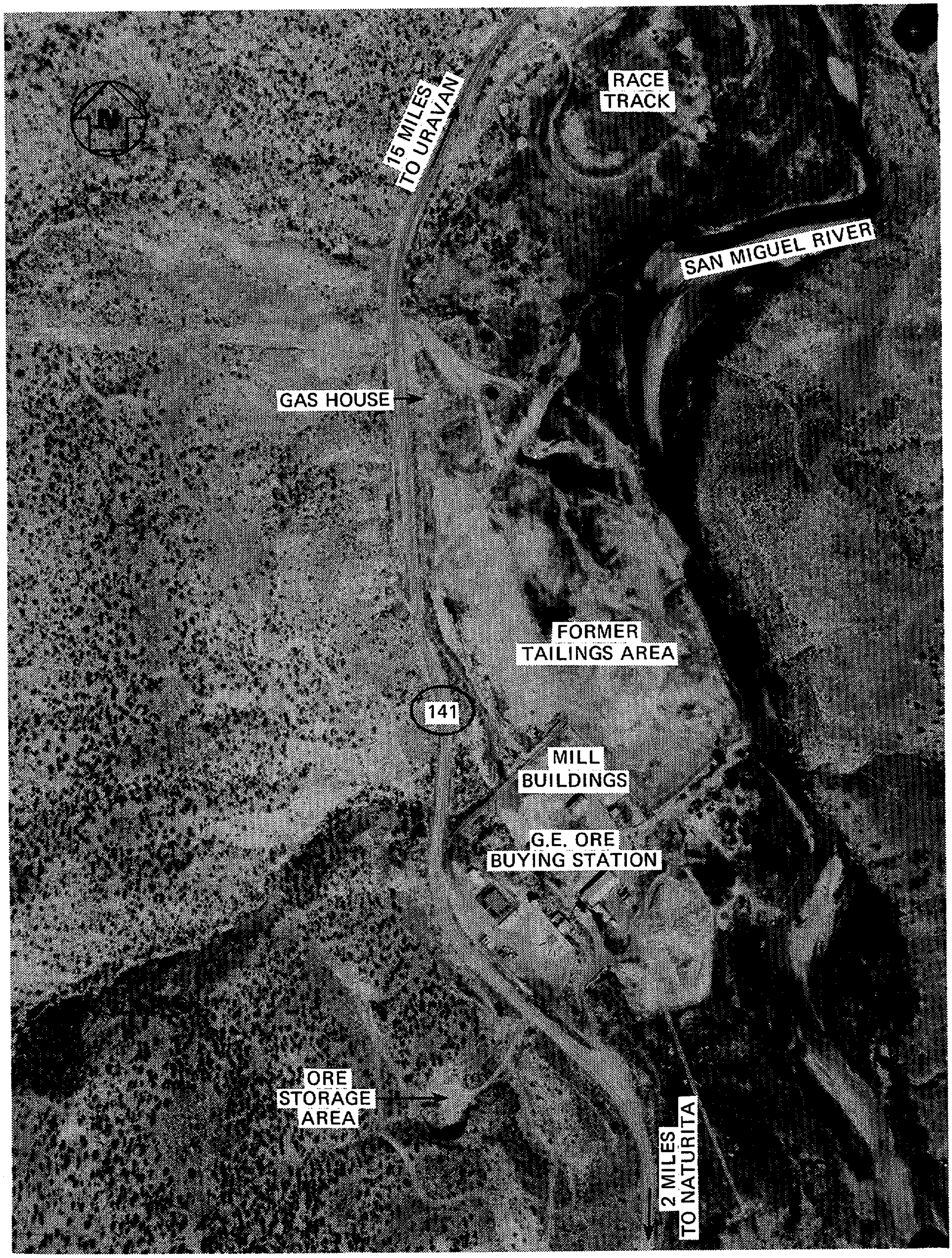

FIGURE 2-1. AERIAL PHOTOGRAPH OF SITE

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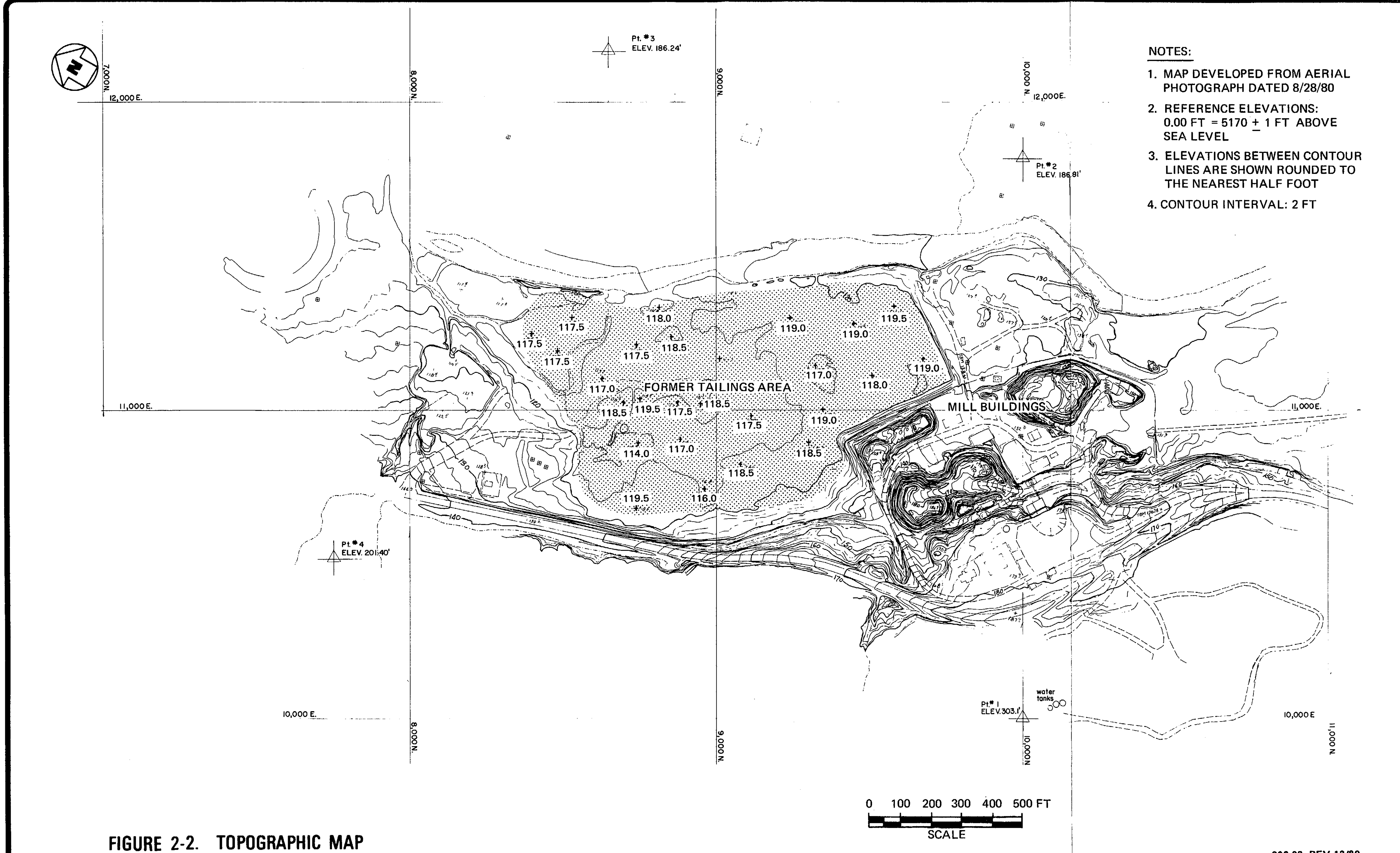

FIGURE 2-2. TOPOGRAPHIC MAP

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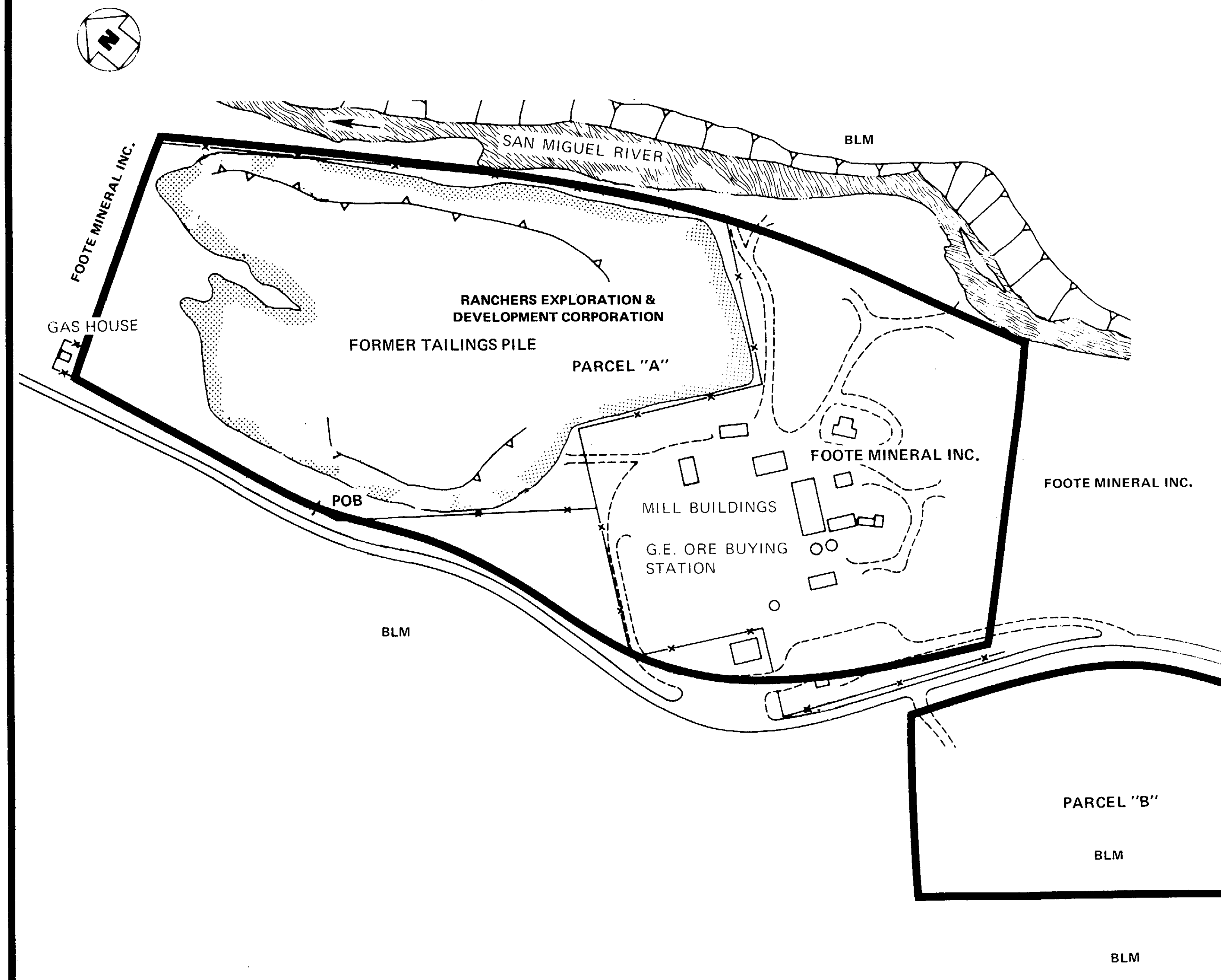


NATURITA SITE

PARCEL "A"

BEGINNING AT THE NO. 3 CORNER OF THE KENTUCKY PLACER MINING CLAIM NO. 2534, SAID POINT BEING N 3°23'49"E, 2528.24 FT (MORE OR LESS) FROM THE S.W. CORNER OF SECTION 14, T46N, R16W, N.M.P.M., SAID POINT ALSO BEING APPROXIMATELY ON THE EASTERLY R/W LINE OF COLORADO STATE HIGHWAY NO. 141, AND RUNNING THENCE NORTHERLY ALONG SAID COLORADO STATE HIGHWAY NO. 141 R/W LINE 882 FT (MORE OR LESS), THENCE N 57°00'50"E, 627.5 FT (MORE OR LESS) TO THE WESTERLY BANK OF THE SAN MIGUEL RIVER, THENCE CONTINUING ALONG SAID WESTERLY BANK THE FOLLOWING COURSES AND DISTANCES, S 56°16'15"E, 260.51 FT; S 47°24'E, 644.3 FT; S 40°40'E, 500 FT; S 36°30'18"E, 795 FT, THENCE LEAVING SAID BANK OF THE SAN MIGUEL RIVER S 56°04'W, 950 FT (MORE OR LESS) TO THE SAID EASTERLY R/W LINE OF COLORADO STATE HIGHWAY NO. 141, THENCE NORTHERLY ALONG SAID R/W LINE 1350 FT (MORE OR LESS) TO THE POINT OF BEGINNING.

CONTAINS 37 ACRES (MORE OR LESS)

PARCEL "B"

BEGINNING AT A POINT WHICH IS S 47°28'W, 55 FT (MORE OR LESS) FROM THE CORNER NO. 1 OF THE "KENTUCKY PLACER MINING CLAIM NO. 2534," SAID POINT BEING ON THE WESTERLY R/W LINE OF COLORADO STATE HIGHWAY 141, SAID CORNER NO. 1, OF THE "KENTUCKY PLACER MINING CLAIM NO. 2534" BEING N 58°52'28"E, 1660 FT (MORE OR LESS) FROM THE S.W. CORNER OF SECTION 14, T46N, R16W, N.M.P.M., AND RUNNING THENCE S 47°28'W, 400 FT (MORE OR LESS), THENCE N 42°32'W, 1000 FT (MORE OR LESS), THENCE N 47°28'E, 425 FT (MORE OR LESS) TO THE WESTERLY R/W LINE OF COLORADO STATE HIGHWAY 141, THENCE SOUTHERLY ALONG SAID HIGHWAY R/W LINE 1050 FT (MORE OR LESS) TO THE POINT OF BEGINNING.

CONTAINS 13 ACRES (MORE OR LESS)

NOTE: ADAPTED FROM REFERENCE 1

NO SCALE

FIGURE 2-3. LAND OWNERSHIP AND SITE DESIGNATION MAP

360-08 REV 12/80

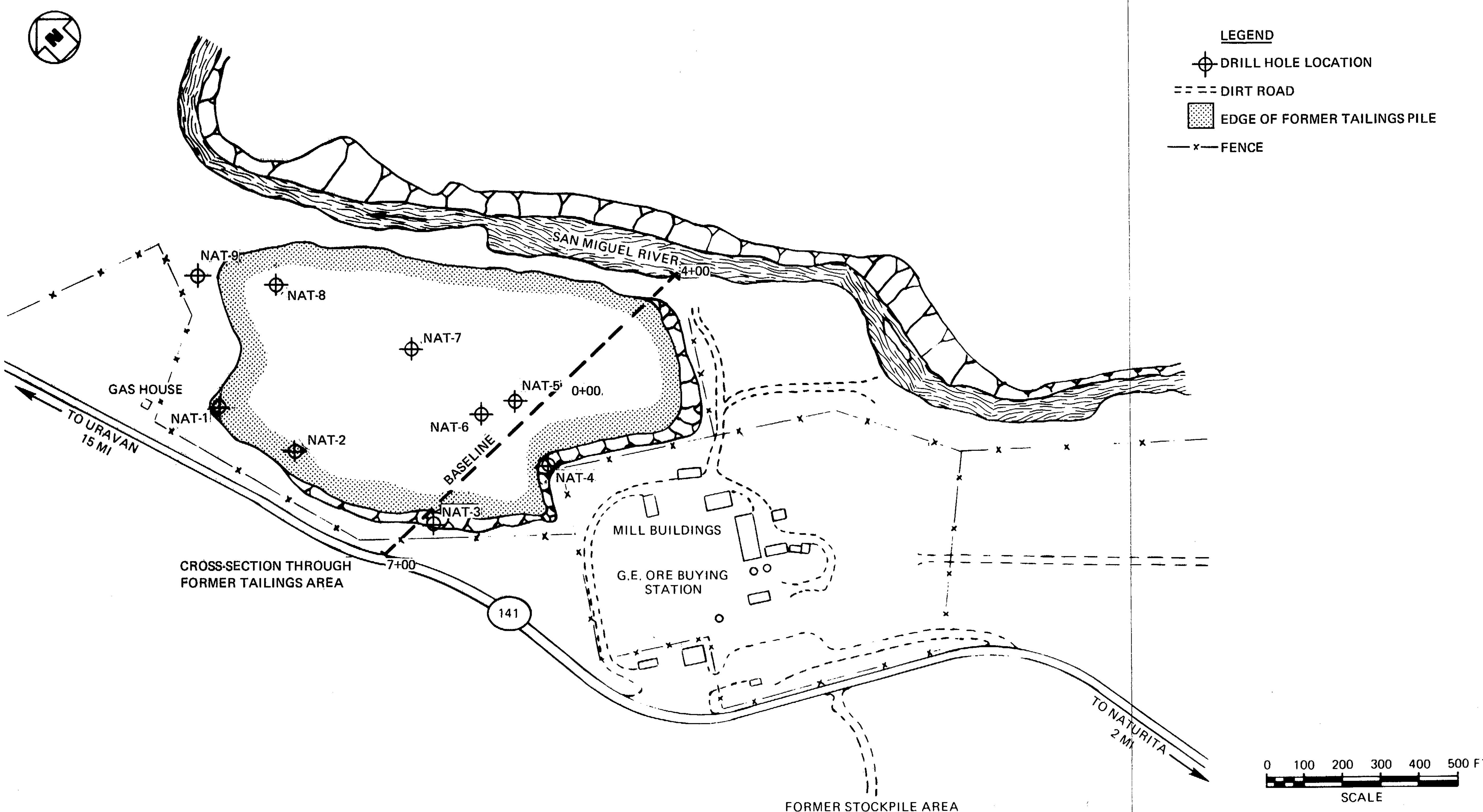


FIGURE 2-4. DESCRIPTIVE MAP/DRILL HOLE LOCATIONS

360-08 REV 12/80

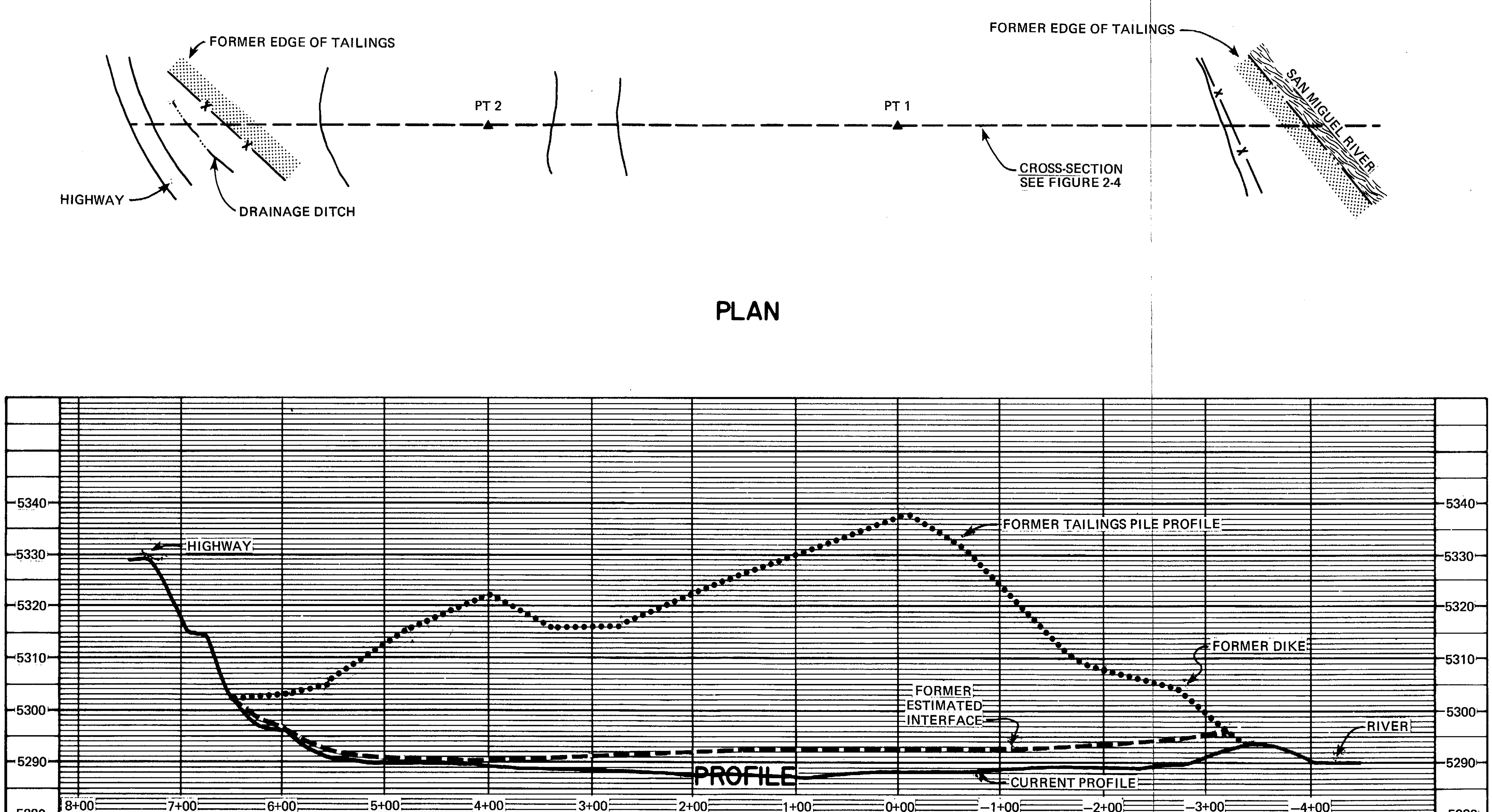


FIGURE 2-5. CROSS-SECTION THROUGH FORMER TAILINGS PILE AND CURRENT PROFILE

360-08 REV 12/80

SYSTEM	FORMATION	THICKNESS (FT)	CHARACTER	POSITION OF THE TAILINGS
CRETACEOUS	MANCOS SHALE	2,000-5,000	GRAY SHALE; FORMS VALLEYS AND SLOPES; AQUICLUDE	
	DAKOTA SANDSTONE	0-200	GRAY AND BROWN SANDSTONE, SHALE AND CONGLOMERATE; CAPS MESAS AND FORMS CLIFFS; LOW QUALITY, LOW QUANTITY AQUIFER	
	BURRO CANYON FORMATION	50-250	BLUFF CONGLOMERATIC SANDSTONE AND MAROON AND GREEN MUDSTONES; FORMS SLOPES, SANDSTONES FORM CLIFFS; LOW QUALITY, LOW QUANTITY AQUIFER	
JURASSIC	MORRISON FORMATION	300-500	BRUSHY BASIN MEMBER; VARICOLORED SHALES, SOME SANDSTONE; FORMS SLOPES; SANDSTONES YIELD WATER	← NATURITA TAILINGS
			SALT WASH MEMBER; LIGHT COLORED SANDSTONE, RED MUDSTONE; OCCASIONAL LIMESTONE; FORMS BENCHES; SANDSTONES YIELD WATER	
	SUMMERVILLE FORMATION	0-400	VARICOLORED MUDSTONES; THIN SANDSTONE UNITS; FORMS SLOPES; AQUICLUDE	
	ENTRADA SANDSTONE	50-1,000	MOAB MEMBER; FINE GRAINED WHITE SANDSTONES; FORMS STEPS; AQUIFER	
			SLICK ROCK MEMBER; LIGHT COLORED MASSIVE SANDSTONE; FORMS CLIFFS; AQUIFER	
TRIASSIC(?)	KAYENTA FORMATION	0-200	LENTICULAR SANDSTONES AND RED/PURPLE MUDSTONES; FORMS BENCHES; SANDSTONE ARE POTENTIAL LOW QUANTITY AQUIFERS	
TRIASSIC	WINGATE SANDSTONE	200-400	LIGHT COLORED MASSIVE SANDSTONES; FORMS CLIFFS; LOW QUANTITY AQUIFER	
OLDER SEDIMENTARY ROCKS				

FIGURE 2-6. SIMPLIFIED STRATIGRAPHIC COLUMN

360-08 11/77

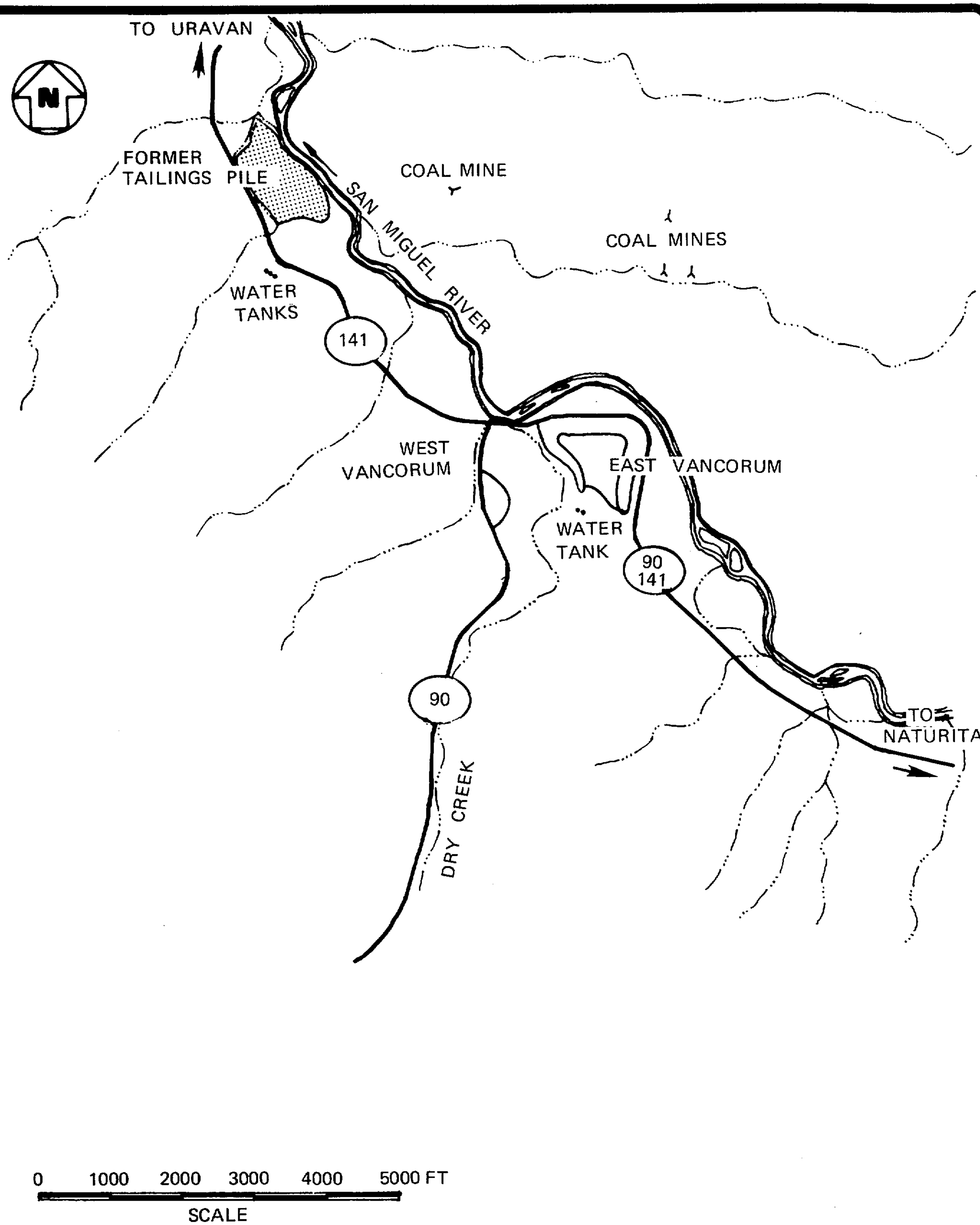
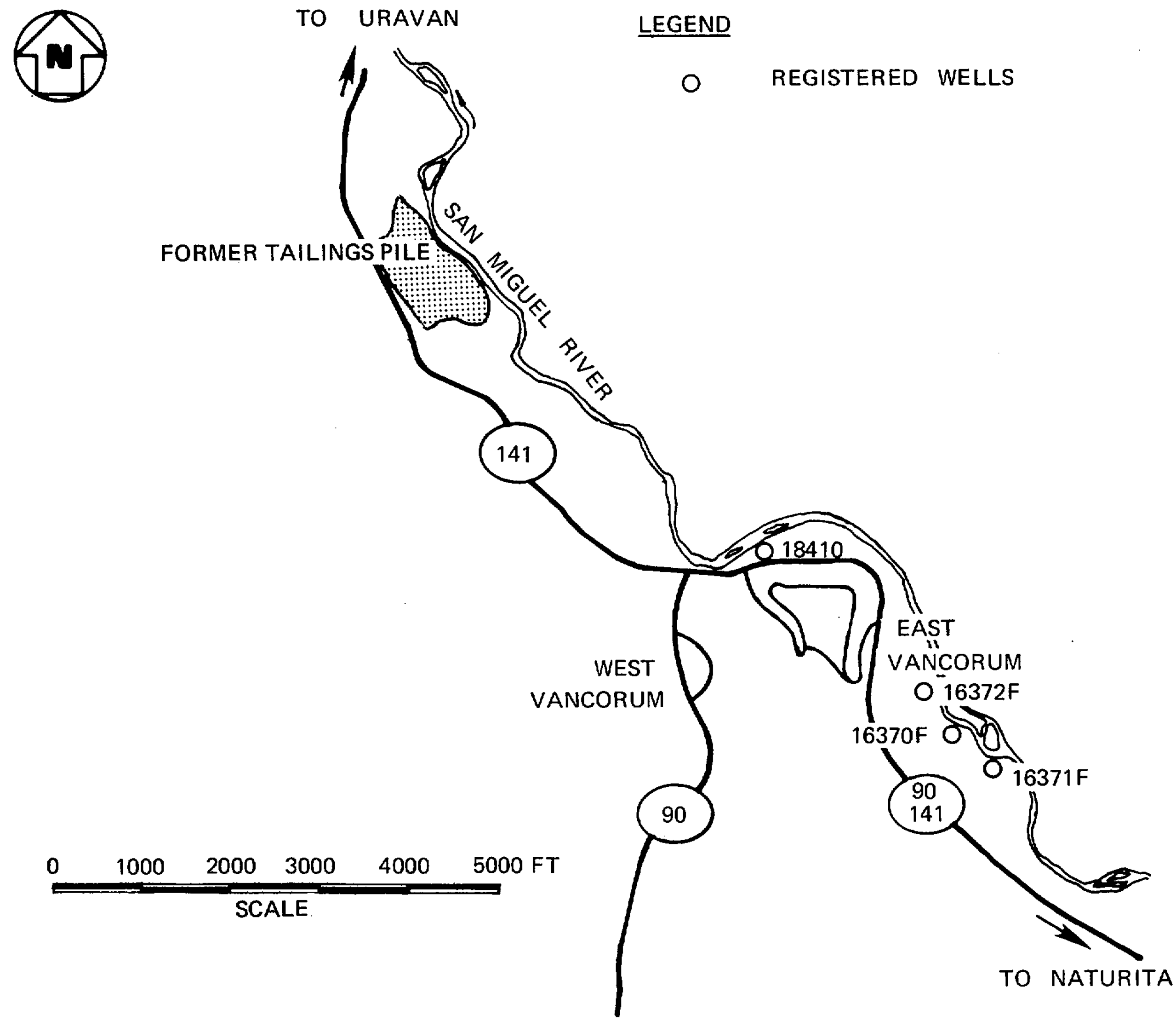


FIGURE 2-7. SURFACE DRAINAGE

360-08 11/77



Permit No.	Location	Yield (gal/min)	Depth (ft)	Static Water Level
18410	SW 1/4 SE 1/4, Sec. 14, T46N, R16W Non-Alluvial Well	8.0	240	218
16370F	SW 1/4 NW 1/4, Sec. 24, T46N, R16W	200	50	10
16371F	SW 1/4 NW 1/4, Sec. 24, T46N, R16W	200	50	10
16372F	SW 1/4 NW 1/4, Sec. 24, T46N, R16W	200	15	3

FIGURE 2-8. REGISTERED WELLS NEAR NATURITA

360-08 11/77

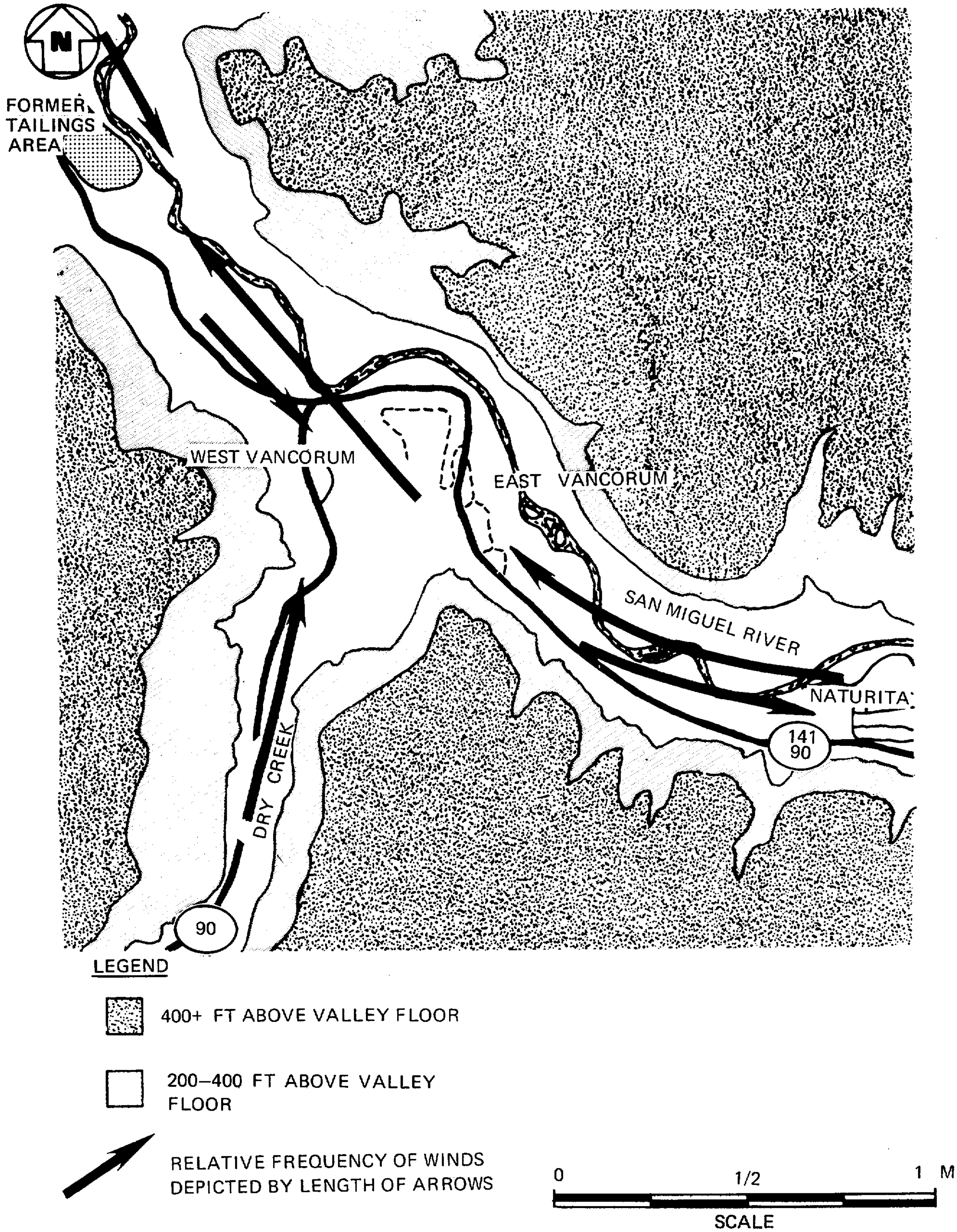


FIGURE 2-9. WIND MAP

360-08 11/77

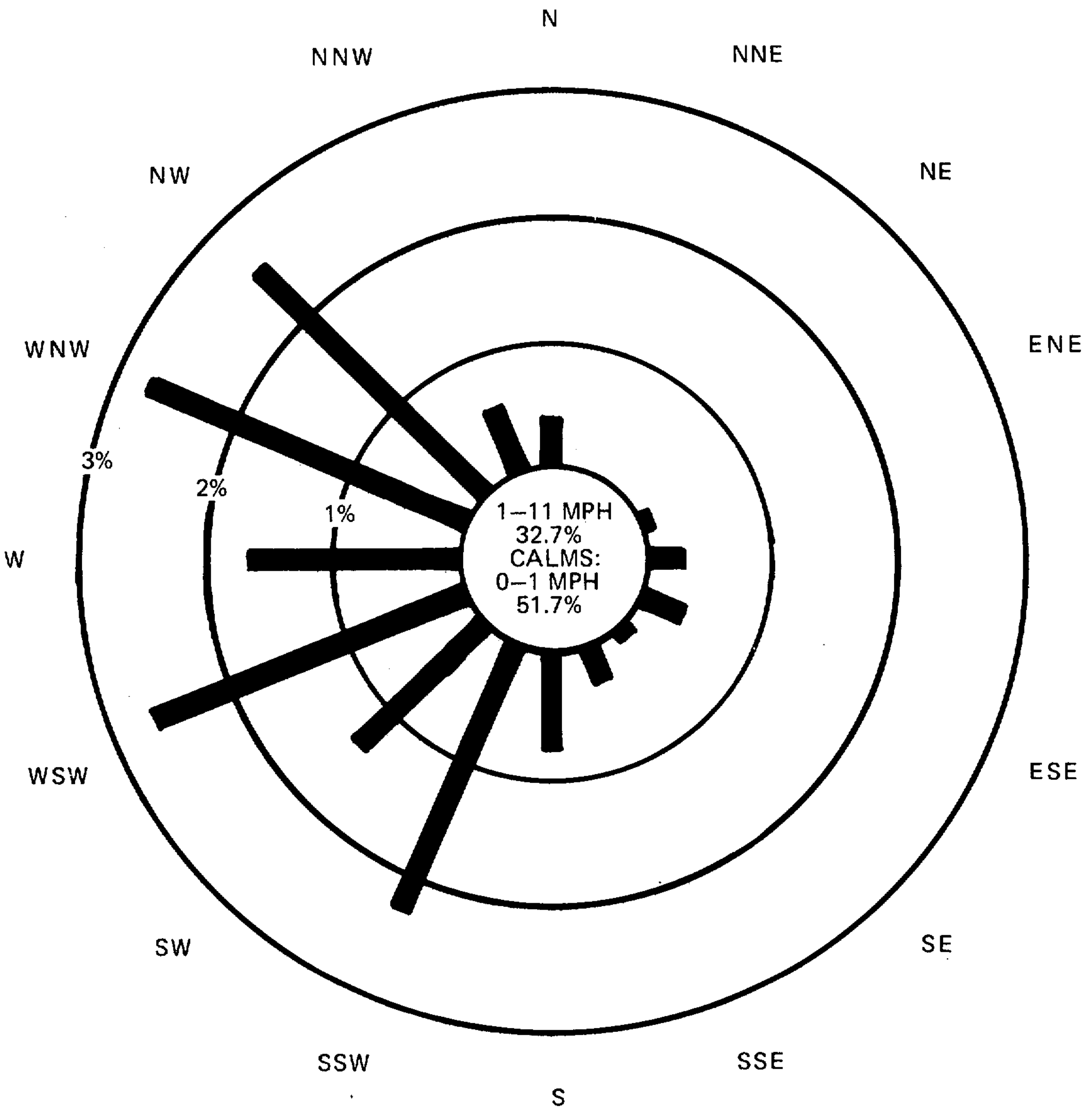


FIGURE 2-10. HOPKINS–MONTROSE COUNTY AIRPORT SURFACE WIND ROSE (CUMULATIVE DATA FROM 1970 AND 1971)

360-08 11/77

TABLE 2-1

TAILINGS SITE MATERIALS

Material	Volume (yd^3)	Weight[a] (tons)
Contaminated Soil in Former Tailings Area[b]	111,500	141,000
Contaminated Soil in Mill Area[c]	62,000	78,500
Contaminated Soil in Ore-Storage Area[d]	7,000	9,000
Contaminated Soil in Windblown Area[e]	85,000	107,500
Debris and Rubble	5,000	8,000
Total	270,500	344,000

[a]Weight based on average existing field densities which include moisture

[b]Based on 23 acres contaminated to an average depth of 3 ft

[c]Based on 19.3 acres contaminated to an average depth of 2 ft

[d]Based on 1.5 acres contaminated to an average depth of 3 ft

[e]Based on 105.7 acres contaminated to an average depth of 0.5 ft

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CHAPTER 2 REFERENCES

1. U.S. Department of Energy; "Proposed Designation of Processing Sites and Establishment of Priorities under the Uranium Mill Tailings Radiation Control Act of 1978 (Pub. L 95-604)"; Federal Register; Vol 44, No. 173, 51894; Sep 5, 1979.

2. Phase I "Report on Conditions of Uranium Millsite and Tailings at Naturita, Colorado"; AEC; Grand Junction, Colorado; Oct 1974.

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

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

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

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

CHAPTER 3

RADIOACTIVITY AND POLLUTANT IMPACT ON THE ENVIRONMENT

CHAPTER 3

RADIOACTIVITY AND POLLUTANT IMPACT ON THE ENVIRONMENT

A radiological survey of the Naturita site was conducted by Oak Ridge National Laboratory (ORNL),[1] concurrently with work performed by FB&DU in 1976. The relevant results of that work are included in this engineering assessment. In addition, this chapter describes briefly the potential radioactive and chemical pollutants and their pathways in the environment. The notations and abbreviations used are given in Table 3-1.

3.1 RADIOACTIVE MATERIAL CHARACTERISTICS

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

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

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

The activity and the total number of radioactive atoms of a particular type depend upon their creation rates as well as their half life for decay. If left undisturbed, the radioactive 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, as at Naturita, 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 1.3×10^5 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 18 off-site soil samples for each member of the uranium decay chain, assuming equilibrium, was 1.5 pCi/g.(1) The sample locations taken within a 130-mi radius of Naturita and the corresponding ^{226}Ra concentrations are shown in Figure 3-2. No previous measurements are available for the area. Another natural source of radiation in the environment arises from the decay of ^{232}Th, the predominant thorium isotope. The half-life of ^{232}Th is 1.4×10^{10} yr. It is also the parent of a decay chain containing isotopes of radium and radon. The average background value in the same off-site samples for each member of the thorium decay chain, assuming equilibrium, is about 1.1 pCi/g of soil. Table 3-2 lists the major background radioactive sources. Background values of the radium and thorium chains vary with locations by factors of 6 and 14, respectively.

Soil samples obtained in 1980 at distances of approximately 1 mi north, northeast, and south of the former site were analyzed for ^{226}Ra concentrations near the former Naturita tailings site. The sample taken north of the site contained 24 pCi of ^{226}Ra/g of soil. This value is obviously too high for a background soil sample and is considered to be caused by the presence of ore at the sample location. The samples taken northeast and south of the former site contained 2.9 and 1.8 pCi of ^{226}Ra/g of soil, respectively. For the purpose of this report, an average value of 2.3 pCi/g is taken to be the background concentration of ^{226}Ra in the soil at Naturita.

Background values of radon concentrations were measured at five locations using continuous radon monitors supplied by ERDA.(2) An average background value of 2.0 pCi/l was obtained from the 24-hr samples in the vicinity of the Naturita tailings pile. However, the range of the measurements extends from 1.0 to 3.2 pCi/l.

Background gamma ray levels, as measured 3 ft above the ground, also were determined at several locations within 1 mi of the site by using a calibrated and energy compensated Geiger Mueller detector. A value of 10 μR/hr was established as the average background level, but the values ranged from 7 to 13 μR/hr.(1) Cosmic rays are part of the radiation levels. The contribution from cosmic rays is generally dependent upon the altitude and is approximately 7 μR/hr in the Naturita area,[3] or approximately 70% of the measured average background value.

3.4 RADIATION EXPOSURE PATHWAYS AND CONTAMINATION MECHANISMS

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

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

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

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

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

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

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

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

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

3.4.1 Radon Gas Diffusion and Transport

Field measurements of the radon exhalation flux from the site were made on July 17 and 18, 1980, using the charcoal canister technique.(4) The locations of the canisters and the corresponding flux values are shown in Figure 3-3. These updated values range from 1 to 124 pCi/m^2-s with an area-weighted average value of 34 pCi/m^2-s on the former tailings site. The large variations in radon flux from the surface where the tailings pile originally stood may be explained as being due to scattered areas of residual contamination by uranium tailings. A relatively high flux value was obtained in the mill area, possibly due to spilled ores. The weather was warm and dry during the measurement period and the soil surface was dry. Radon flux depends primarily on radium content of the tailings in soil; however, reported values of radon flux vary considerably between measurements taken at a single location at different times. These variations are due, in part, to differing moisture, soil characteristics, climatological factors, and major changes in pile configuration.

Since calibrated Wrenn chambers(2) were not available at the time of the 1980 field work, the current atmospheric radon conditions could not be measured. Radon concentration measurements reported in the November 1977 engineering assessment are no longer considered accurate because the tailings pile has been removed. The estimated background radon concentration, however, remains unchanged at 2 pCi/l and radon concentrations in the vicinity of the former tailings site are judged to be close to background concentrations.

3.4.2 Direct Gamma Radiation

The external gamma radiation (EGR) levels measured on the site of the former tailings pile are shown in Figure 3-4. These uncorrected measurements included background and were taken with a gamma scintillometer held about 3 ft above ground. The uncorrected measurements on site ranged from 30 to 850 μR/hr, with the site average being about 200 μR/hr. This average is about 20 times the average background value mentioned in the November 1977 engineering assessment. One of the highest gamma radiation rates, 550 μR/hr, was measured at the location where the highest radon flux was measured--near the southwest corner of the former tailings pile.

EGR levels taken in 1976 in the stockpile area south of Highway 141 are also depicted in Figure 3-4. The measurements of external gamma radiation off the former tailings area reported in the November 1977 engineering assessment report can be considered as conservatively high estimates.

Although gamma surveys off the site at Naturita were conducted in 1976, the levels are believed to have been reduced only within about 0.1 mi of the former pile where EGR levels were influenced by shine from the former pile. Measurements of EGR levels away from the tailings pile, taken at 100-yd intervals, reached background levels at less than 0.2 mi to the northeast and southwest of the site. Along the San Miguel River Valley, where the wind had carried tailings, background levels of gamma radiation were reached at a distance of 0.3 mi in the southeasterly direction. In the north-northwesterly direction the gamma radiation was still two times background at 0.8 mi; however, the gamma radiation in this direction beyond 0.3 mi is mainly caused by sources other than the tailings pile (e.g., natural surface deposits, spilled ore, tailings, and mill stack contamination). These gamma radiation rate measurements are shown in Figure 3-5. The reduction of gamma radiation as a function of distance from the pile is shown in Figure 3-6.

3.4.3 Windblown Contaminants

Measurements and data analyses were performed in 1980 to establish the boundary of that region around the site which exceeds 5 pCi/g of ^{226}Ra concentration in the soil. A lead-shielded scintillometer had one unshielded end directed towards 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 the "delta", represents the concentration of radioactive materials in the soil at that location. A difference of about 400 counts/min between the shielded and unshielded count rates has been experimentally determined to indicate an area of about 5 pCi/g of ^{226}Ra soil concentration with the meter used.

Eight traverses were conducted with the scintillometer across open lands adjacent to the tailings pile and were extended to those locations where 5 pCi/g of ^{226}Ra in the soil was indicated. These locations are connected in Figure 3-7 to indicate the estimated 5-pCi/g contour around the site. The off-site lands which are included within this contour are designated as windblown contaminated lands and cover approximately 106 acres. For the purposes of remedial action cost estimating, it is assumed that the windblown contaminated lands will be cleaned up by removing an average of 6 in. of topsoil from this area. No attention has been given the topography adjacent to the site in defining the windblown boundary, although the boundary does include some very rugged terrain.

The estimated 5-pCi/g contour was reached within 400 ft east of the San Miguel River and 600 ft west of Highway 141. However, due to prevailing winds at the site, which blow primarily up and down the canyon, the 5-pCi/g boundary extends 1,800 ft to the northwest and 1,200 ft to the southeast of the site.

The results of a 1974 EPA gamma survey[5] in the vicinity of the Naturita site are presented in Figure 3-8. The estimated 5 pCi/g boundary described above corresponds reasonably well to the 10 μR/hr iso-exposure line developed by the EPA.

3.4.4 Ground and Surface Water Contamination

The entire former tailings area is subject to flooding from the San Miguel River, and no dike exists to protect the area. Therefore, spreading of the residual contamination at the site could occur through surface water action.

Since the majority of the tailings have been removed, there is little possibility that the remaining soil contamination will cause any appreciable contamination of surface waters. Although measurements made in 1976 of ^{226}Ra concentrations in surface waters at Naturita[1] may be of limited value due to the tailings removed, these data are presented in Figure 3-9 and Table 3-3. In spite of the presence of the tailings pile, the levels of contamination were considerably below the EPA Interim Primary Drinking Water Regulations in 1976. The quality of the San Miguel River with respect to ^{226}Ra was monitored from 1961 to 1970. The average ^{226}Ra level during this period upstream from the tailings was 70.06 pCi/l, and the average level downstream was 0.17 pCi/l.[6] ?

3.4.5 Soil Contamination

The technique for identifying areas where the ^{226}Ra concentration in the soil exceeds 5 pCi/g, described in Paragraph 3.4.3, was used at 400-ft intervals over the former tailings pile area. More than 80% of the "delta" measurements exceeded 400 counts/min, indicating areas where the ^{226}Ra concentration exceeded 5 pCi/g. These measurements show that not all of the residual contamination was removed from the site and additional remedial action is required to meet EPA standards.

The ^{226}Ra activity in the soil was determined by logging the gamma profile in drill holes at nine locations at the site of the former tailings pile. Drill hole locations (labeled "NAT") are shown in Figure 2-4. The gamma profile was measured in these holes using a Geiger tube with a lead shield that collimated the radiation. Soil samples were collected from the drill holes at depth intervals of 1 ft for radiological analysis. The ^{226}Ra concentration in the soil samples is shown in Table 3-4.

Typical ^{226}Ra activity profiles of bore holes on the Naturita site are shown in Figures 3-10 and 3-11. Figure 3-10 illustrates the ^{226}Ra profile at hole NAT-1, located in the northwest corner of the former tailings pile area. Figure 3-11 illustrates the radiometric profile of auger hole NAT-7, located in the central portion of the former tailings pile area.

It is estimated that contamination in excess of 5 pCi/g above background can be found as much as 5 ft below the present surface of the ground in some areas. The average depth of contamination to be cleaned during remedial action is considered to be about 3 ft in the former tailings area.

3.4.6 Off-Site Tailings Use

Some of the uranium tailings have been moved physically from the site and used as fill material under and around structures in Naturita and Nucla. These locations have been identified by a mobile survey and by follow-up gamma surveys of individual locations in 1976. The locations and survey results are discussed in Chapter 7 where remedial action is considered.

3.5 REMEDIAL ACTION CRITERIA

The Grand Junction criteria for remedial action were adopted as a basis for the engineering assessments that preceded the enactment of PL 95-604, the Uranium Mill Tailings Radiation Control Act of 1978. The criteria adopted applied to: (a) the cleanup of structures[7] 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 standards (45 FR 27366) and proposed cleanup standards (46 FR 2556). Some changes may be made based on public comments; however, in the absence of substantial new information, changes in the standards sufficient to affect the cleanup actions required or the estimated costs are not expected.

3.5.1 EPA Interim and Proposed Standards

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

3.6 POTENTIAL HEALTH IMPACT

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

(a) Radon Diffusion - Inhalation of radon daughters from radon diffusion constitutes the most significant pathway and results in the largest estimated population dose.[1,8] Elevated concentrations were measured to 0.4 mi from the former tailings pile.

(b) External Gamma Radiation - Gamma radiation above background is measurable to distances up to 0.2 mi to the northeast and southwest of the pile, an area with very few inhabitants. People on site will receive some gamma exposure until the pile is covered with sufficient material to reduce the gamma radiation. Exposure to the local population within 0.3 mi from the pile has been evaluated and found to have negligible health impact compared with exposure from radon daughters.

(c) Airborne Activity - The limited, directional spread of significant quantities of windblown tailings toward inhabited areas indicates that direct inhalation or ingestion of tailings particles may be a minor component of the total population dose. This is a general result also reported at other uranium tailings piles.[9,10] Added stabilization of the Naturita former tailings area against wind erosion would eliminate the gradual accumulation of tailings off the site, particularly to the north and southeast if the contamination were not moved.

(d) Water Contamination - The low ^{226}Ra activity in nearby off-site surface water indicates slight ^{226}Ra contamination from the tailings, as confirmed by measurements since 1961.

(e) Subsoil Contamination - Leaching of radioactive materials into the ground beneath the former pile and at the millsite is considerable in some areas. Water analyses do not indicate significant contamination from this pathway, however.

(f) Physical Removal - Tailings that have been placed near a structure or used in its construction are sources for elevated gamma levels and radon daughter concentrations in the structure. Radiation exposure to individuals living or working in these structures can be significant. (For details refer to Chapter 7.)

Only the potential health effects from the inhalation of radon daughters (pathway a) are estimated quantitatively in this assessment because this pathway produces the most significant exposure.[8,10] 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 in this analysis. For the purpose of this engineering study, lung cancer is the potential health effect considered for RDC. The health effects were estimated using an absolute risk model.

3.6.1 Assumptions and Uncertainties in Estimating Health Effects

Since radiation exposure from ^{222}Rn progeny is expressed in terms of working levels (WL) and working level months (WLM), total population exposures as well as health risk estimates are based upon these units; i.e., person-WLM. Exposures and resulting health effects are often expressed in terms of rems, however, estimates of the WLM-to-rem conversion factor for internal lung exposure to alpha particles from ^{222}Rn progeny are observed to vary by over an order of magnitude.(11) 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(12) risk estimator for lung cancer is based only on the absolute model since the relative risk model is not considered valid.(13)

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.[14] 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 specific 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.[15] For the lifetime plateau to age 75, no cancers were assumed to occur in the years subsequent to age 75. The following cumulative risk estimator for the population at large is obtained using a lifetime plateau to age 75 and weighting by the age distribution of the U.S. population:

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

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

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

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

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

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

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

The risk estimator used for continual exposure to gamma radiation is expressed as:[16]

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

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

3.6.2 Health Effects

The health effects were calculated using a ^{222}Rn flux of 100 pCi/m^2-s for the pile, which was calculated using diffusion theory and the physical properties of the contaminated soil. 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 contaminated area was modeled using a Gaussian plume model, meteorology characteristics of the Naturita area, site characteristics, and population distribution surrounding the former tailings area as a function of radius and direction from the edge of the site. The contaminated area was modeled as a cylindrical source with a surface area equivalent to the total exposed area of the site.

Outdoor ^{222}Rn concentration is shown as a function of distance from the center of the former tailings area in Figure 3-12. The predicted radon concentrations are much lower than the measured values shown in Figure 3-12, since the measurements were made when the pile was present, whereas the predictions are based on conditions after the pile was removed.

Figure 3-13 shows the lung cancer risk per year from continuous exposure to radon as a function of distance from the edge of the contaminated area. As shown in the figure, the risk of developing lung cancer from radon being released from the former tailings area in Naturita is less than 1.2 times the natural occurrence from all causes at a distance of 0.1 mi from the edge of the contaminated area.

The population distribution within 4 mi of the edge of the contaminated area was developed using 1980 census estimates for the Naturita-Nucla vicinity,(17) as presented in Chapter 4. Three population projections to the year 2005 were used: 0.8 and 2% constant growth rates, and a 5% declining growth rate, as outlined in Chapter 4.

Table 3-5 lists the estimated health impacts from the tailings area for 0 to 4 mi from the edge of the former tailings site, based on updated 1980 population figures. Also included are the 25-yr cumulative health effects for the three growth scenarios. In Table 3-5, the health effects attributable to radon emanating from the area are shown to be about 0.3% of those caused by background radon, for the vicinity within 4 mi of the edge of the former tailings pile.

3.7 NONRADIOACTIVE POLLUTANTS

Chemical analyses of tailings samples obtained from drill holes during the 1976 field work showed arsenic and lead in concentrations measuring 0.5 and 3.5 ppm, respectively. Vanadium was present in concentrations as high as 3,000 ppm.

Four water samples were taken in 1976 from the Naturita tailings pile and vicinity and chemically analyzed. The locations of these samples are shown in Figure 3-6. Samples A and C were obtained from the San Miguel River 100 yd upstream and 100 yd downstream from the pile, respectively. Samples B and D were taken from standing water in a ditch along the northern edges of the tailings pile.

All of these water samples, except sample A from the San Miguel River, contained selenium above the EPA Interim Primary Drinking Water Regulations, as shown in Table 3-3. The selenium content increased about 30% in the San Miguel River as it flowed by the Naturita tailings pile to about 1.2 times the EPA standard of 0.01 mg/l. River samples both upstream and downstream from the tailings contained chromium at or above the limit of the EPA Interim Primary Drinking Water Regulations. Standing water that had flowed off the tailings did not contain measurable amounts of chromium.

Standing water north of the former tailings pile contained higher than acceptable levels of arsenic, lead, and selenium; however, the San Miguel River samples did not indicate an increase in the arsenic and lead as the river flowed by the pile.

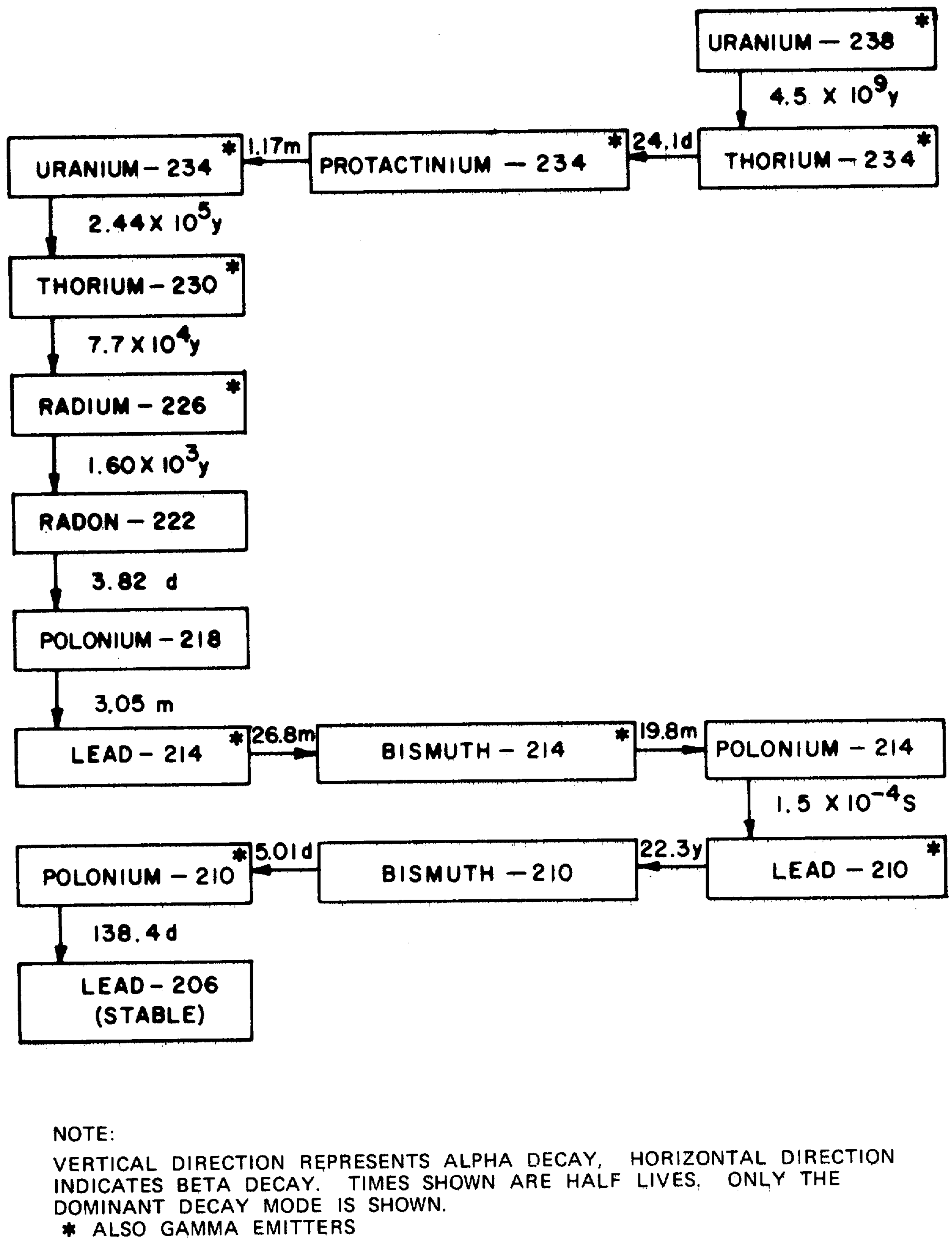


FIGURE 3-1. RADIOACTIVE DECAY CHAIN OF URANIUM-238

360-08 11/77

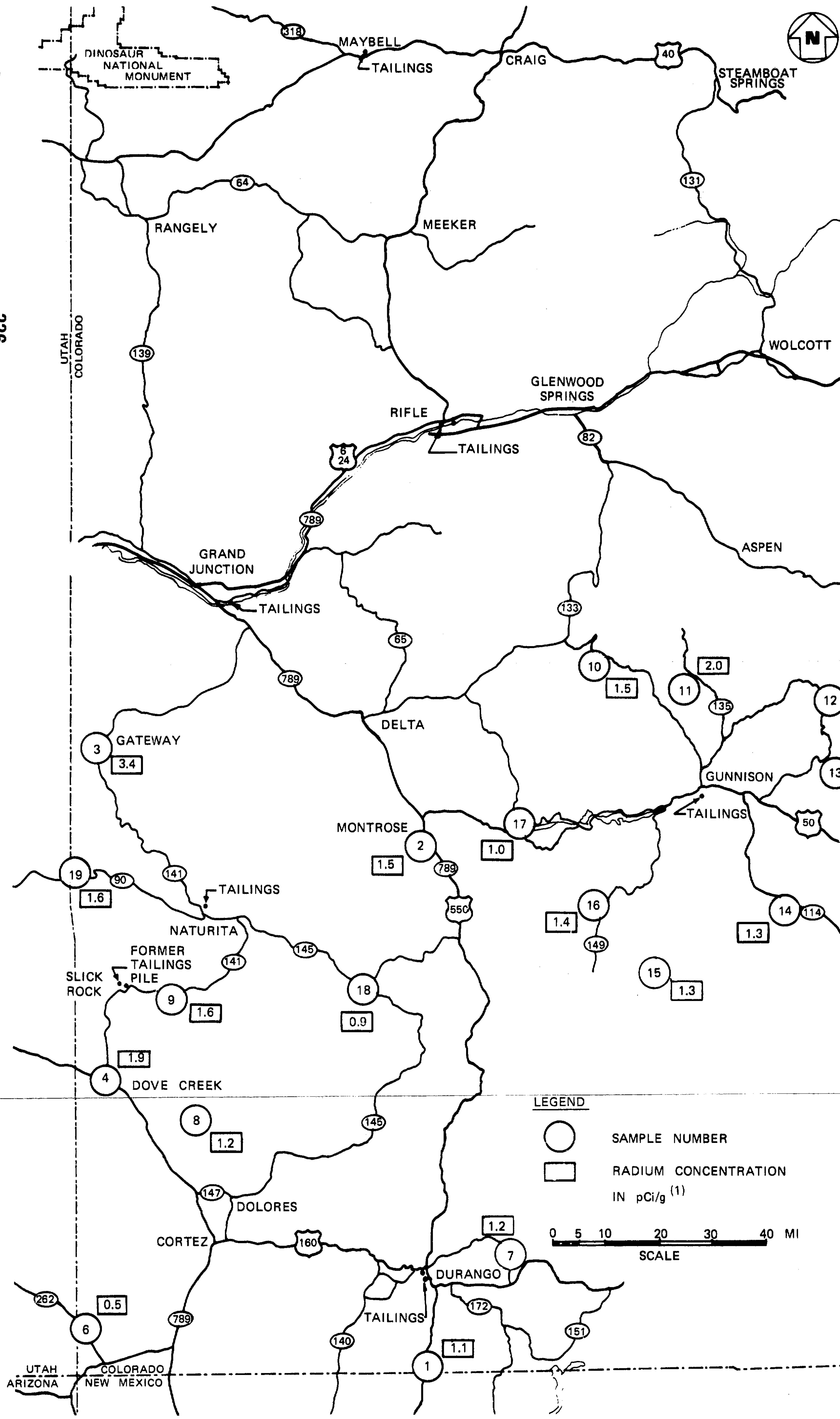


FIGURE 3-2. LOCATIONS FOR ^{226}Ra BACKGROUND SAMPLES

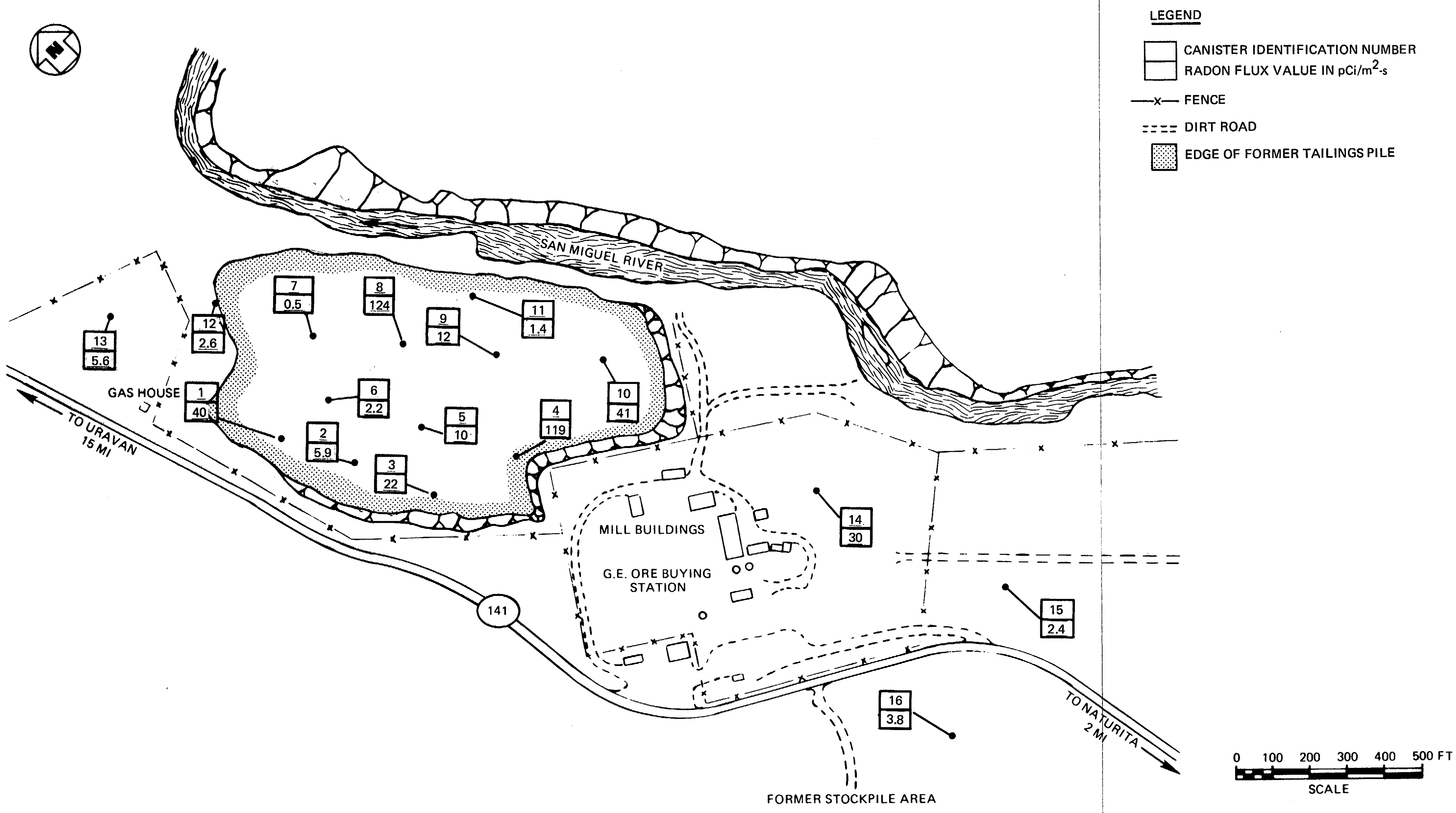


FIGURE 3-3. RADON CANISTER LOCATIONS AND FLUX VALUES

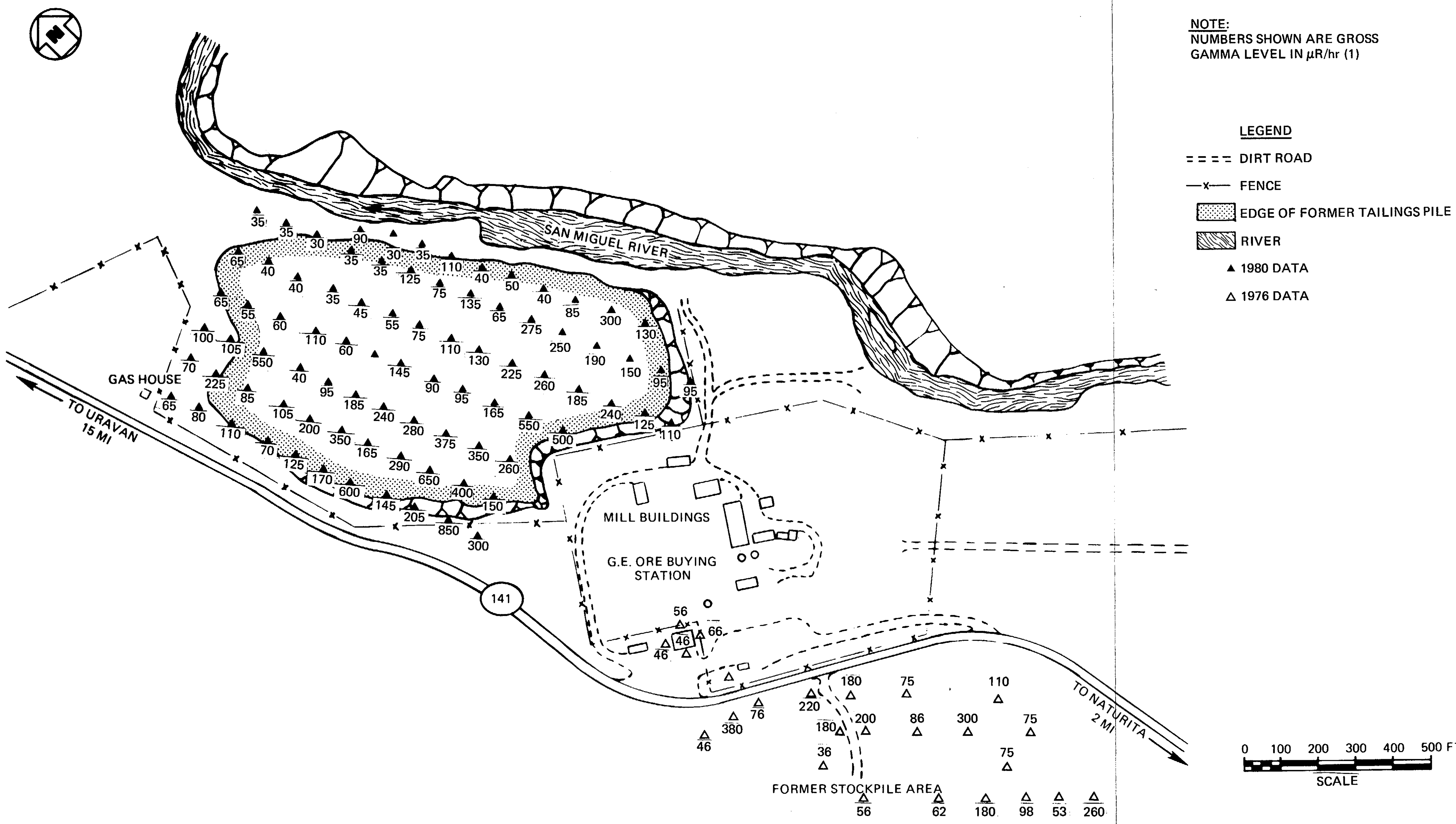
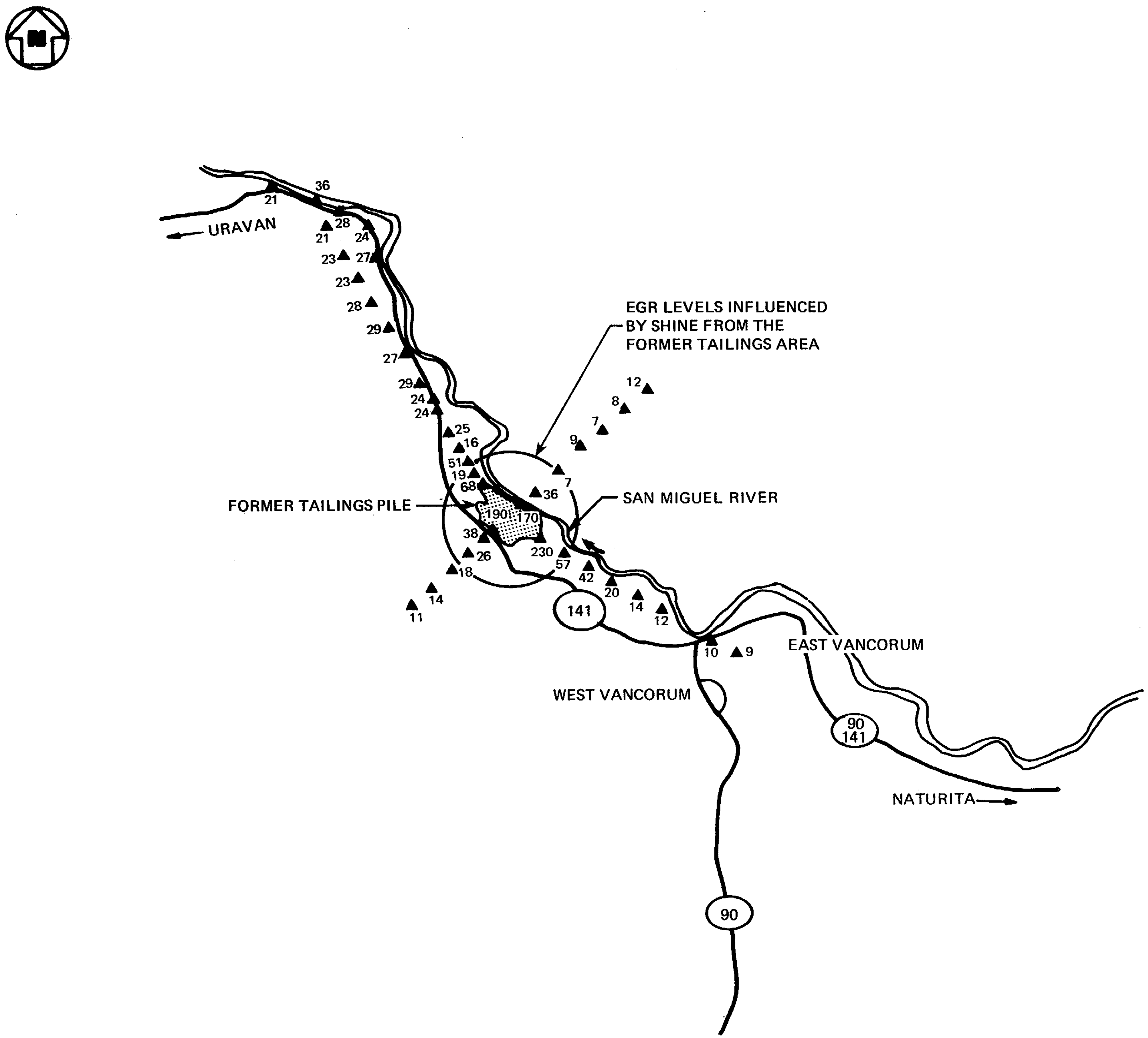


FIGURE 3-4. GAMMA LEVELS AT SITE 3 FT ABOVE GROUND

360-08 REV 6/81



NOTES:

1. NUMBERS SHOWN ARE GROSS GAMMA LEVELS IN μR/hr [1]

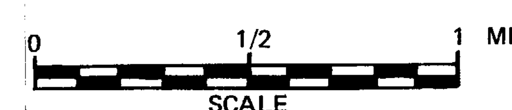


FIGURE 3-5. GAMMA LEVELS IN VICINITY 3 FT ABOVE GROUND

360-08 REV 6/81

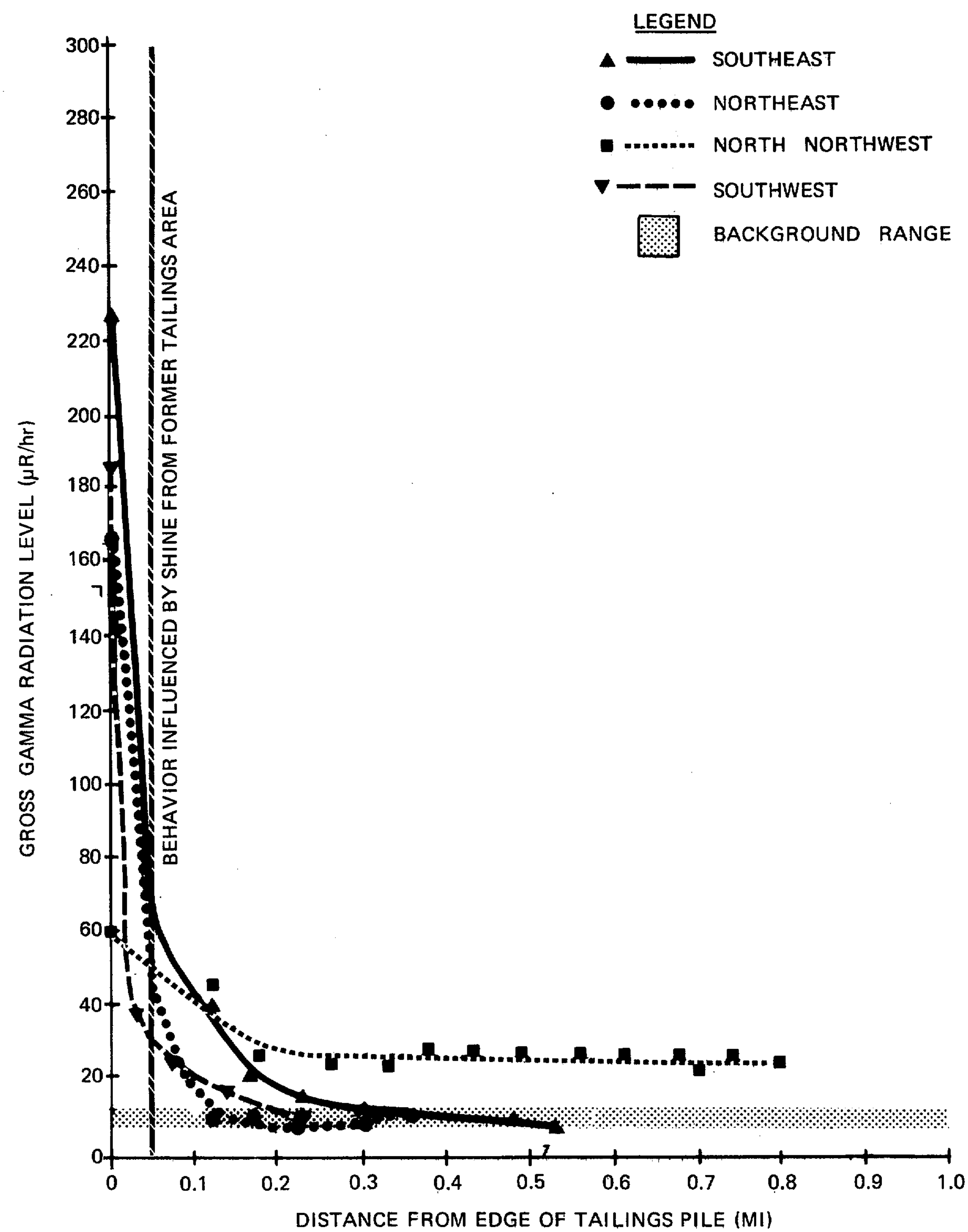


FIGURE 3-6. REDUCTION OF EXTERNAL GAMMA RADIATION LEVELS WITH DISTANCE FROM THE TAILINGS PILE

360-08 REV 6/81

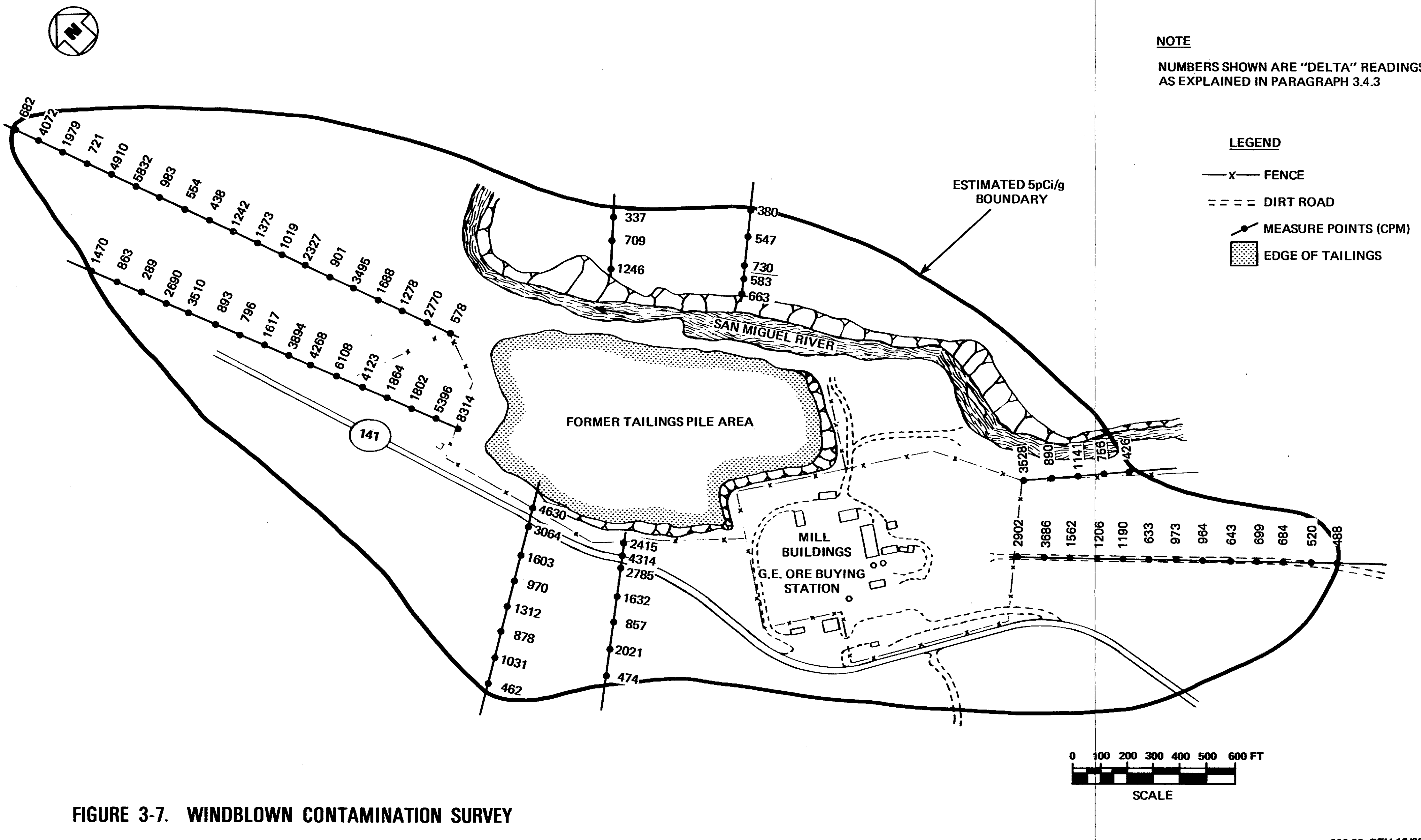


FIGURE 3-7. WINDBLOWN CONTAMINATION SURVEY

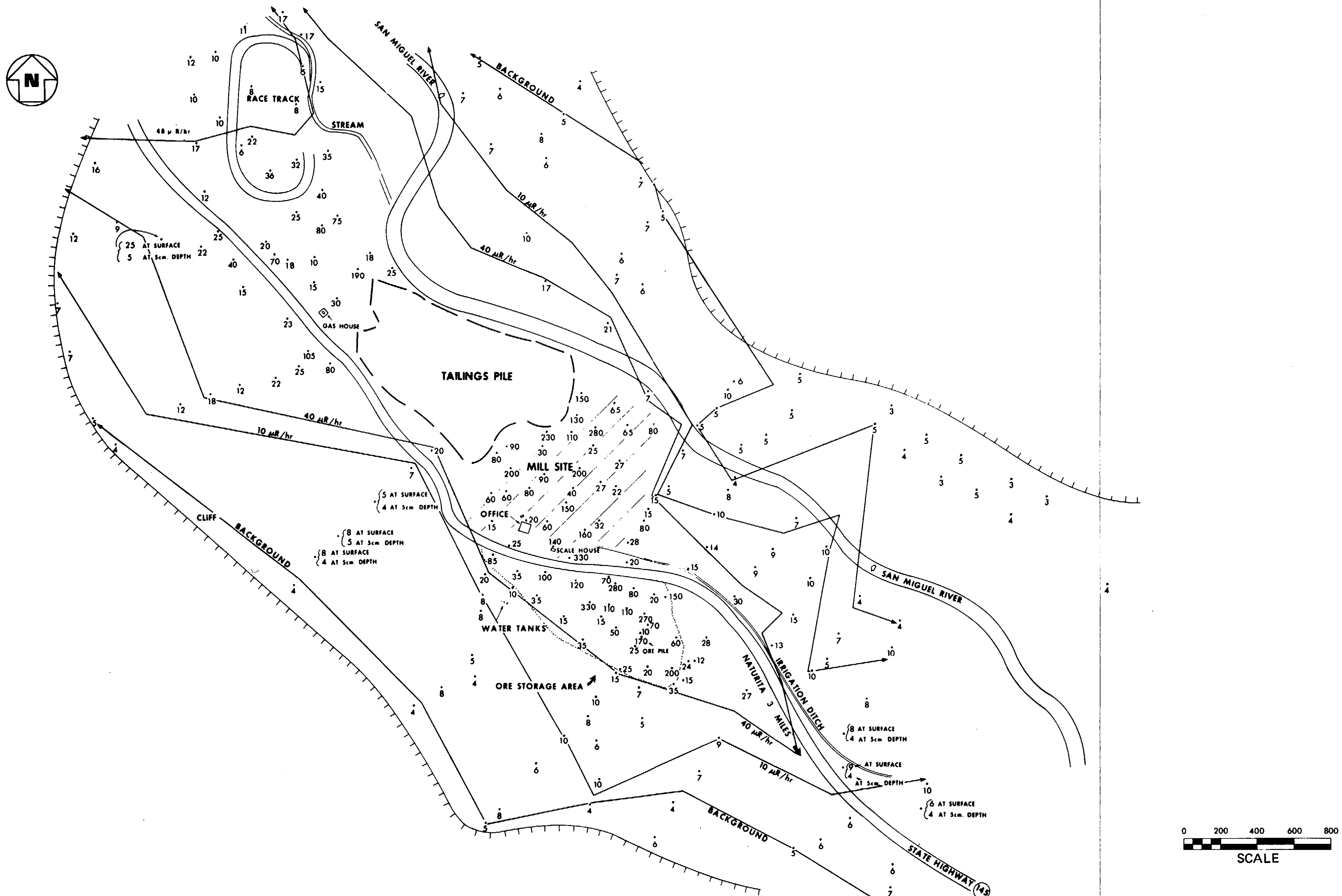


FIGURE 3-8. EPA GAMMA SURVEY AT NATURITA SITE

360-08 6/81

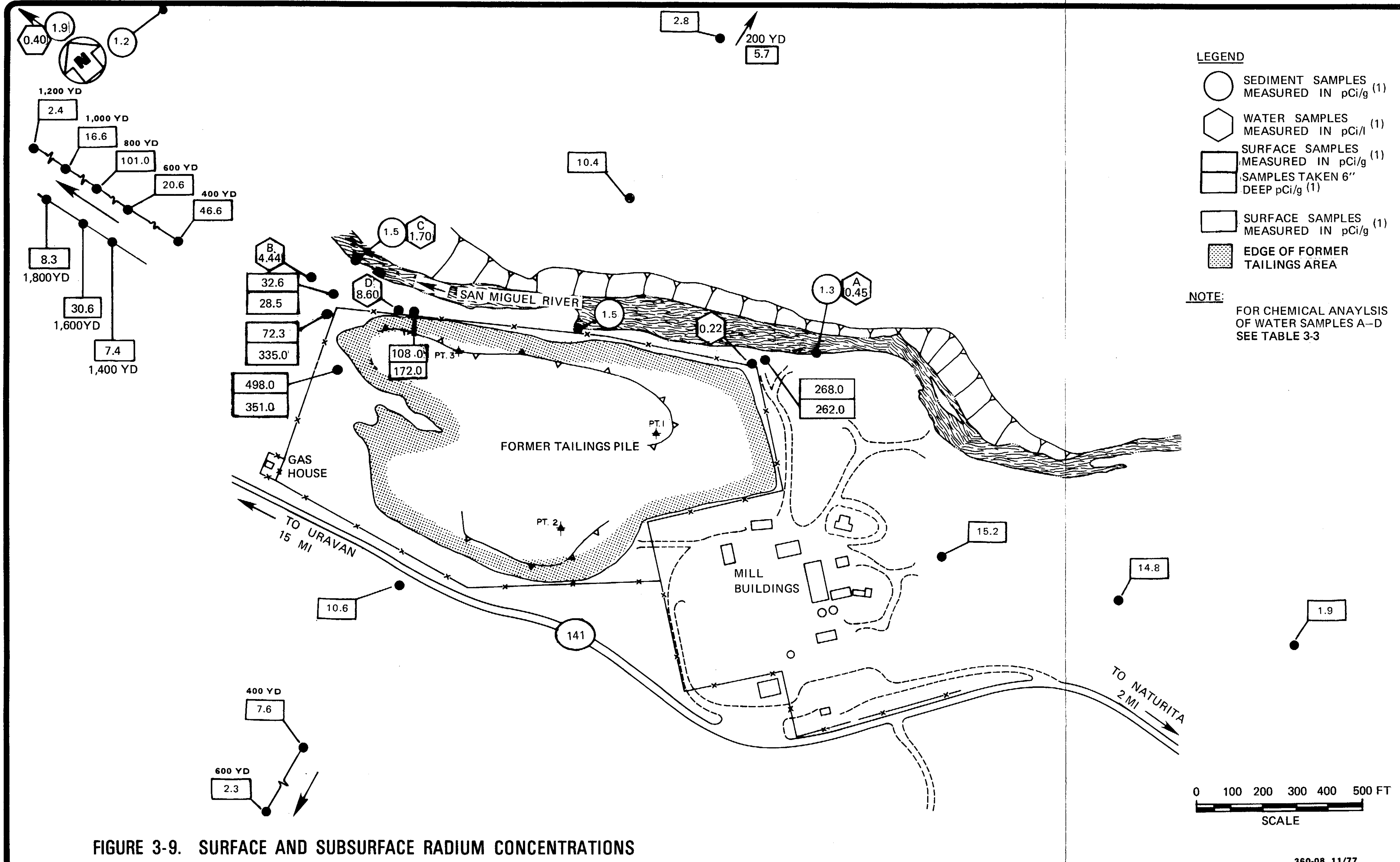


FIGURE 3-9. SURFACE AND SUBSURFACE RADIUM CONCENTRATIONS

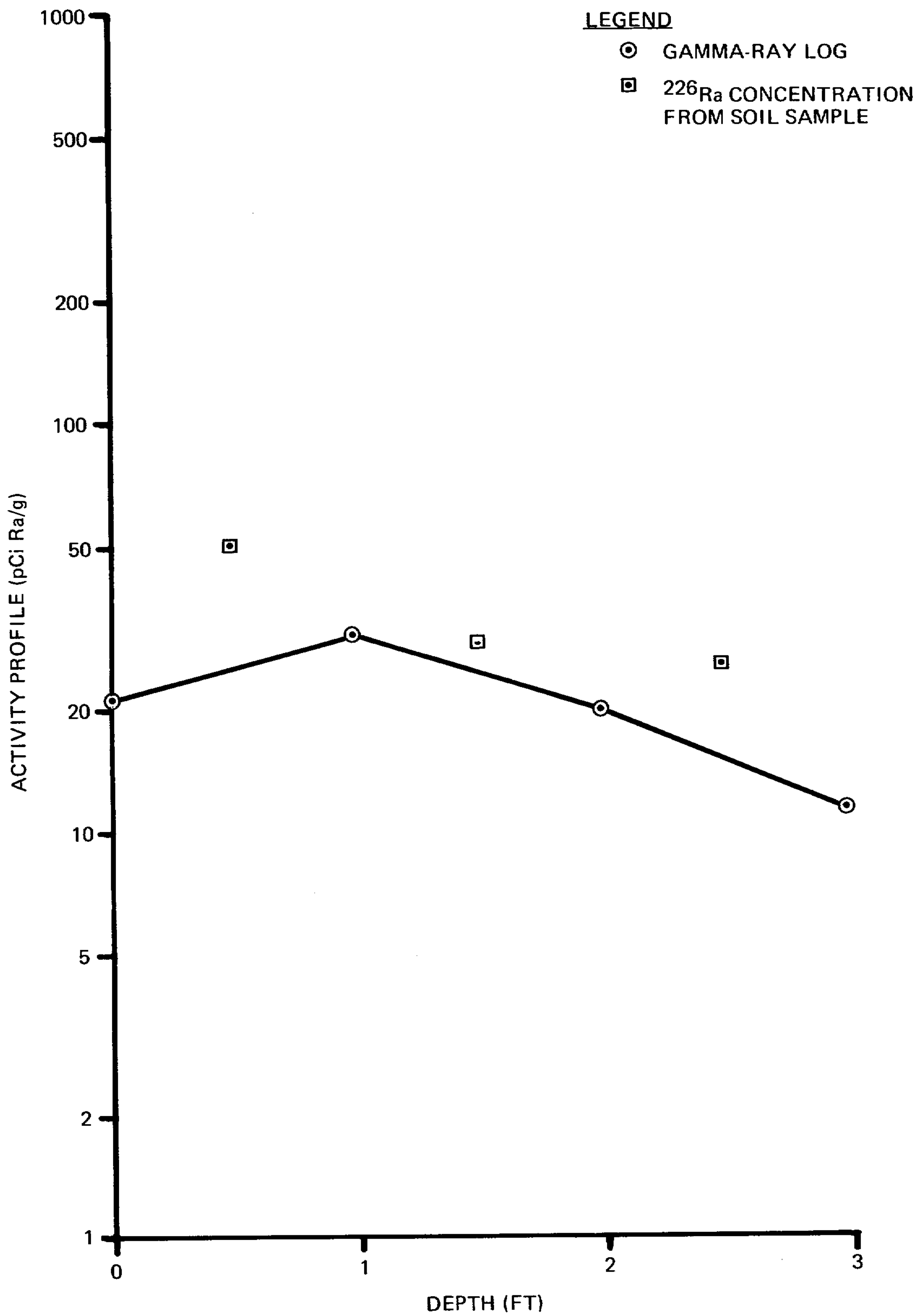


FIGURE 3-10. RADIOMETRIC PROFILE AT DRILL HOLE NAT-1

360-08 REV 12/80

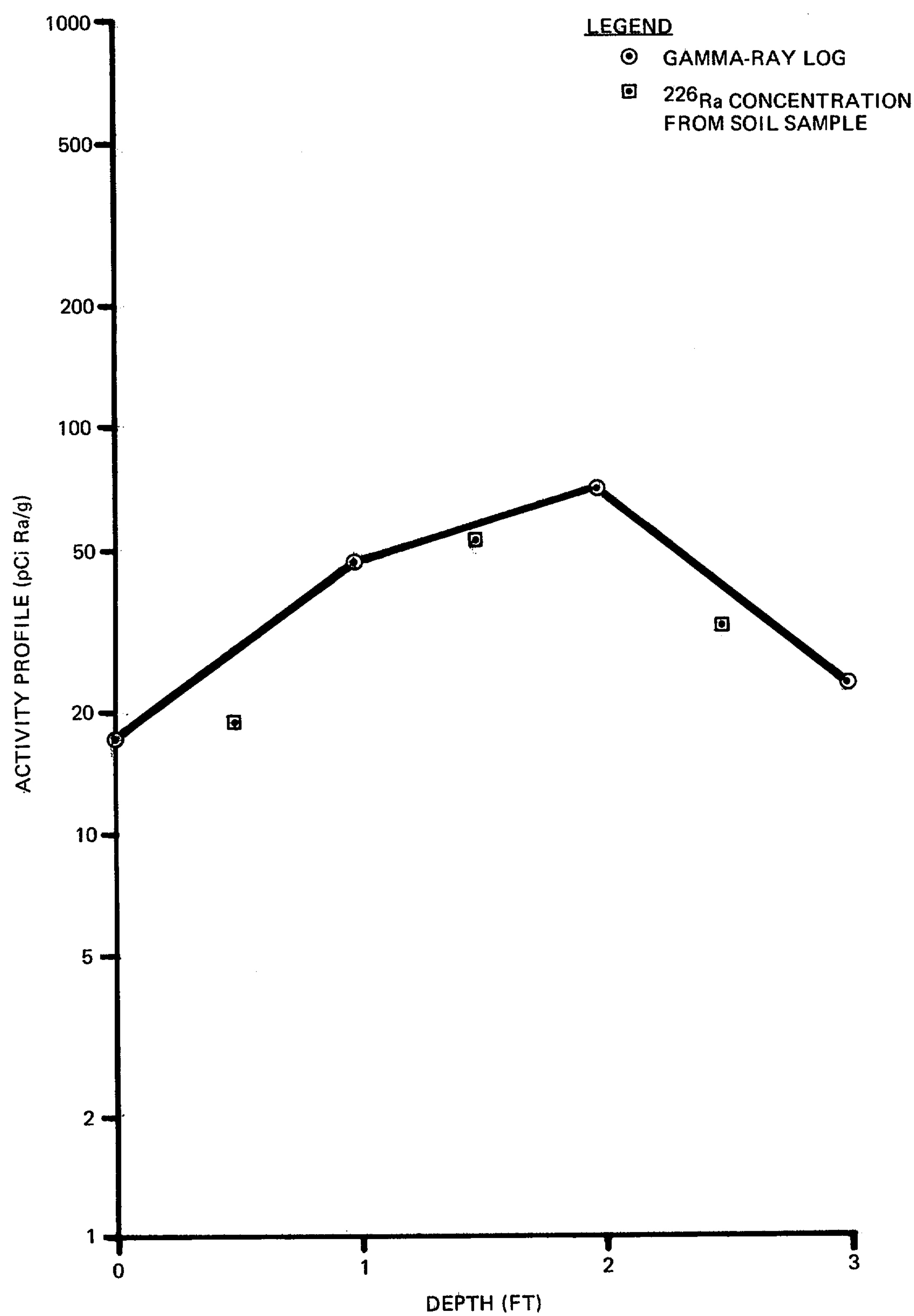


FIGURE 3-11. RADIOMETRIC PROFILE AT DRILL HOLE NAT-7

360-08 REV 12/80

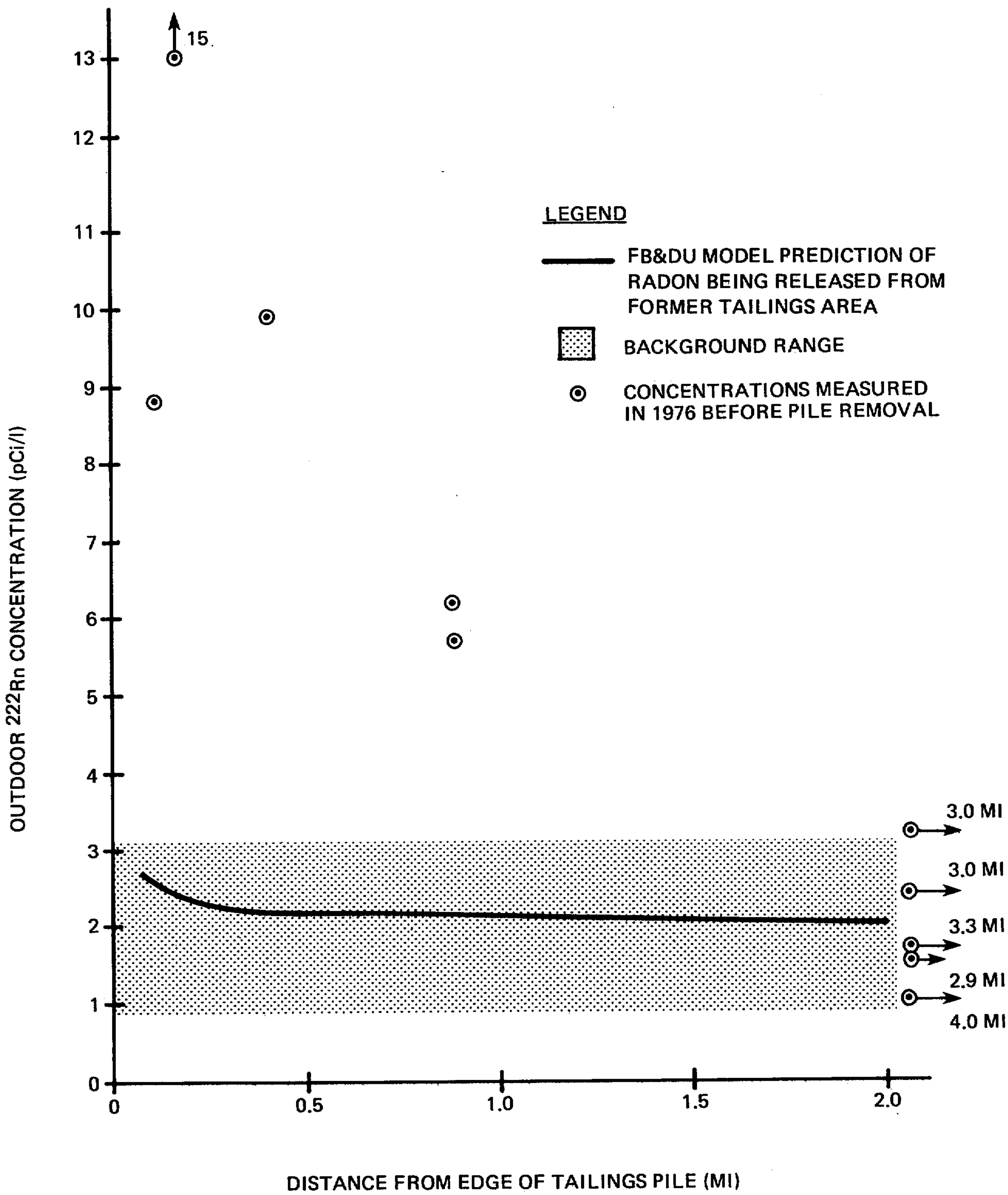


FIGURE 3-12. REDUCTION OF OUTDOOR ^{222}Rn CONCENTRATION WITH DISTANCE FROM THE FORMER TAILINGS PILE

360-08 REV 12/80

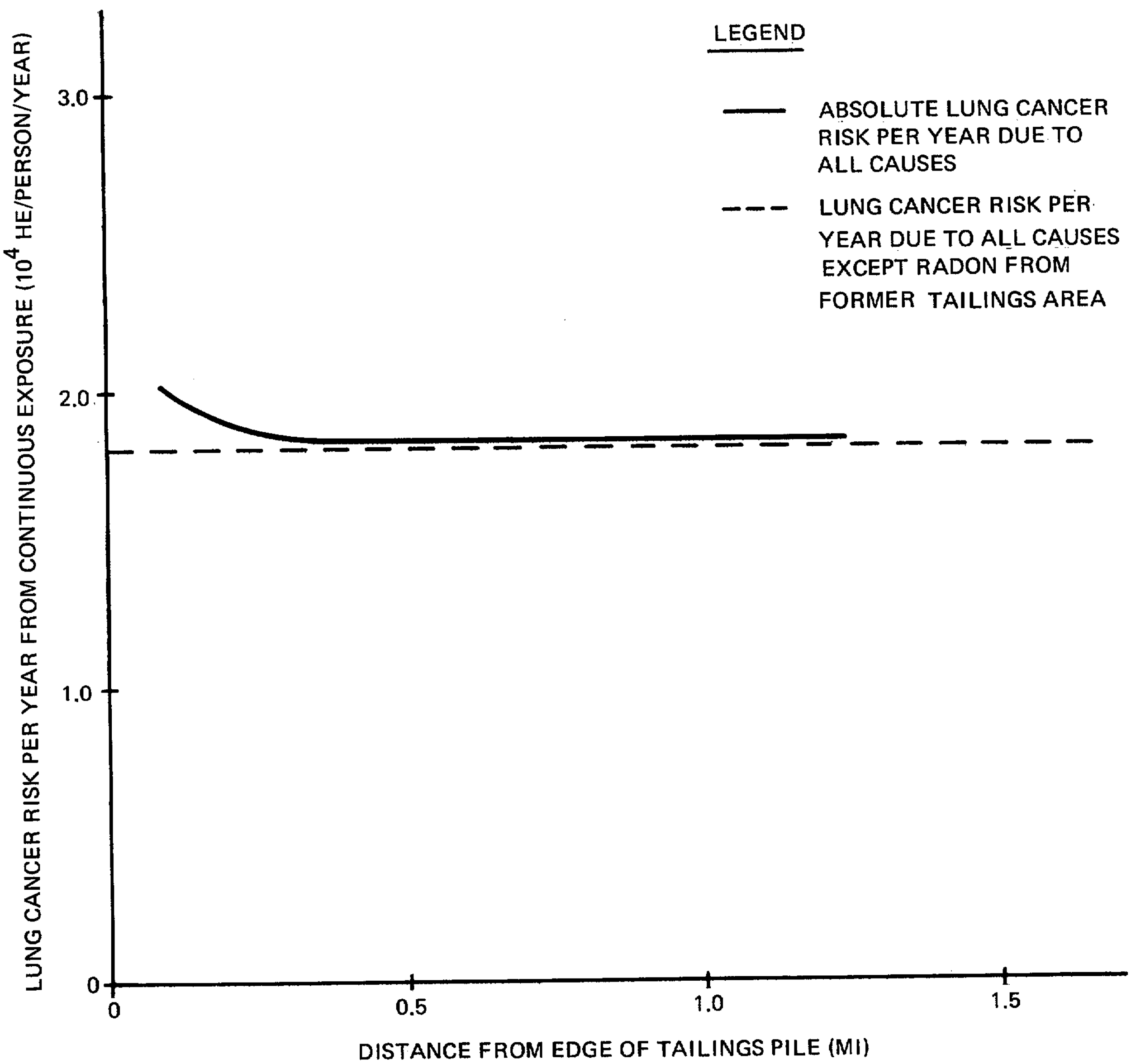


FIGURE 3-13. LUNG CANCER RISK FROM CONTINUOUS EXPOSURE TO RADON

360-08 REV 6/81

TABLE 3-1

NOTATIONS AND ABBREVIATIONS USED IN CHAPTER 3

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

Isotope Abbreviations:

^{238}U = Uranium-238
^{234}Th = Thorium-234
^{232}Th = Thorium-232
^{234}Pa = Proctactinium-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).
one 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.

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TABLE 3-2

BACKGROUND RADIATION SOURCES IN SOIL FROM SOUTHWEST COLORADO

Isotope (Decay Chain)	Average Value (pCi/g)	Range (pCi/g)
^{226}Ra (^{238}U)	1.48 ± 0.63	0.54 - 3.4
^{232}Th (^{232}Th)	1.11 ± 0.32	0.10 - 1.46

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TABLE 3-3

CHEMICAL ANALYSES OF NATURITA WATER SAMPLES (mg/l)

Sample[a]	As	Ba	Cd	Cr	V	Fe	Pb	Se
A - San Miguel River 100 yd upstream from pile	<0.001	<0.001	<0.001	0.05	<0.01	0.84	0.031	0.009
B - Standing water in ditch, north edge of pile	0.327	0.034	<0.001	<0.001	7.47	0.73	0.075	0.165
C - San Miguel River 100 yd downstream from pile	<0.001	0.048	<0.001	0.100	<0.01	1.20	0.026	0.012
D - Standing water in ditch, north edge of pile	0.028	0.012	<0.001	<0.001	0.42	1.40	0.025	0.043
EPA Interim Primary Drinking Water Regulations[b]	0.05	1.0	0.01	0.05	--	0.3[c]	0.05	0.01

[a]See Figure 3-6 for locations.

[b]Federal Register, Dec 24, 1975.

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

TABLE 3-4

CONCENTRATION OF ^{226}RA IN SOIL SAMPLES

Location	Depth (ft)	^{226}Ra Concentration (pCi/g)
NAT-1	1	52.6
	2	30.2
	3	26.1
NAT-2	1	2.7
	2	2.6
	3	1.4
NAT-3	1	116.6
	2	55.5
NAT-4	1	3.6
	2	2.0
	3	1.8
NAT-5	1	7.3
NAT-6	1	31.0
	2	42.0
	3	54.2
NAT-7	1	18.8
	2	70.2
	3	34.3
NAT-8	1	3.0
	2	4.7
	3	53.2
	4	49.0
NAT-9	1	29.3
	2	11.6
	3	4.3

Note: Drill hole locations are shown in Figure 2-4.

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TABLE 3-5

ESTIMATED HEALTH IMPACT FROM NATURITA 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	2,554	0.00061	0.19
2005 (0.8% constant growth rate)	3,117	0.00073	0.23
2005 (2.0% constant growth rate)	4,190	0.0010	0.32
2005 (5.0% declining growth rate)*	4,840	0.0011	0.37

Growth Projection	25-Yr Cumulative RDC Health Effects: Pile-Induced	25-Yr Cumulative RDC Health Effects: Background
0.8% constant growth rate	0.018	5.2
2.0% constant growth rate	0.019	6.3
5.0% declining growth rate*	0.023	7.7

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

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CHAPTER 3 REFERENCES

1. F.F. Haywood, et al.; "Radiological Survey of the Inactive Uranium Mill Tailings Piles at Naturita, Colorado"; ORNL-5454; Oak Ridge National Laboratory, Oak Ridge, Tennessee; Mar 1980.

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

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

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

5. R.L. Douglas and J.M. Hans, Jr.; "Gamma Radiation Surveys at Inactive Uranium Mill Sites"; Technical Note ORP/LV-75-5; EPA; Office of Radiation Programs; Las Vegas, Nevada; Aug 1975.

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

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

8. 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).

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

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

11. A.K.M.M. Haque and A.J.L. Collinson; Health Physics; Vol 13, p. 431, 1967.

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

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

14. "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.

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

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

17. Y.R. Lin, et al.; "Colorado Population Reports - Population Estimates and Projections", Series CP-25, No. 79(C)-1; Oct 1979.

CHAPTER 4

SOCIOECONOMIC AND LAND USE IMPACTS

CHAPTER 4

SOCIOECONOMIC AND LAND USE IMPACTS

This chapter describes the population distribution and land use in the vicinity of the former Naturita tailings. The basis for estimating population growth for the health effects calculations is also discussed.

4.1 SOCIOECONOMIC BACKGROUND

The closest population concentration with commercial activity is Naturita, 3 mi southeast of the former tailings site. Colorado Highways 143, 141, and 90 service the area. Two other small communities, East and West Vancorum, are located along Colorado Highway 141, approximately halfway between Naturita and the former tailings area. In addition, the community of Nucla is located approximately 5 mi northeast of the former site. The city of Montrose is the county seat of Montrose County, in which Naturita is located.

The boundaries of Montrose County are shown in Figure 4-1. The demographic and economic conditions of Naturita can be projected by extrapolating statistical data obtained for the four census records of 1940 through 1970.[1] The population of Naturita and its environs has been highly dependent upon activities of the uranium mining industry in the area. It experienced substantial growth in the 1940's and 1950's, a decline in growth during the 1960's, and no noticeable growth in the 1970's. Montrose County has experienced virtually no population change over the past decades, except for an increase during the 1950's. These population fluctuations are in contrast to the constant, smooth growth exhibited by the population of the State of Colorado. The median age of Montrose County declined from 29.1 in 1940 to 26.6 in 1960, and then increased to 29.1 in 1970. The percentage of the male population of Naturita decreased from 59.3% in 1940 to 51.9% in 1970.

Ethnically, the population of Naturita is dominantly Caucasian; 2% are Indian. Educational attainment and median income are lower than the state's averages. Most workers now are employed as farmers, clericals, craftsmen, and service providers; however, farmers and farm laborers show a consistent decline in both real numbers and percent of the total. The Naturita area supports a significant amount of mining and gravel excavation activity and these industries are growing in the area. To accommodate the transient labor force of the mining sector, a new trailer court is planned to be located on the east side of Naturita and another in Nucla.

4.2 POPULATION ESTIMATES

The preliminary census data for Montrose County showed that the population of the county increased 25.8% (2.3%/yr) from 18,336 people in 1970 to 23,105 in 1980. The census also showed that the population of the town of Naturita declined 6% (0.6%/yr) from 820 to 771 and the population of the town of Nucla increased 3.1% (0.3%/yr) from 949 people to 978 during the years 1970 to 1980. The Demographic Section of the Colorado Division of Planning estimated(2) the population of Naturita to be 1,389 and the population of Nucla to be 1,019 in 1980.

Based on site and area inspections, the population within 1.5 mi of the site is estimated to be approximately 154 people. This figure includes 12 workers within 1.5 mi of the site. For exposure calculations, this number of workers was divided by 4 to account for the fact that they are on the job only 25% of the time. Most residents are located in East Vancorum and West Vancorum, two small residential communities located between 0.75 and 1 mi southeast of the site. Table 4-1 shows the estimated 1980 population distribution around Naturita as a function of distance and direction from the site.

Figure 4-2 shows three population projections for the Naturita and Nucla areas. The most optimistic projection is a 5% declining growth rate and assumes that the annual population growth rate will decline linearly from its initial rate of 5%/yr to zero growth after 25 yr. This growth rate is suggested by the population projections(2) of the Demographic Section of the Colorado Division of Planning and is considered in this report as an upper bound on the growth of the area. If this growth rate were followed, there would be about 1.5 times the present population by 1990 and a constant population after the year 2005 of about 1.9 times the present population.

The least optimistic projection in Figure 4-3 is a 0.8% constant annual growth rate. This is the general growth rate experienced by the United States in recent years.(1) If this growth rate were followed, the population of the area would increase 0.8%/yr from 2,554 people at the present time to 3,117 people by the year 2005.

The most probable of these population projections for the area is the 2% constant annual growth rate. This is the growth rate experienced by the Rocky Mountain States in 1974 and is the growth rate expected for Naturita if moderate development of the mineral resources in the area would occur. If this growth rate were followed, the population of the area would increase 2%/yr from 2,554 people at the present time to 4,190 people by the year 2005.

4.3 LAND USE

Figure 4-3 shows the present land use in the vicinity of the former tailings site. The tailings have been removed from the site, reprocessed, and disposed of at a distant site by Ranchers Exploration and Development Corporation. The millsite adjacent to the pile is still leased and operated as a uranium ore-buying facility by General Electric Company.

East Vancorum and West Vancorum, the two residential concentrations nearest the site, have not experienced any new construction. However, the 16 residential units at East Vancorum and about 36 units at West Vancorum were occupied during the summer of 1980.

The nearest commercial and service activities are in the towns of Naturita and Nucla. Several uranium mines, gravel pits, and a coal mine are located in the area. A large majority of the land surrounding the site is still devoted to low-density grazing and other agricultural uses. There is very little irrigated land for crops.

Figure 4-4 shows the present land ownership in the area according to plat maps and ownership records in the Montrose County Assessor's office. Much of the property surrounding the Naturita site is under the control of the Bureau of Land Management.

4.4 IMPACT OF THE TAILINGS ON LAND VALUES

The 70 acres of land owned by Foote Mineral Company on the north and south of the old tailings area had an approximate market value of $160/acre in 1978. The buildings on the Foote Mineral property which are now leased to General Electric Company as an ore-buying facility had an estimated market value of about $106,300 in 1978.

The 24 acres owned by Ranchers Exploration and Development Corporation where the tailings were formerly located had an approximate market value of $200/acre in 1977. In general, the grazing land surrounding the site presently has a market value of approximately $6 to $9/acre.[3]

Although tailings have been removed from the site, sufficient contamination remains to restrict its use. However, the loss of grazing land is minimal and the presence of the contamination has little effect on land use and land values of the surrounding property. There is no evidence that land values have increased at the site or in the surrounding areas since the removal of the tailings. However, several community members expressed their feelings that the aesthetic quality of the site has improved now that the tailings have been removed.

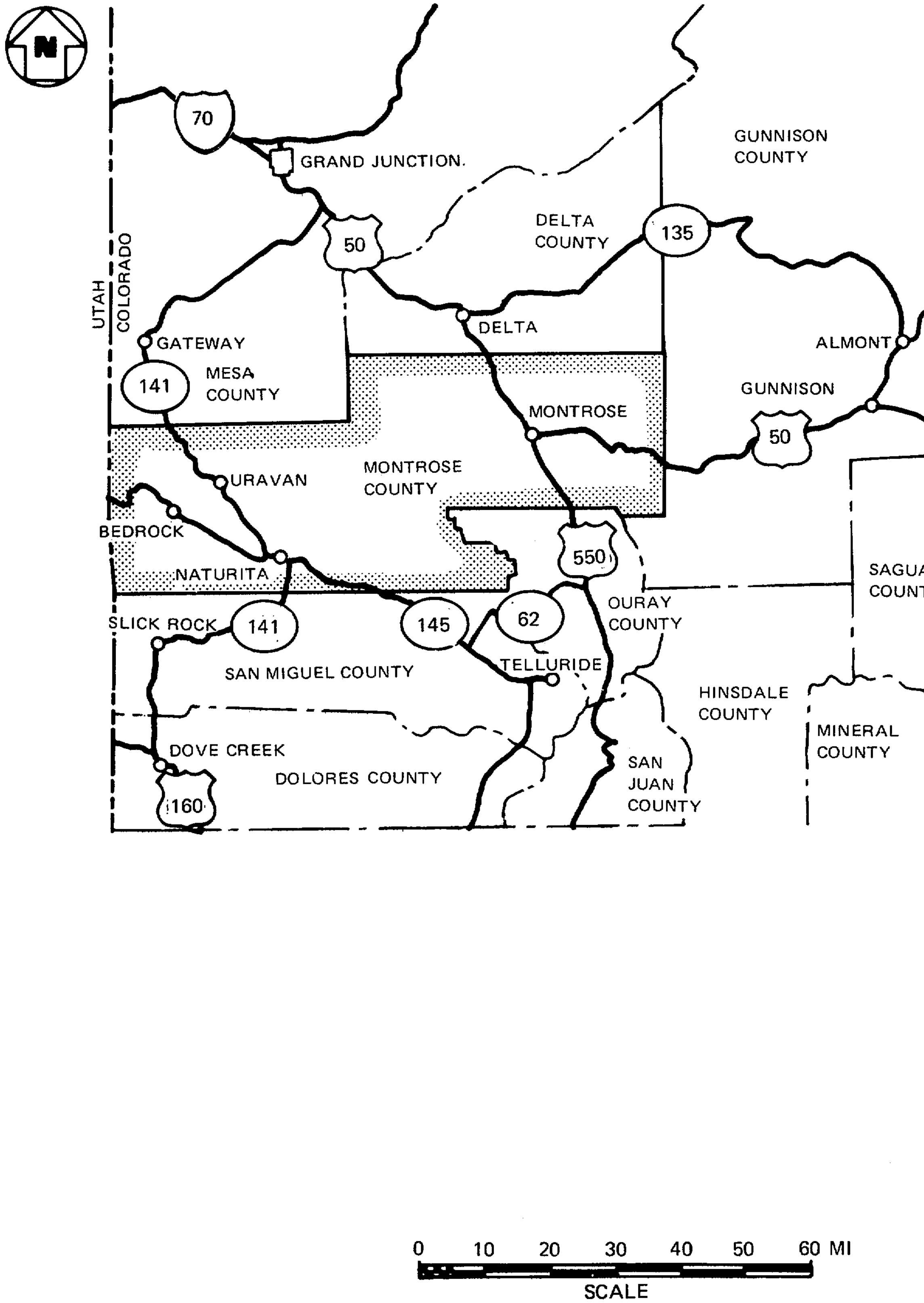

FIGURE 4-1. MAP OF MONTROSE COUNTY BOUNDARIES

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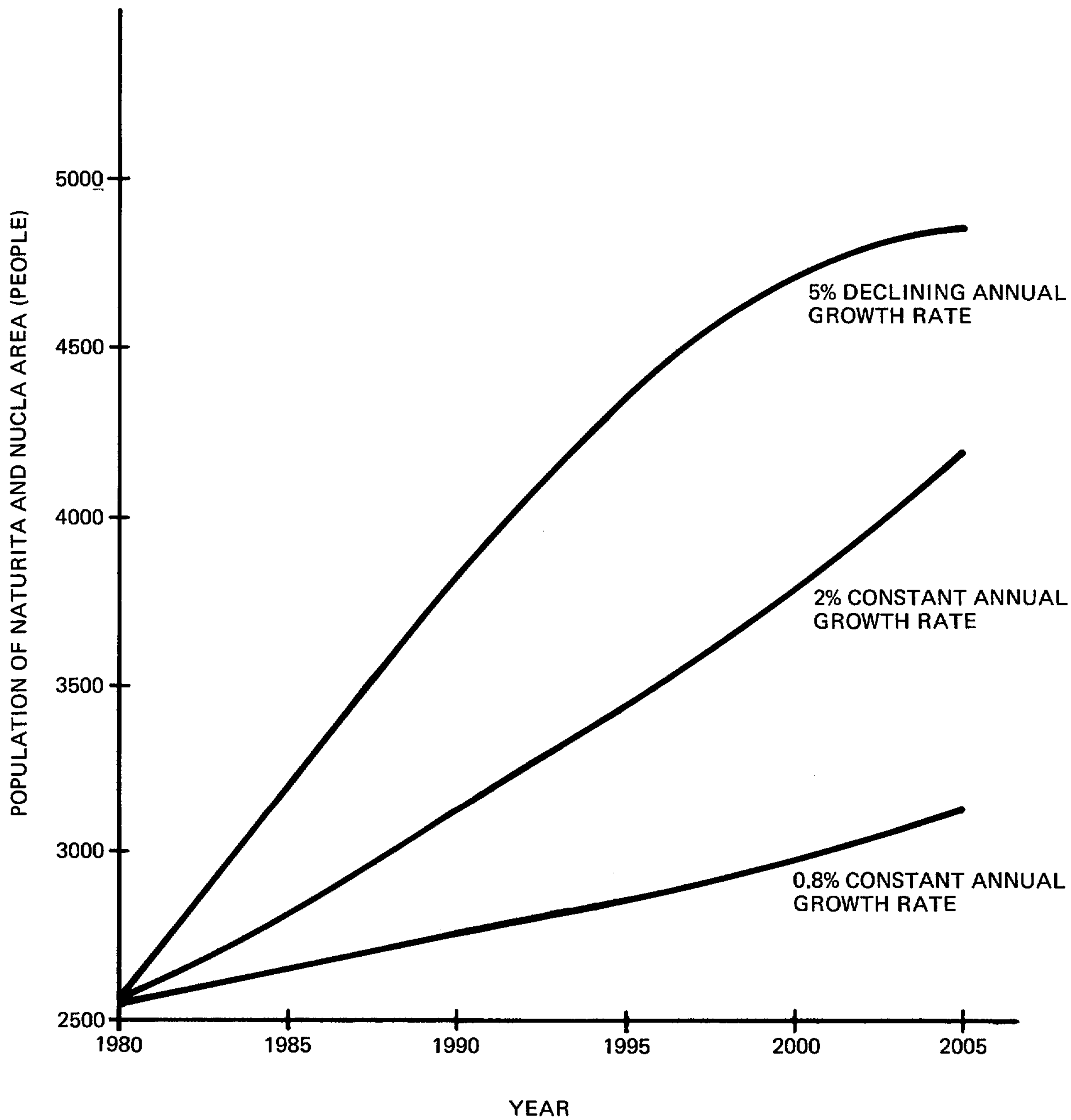

FIGURE 4-2. POPULATION PROJECTIONS

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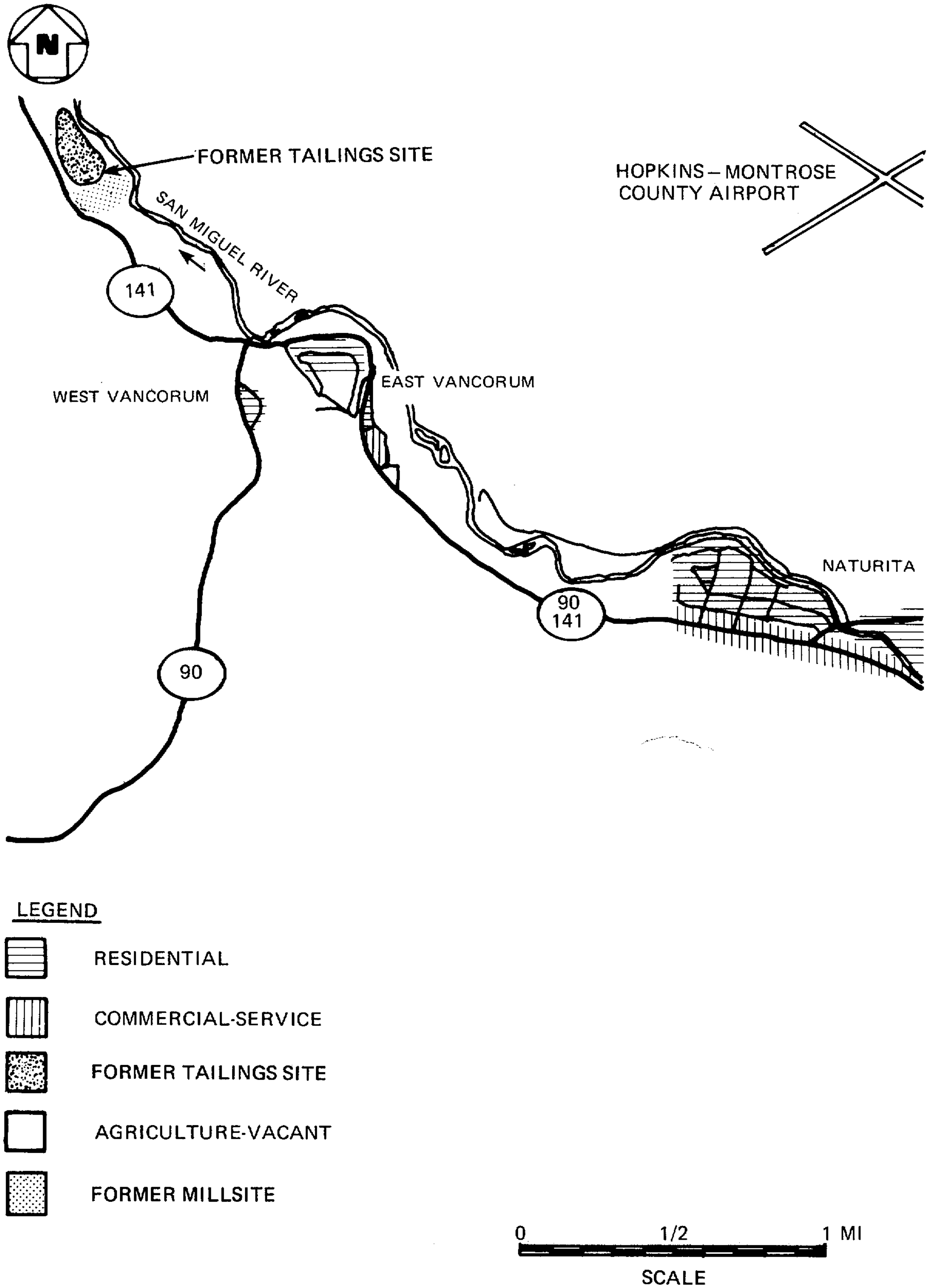

FIGURE 4-3. VICINITY LAND USE

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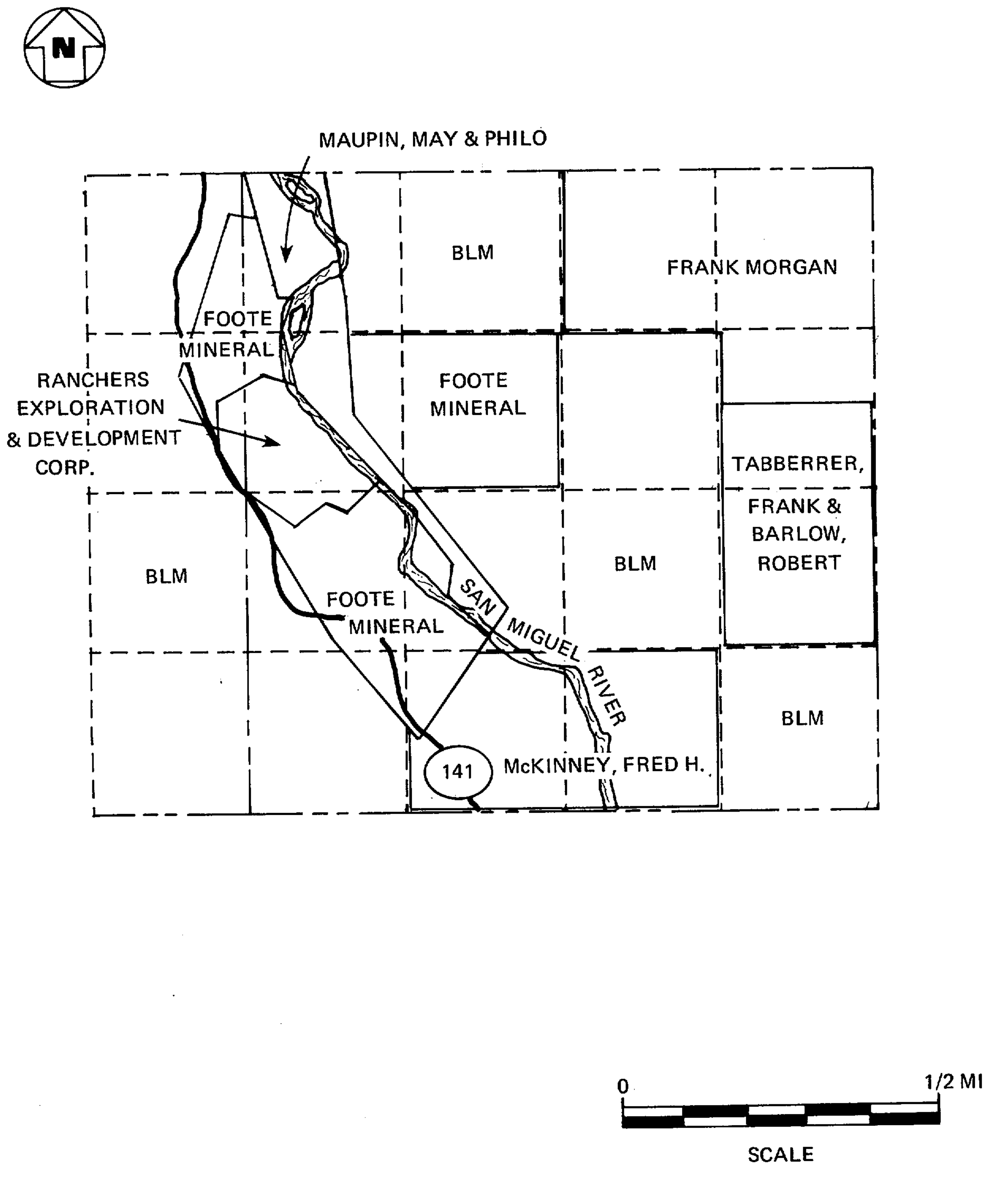

FIGURE 4-4. LAND OWNERSHIP MAP

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TABLE 4-1

ESTIMATED 1980 POPULATION DISTRIBUTION
CENTERED ON FORMER TAILINGS PILE

Number of People	Distance From Tailings Pile (mi)	Direction From Tailings Pile
3*	0.10	South
6	0.25	South
80	0.75	South-Southeast
34	1.00	Southeast
23	1.50	Southeast
695	2.00	Southeast
694	2.50	Southeast
1,019	4.00	Northeast
Total 2,554		

*This number represents the 12 workers at G.E.'s ore-buying facility and has been divided by a factor of 4 to account for the fact that these people are exposed to radiation from the site only 25% of the time.

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CHAPTER 4 REFERENCES

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

2. Y.R. Lin, et al.; "Colorado Population Reports - Population Estimates and Projections"; Series CP-25, No. 79(C)-1; Oct 1979.

3. M. Hoover; Montrose County Assessor; personal communication; July 22, 1980.

CHAPTER 5

RECOVERY OF RESIDUAL VALUES

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RECOVERY OF RESIDUAL VALUES

Ranchers Exploration and Development Corporation reprocessed the Naturita tailings using a 1,200 ton/day heap-leach facility during 1978 and 1979. The heap-leach facility used is located about 3 mi southwest of the intersection of Highways 90 and 141 at Vancorum, along Colorado State Highway 90. This location is in Section 34 of Township 46 North, Range 16 West, New Mexico Principal Meridian.

In their 1979 annual report, Ranchers published information on reprocessing the Naturita tailings. The operating costs for uranium recovery were reported at about \$34/lb of U_3O_8 recovered, equivalent to \$20.50/ton of tailings processed.

There is no noteworthy mineral resource remaining at the former tailings site, other than those owned by General Electric Company and associated with their ongoing ore-buying activities. Therefore, no further attention is given to recovery of residual mineral values.

CHAPTER 6

MILL TAILINGS STABILIZATION

CHAPTER 6

MILL TAILINGS STABILIZATION

In all alternate 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 Naturita, precipitation averages about 11 in. annually.

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

6.2 PREVENTION OF LEACHING

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

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

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

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

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

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

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

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

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

*Registered trademark.

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

(d) Rubberized asphalt membrane

(e) Hydraulic asphalt concrete

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

(g) Bentonite, sand and gravel mixture

(h) Catalytic airblown asphalt membrane

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

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

6.3 REDUCTION OF RADON EXHALATION

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

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

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

*Registered trademark.

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

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

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

6.4 REDUCTION OF GAMMA RADIATION

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

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

6.5 ASSESSMENT OF APPLICABILITY

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

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

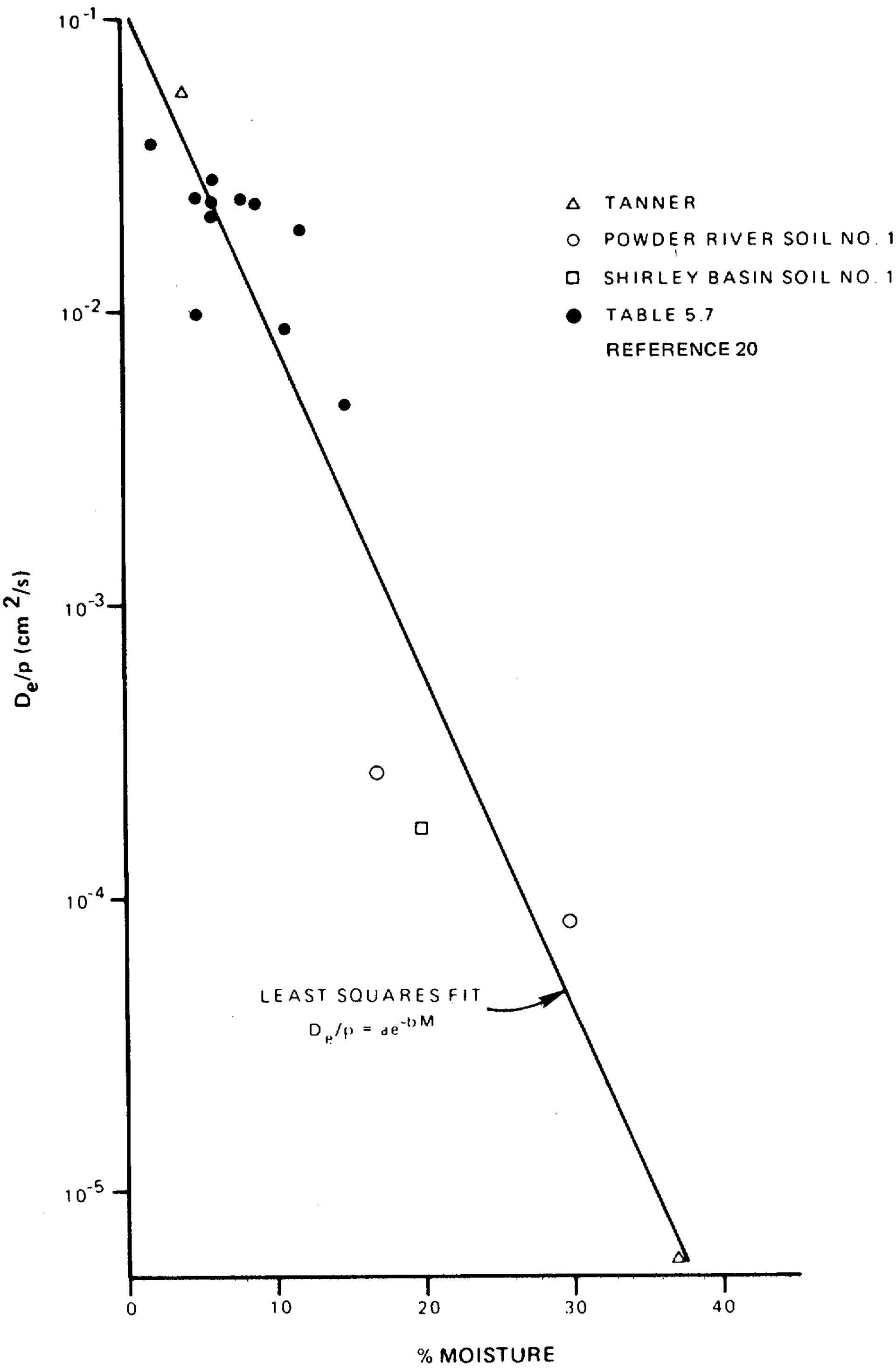

FIGURE 6-1. EXPONENTIAL MOISTURE DEPENDENCE OF THE DIFFUSION COEFFICIENT

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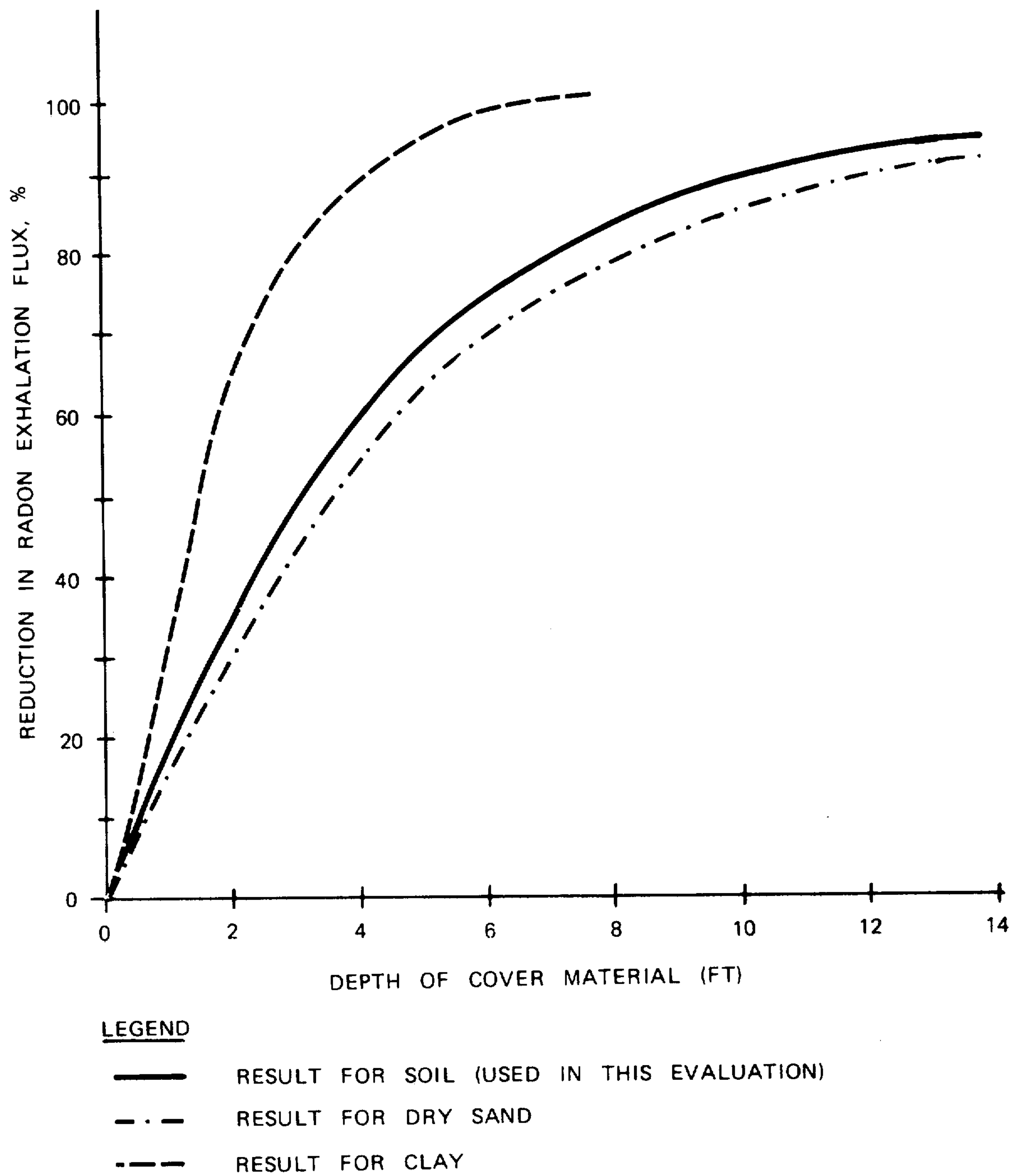

FIGURE 6-2. REDUCTION OF RADON EXHALATION FLUX WITH DEPTH OF COVER

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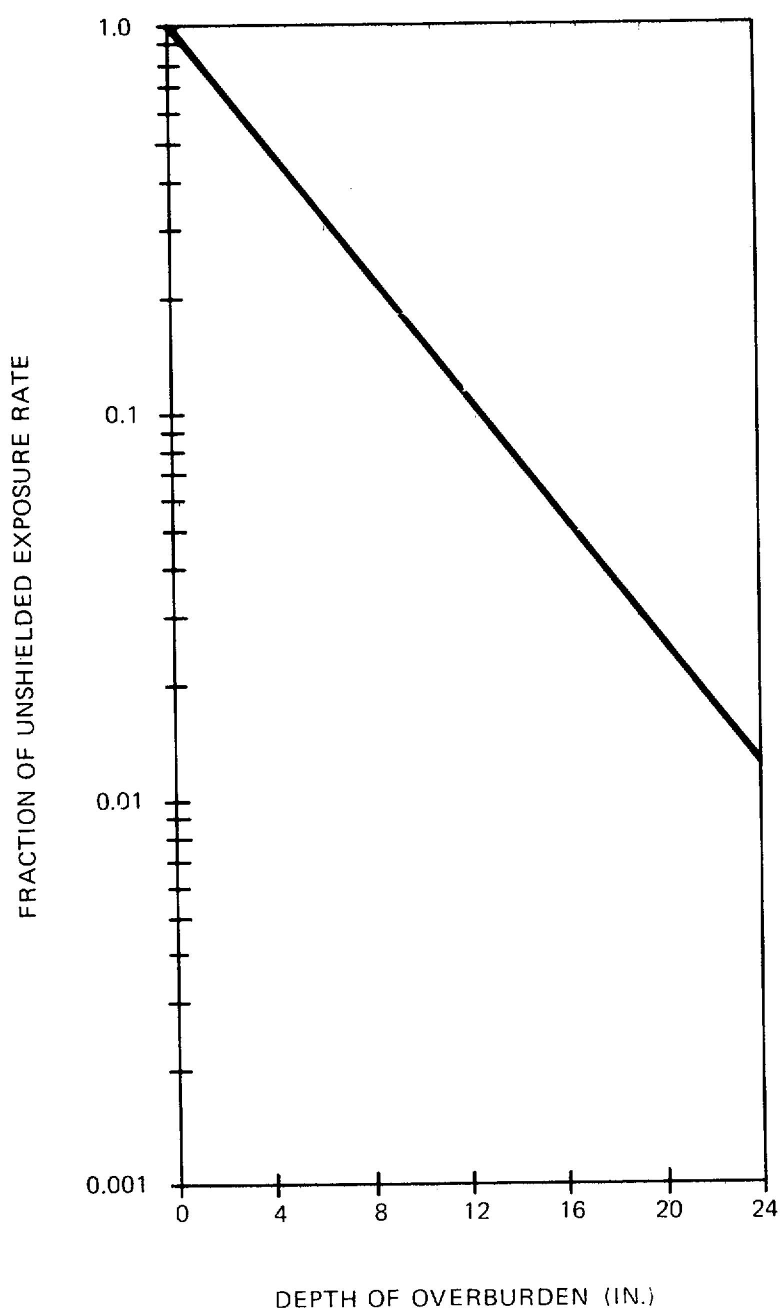

FIGURE 6-3. REDUCTION OF GAMMA EXPOSURE RATE RESULTING FROM PACKED EARTH SHIELDING

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CHAPTER 6 REFERENCES

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

18. A.B. Tanner; "Radon Migration in the Ground: A Review"; The Natural Radiation Environment; J.A.S. Adams and W.M. Lowder, eds; University of Chicago Press; pp. 161-190; 1964.

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

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

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

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

CHAPTER 7

OFF-SITE REMEDIAL ACTION

CHAPTER 7

OFF-SITE REMEDIAL ACTION

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

For the purpose of this report, locations where tailings have been transported off site by individuals are considered as off-site properties. Other locations outside the designated site boundary are considered as off-site windblown areas. Contaminated areas within the designated site boundaries, i.e., the ore-storage area, former tailings pile, millsite, windblown contamination of open areas, etc., are considered as the tailings site and are discussed in Chapter 9. Cleanup of the off-site and windblown contamination would be accomplished under both options discussed in Chapter 9.

7.1 DATA SOURCES

A mobile scanning unit, operated by the AEC under an interagency agreement with the EPA, performed gamma radiation surveys of the the Naturita and Nucla, Colorado, areas in 1971. Of the 219 structures scanned in Naturita, 33 anomalies were reported; while at Nucla, 13 anomalies resulted from the survey of 265 structures. A joint team from the EPA Office of Radiation Programs, Las Vegas, Nevada, (EPA-ORP-LV) and the Colorado Department of Health performed individual gamma surveys of the 46 anomalies to determine their sources and, if tailings, how they had been used.[1,2] High and low inside and outside gamma readings were recorded. A gamma map was drawn of areas inside the structures where gamma readings exceeded 20 μR/hr. The gamma survey at the Naturita site and the 5-pCi/g boundary mentioned in Paragraph 3.4.3 were the data sources for the consideration of remedial action for windblown areas.

7.2 REMEDIAL ACTION FOR OFF-SITE PROPERTIES OTHER THAN WINDBLOWN

Follow-up surveys of the anomalies[1,2] indicated that there were 10 tailings use locations in Naturita and 3 in Nucla. In Naturita, the tailings uses ranged from use in foundations to fill under walkways and slabs and included such miscellaneous uses as planter fill, use of contaminated fire brick, and contamination resulting from incineration of contaminated trash. In Nucla, the tailings were used under building floor slabs and as fill in a driveway.

Of the remaining 33 anomalies identified in the 1971 scanning survey, 26 were caused by the presence of radioactive material in instruments or ore, 3 resulted from natural radioactive materials, and 4 could not be verified as anomalies.

Additional tailings use may be identified during future work. An extended series of measurements, such as required in the full application of the Grand Junction remedial action criteria, might modify the actual number of locations included in the remedial action.

The cost for remedial action at the 13 identified off-site locations was estimated to be $217,000, exclusive of engineering and contingency allowances, based on available information and on adjusted Grand Junction off-site remedial action costs. This cost includes cleanup, backfill, and health physics and monitoring services.

7.3 REMEDIAL ACTION FOR OFF-SITE WINDBLOWN PROPERTIES

The extent of windblown tailings is indicated by the estimated 5-pCi/g line in Figure 3-7. Decontamination of those areas containing windblown tailings would involve removing the off-site contaminated soil and replacing it with clean fill. This action is assumed to satisfy remedial action criteria as discussed in Paragraph 3.5.

The millsite and ore storage areas were considered as part of the tailings site. Therefore, cleanup costs of these areas are not included under remedial action for windblown areas, but are included in the estimates in Chapter 9.

The 5-pCi/g boundary line extends to include a small gas metering station on the north side of the former tailings pile area. Cleanup and restoration costs for this structure and approximately 106 acres of land contaminated by windblown tailings at and in the vicinity of the tailings site are estimated to be $1,514,000, exclusive of engineering and contingency allowances. This cost estimate includes a reasonable allowance for costs associated with unusual measures that might be required in the decontamination of the surrounding rugged terrain included within the 5-pCi/g boundary.

All areas would be decontaminated by moving an average of 6 in. of soil, gravel roads, lawns, etc., to the perimeter of the former tailings area. This material would then be disposed of at a disposal site or placed on the former tailings area and stabilized there depending on which option is selected. After decontamination, the affected area would be restored with the addition of clean material.

CHAPTER 7 REFERENCES

1. "Summary Report of the Radiation Surveys Performed in the State of Colorado at Naturita, Colorado"; EPA-ORP-LV; Mar 1973.

2. "Summary Report of the Radiation Surveys Performed in the State of Colorado at Nucla, Colorado"; EPA-ORP-LV; Mar 1973.

CHAPTER 8

DISPOSAL SITE SELECTION

CHAPTER 8

DISPOSAL SITE SELECTION

Ranchers Exploration and Development Corporation transported the tailings to a new heap leach reprocessing facility built by the company about 3 mi south of the former tailings site. According to information from Ranchers, the tailings were mixed at the plant, placed in heap-leach pits adjacent to the facility, and later covered with 2 to 10 ft of cover material. Because of this action, the identification of additional disposal sites was not attempted in the Naturita area, on the assumption that material from cleanup operations could be disposed of at this site.

Ranchers disposal site is located about 3 mi southwest of the intersection of Highways 90 and 141 at Vancorum, along Colorado State Highway 90, as shown in Figure 8-1. The site is located in Section 34 of Township 46 N, Range 16 West, New Mexico Principal Meridian.

The site is in a flat to gently sloping valley surrounded by rolling hills. The land in the area is vegetated by sage and grasses and the hills are dotted with juniper and cedar trees. Average annual precipitation is 11 in. The site is well isolated from human habitation with the nearest place of residence located over 2 mi away. No pressures to use this land for other purposes are expected in the foreseeable future.

The tailings were processed and stabilized in two large tailings ponds. Half of one pond was not used at the time. It is estimated that the empty portion of this pond is large enough to contain the contaminated material at the former site. It is also assumed that the reprocessing facility buildings will be available for use as support facilities (shower room, office, etc.) during the cleanup and disposal work. Therefore, it is assumed that a minimal amount of preparation work will be required at the disposal site.

The haul to the site would be by truck and/or truck-trailer combination and would proceed southwest for 1 mi along Colorado State Highway 141 to its intersection with State Highway 90 at Vancorum, then southeast along Highway 90 for approximately 2 mi, and then 1 mi over a gravel road to the site. Low permeability soil for cover material is available at distances from 5 to 10 mi from the site. Pit-run gravel from commercial gravel pits located within 5 mi of the site, along Highway 141, can be used as a gravel cap.

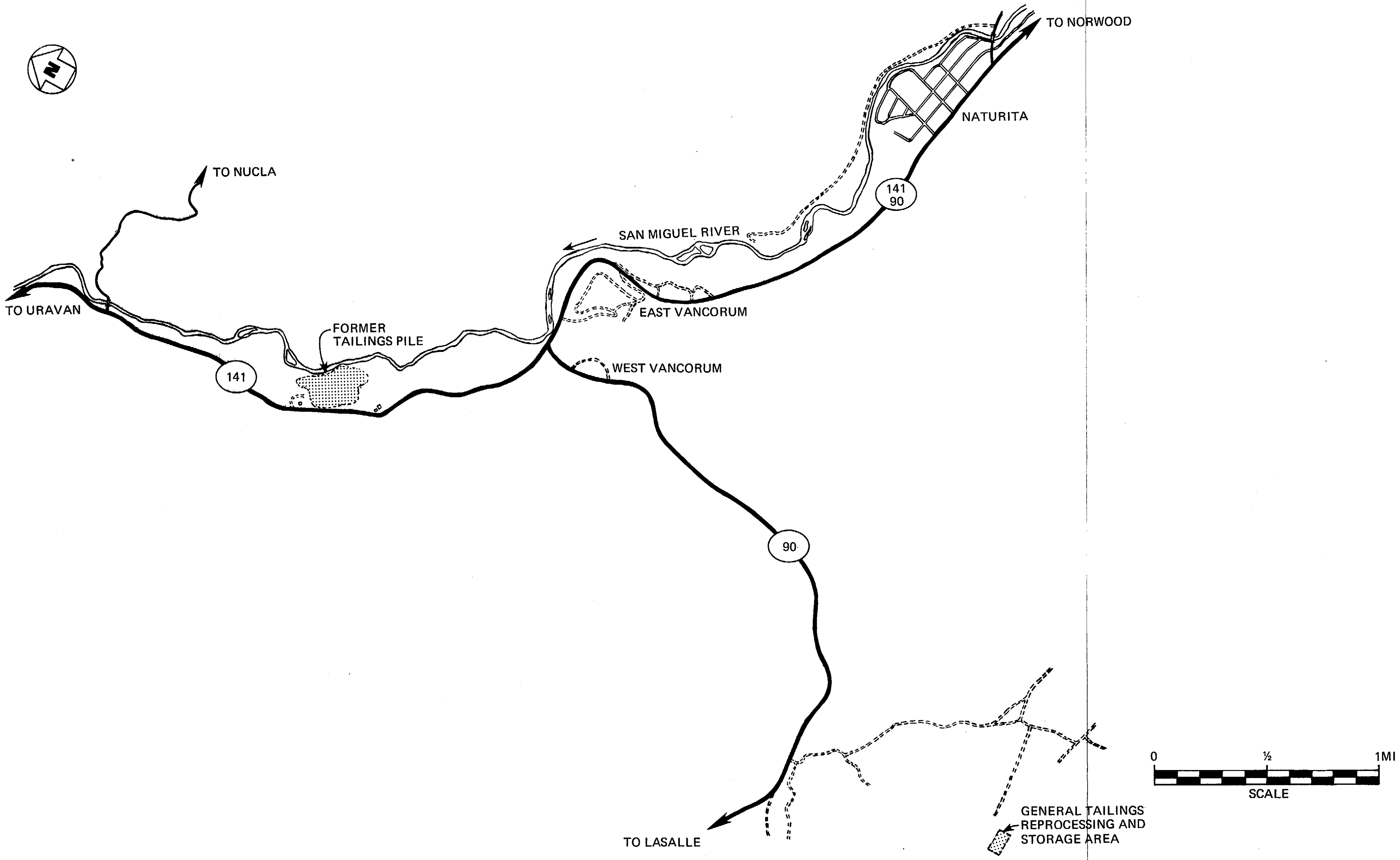

FIGURE 8-1. LOCATION OF RANCHERS EXPLORATION AND DEVELOPMENT CORPORATION'S REPROCESSING AND STORAGE SITE

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CHAPTER 9

REMEDIAL ACTIONS AND COST-BENEFIT ANALYSES

CHAPTER 9

REMEDIAL ACTIONS AND COST-BENEFIT ANALYSES

Two remedial action options for the contaminated materials at the Naturita site were identified and investigated. The remedial actions presented are those considered to be the most realistic and practical when evaluated in regard to the present remedial action criteria, technology, and information available. Costs and benefits have been estimated and evaluated for each option considered.

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

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

Remedial actions designed to meet the EPA interim remedial action criteria were investigated. Only one disposal site, identified in Chapter 8, was evaluated in terms of the cost of disposal. Great care must be exercised in the use of this site-specific cost estimate since there are insufficient data and information available to characterize the site completely for estimating site development costs.

The process of obtaining the necessary permits and the associated costs are considered to be included in the various agency budgets and are not included in this report. Similarly, the former tailings site, the proposed disposal site, and related gravel or clay material borrow pits 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.

On-site stabilization of the contaminated materials (Option I) requires that the windblown tailings and the contamination remaining in the subsoil, which was beneath the former tailings pile and in the mill and ore storage areas, be gathered together on the former site. The remaining mill buildings would either be decontaminated or demolished and placed with the contaminated materials on site. All contaminated materials would then be covered with the required 3 m of cover material and vegetation would be established in the area; a riprap cap would be provided for surface erosion control.

The option for disposal at Ranchers Exploration and Development Corporation's disposal site (Option II) would provide for the relocation of all debris and contaminated materials from the former tailings, millsite, ore-storage, and windblown areas. Thus, in the disposal option, the entire site and surrounding area would be left free of tailings or contaminated materials. The area to be decontaminated at the Naturita site is shown in Figure 9-1.

The moving of the ore that is stockpiled on the old millsite and the decontamination of the land being used for this activity were assumed to be the responsibility of General Electric Company, the present operator of the facility. Therefore, costs for this work are not provided for in either option explained above. The presence of this General Electric Company uranium ore-buying station on the millsite is a complicating factor in any remedial action program. The ore-handling and sampling operations continue to create radioactive dust, which adds to soil contamination in the vicinity. They could also recontaminate areas cleaned up under the remedial action program, making it difficult to meet the criteria that have been adopted.

A discussion of the concepts involved in tailings stabilization and their applicability to the Naturita site has been detailed in Chapter 6. It is assumed that either vegetation will be established or a riprap cap used if the tailings are stabilized on site. However, for the disposal option, 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 CONTAMINATION ON SITE WITH A 3-METER COVER (OPTION I)

In this section the conceptual design of the option to stabilize contamination at the Naturita site is discussed and the estimated cost of the corresponding remedial action presented.

9.1.1 Conceptual Design

The windblown tailings, ore-storage area, and mill area would be cleaned up and all contaminated materials, debris, and tailings would be placed on the former tailings pile area. The main office building at the site (presently occupied by Foote Mineral personnel) would be decontaminated. The remaining mill buildings would be demolished and the rubble would be placed with the contaminated materials on site. Averages of 0.5 ft of soil would be removed from the former tailings pile area and the windblown areas; 2 ft from the mill area, and 3 ft from the ore-storage area, as shown in Figure 9-1. All affected areas would be backfilled to natural grade with clean fill material and landscaped to be similar to original conditions.

After placing the contaminated materials on the former tailings site, these materials would then be covered with 3 m of cover material. The 3 m of cover material may be sufficient to reduce radon exhalation flux to less than 2 pCi/m^2-s. Low permeability soils for cover material are available at distances of 5 to 10 mi from the site.

To protect the stabilized pile from water erosion from the San Miguel River during flood conditions, a riprap dike would be placed along the east side of the pile. The possible migration of contamination via ground water was not considered in this assessment, and the cost estimate does not include the placement of a clay or synthetic liner under the tailings. The cost of this option would increase if the liner were required.

If vegetative stabilization is selected for surface erosion control, all of the newly stabilized areas would be seeded with self-regenerating vegetation native to the area. This vegetation is assumed to be able to survive the summer months without irrigation after an initial establishment period of at least one summer season.

If the Naturita 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 Naturita site is estimated to be $7,200,000. Costs include cleaning up of the windblown tailings, millsite, ore storage areas, mill buildings, and off-site properties; covering all contaminated materials with 3 m of cover; providing riprap diking and cap material; contouring the surface; establishing vegetation; and reclaiming all areas.

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

Option II provides for the complete removal of all tailings, contaminated soil, buildings, materials, and rubble from the tailings site to a disposal site. The amount of soil to be removed depends on the depth of contamination. Removal to averages of 3 ft of soil in the former tailings pile area, 2 ft of subsoil below the former millsite, 3 ft below the ore storage areas, and 0.5 ft from the windblown area will apparently reduce residual radium concentration to less than the required 5 pCi/g above background levels. Finally, the site would be backfilled to natural grade and released for unrestricted use.

9.2.1 Excavation and Loading of Tailings and Soils

Based upon site examination, a review of the limited data portraying the physical properties of the contaminated soil and discussions with earthmoving contractors in the area, it appears that there would be no difficulty in removing the contaminated materials from the tailings site. The contractor performing this work would be able to use any number of conventional loading methods, e.g., front-end tractor loaders or conveyor belt feed to overhead loading. The possibility of encountering water below the tailings suggests the potential need for a dewatering system when excavating contaminated subsoil. There is ample room on site for fast loading and easy truck ingress and egress.

To eliminate further tailings dispersion during loading and transportation operations, dust control equipment and washdown facilities would be provided.

The decontaminated tailings site would be backfilled to natural grade. Local material, all of which must be hauled to the site, would be used as backfill. No special treatments of the final surface other than establishing native grass cover at the decontaminated tailings site are considered in this assessment.

9.2.2 Transportation of the Materials

Rail transportation is not possible because there is no railroad near the site. Therefore, it is assumed that truck transportation will be used.

Slurry pipeline and conveyor technologies were also evaluated. Because of the high costs involved, the relatively short project life, and many social and political uncertainties, neither slurry nor conveyor technology is considered feasible.

If trucks could move the materials at the rate of about 4,800 tons/day, working 5 days/wk, all materials could be removed in approximately 4 mo. This method assumes the use of conventional truck and/or truck-trailer combinations. Contamination control measures, such as covers and washdown facilities for the trucks, are included as capital costs associated with transportation. No costs are included for repair and maintenance of public roads, based on the assumption that legal load limits will not be exceeded and the state gasoline taxes provide the needed revenues for such repair and maintenance.

9.2.3 Disposal at an Alternative Site

A discussion of the proposed disposal site (Ranchers Exploration and Development Corporation's disposal site) is given in Chapter 8. The disposal site was evaluated on its physical, geological, and hydrological characteristics. However, because the Federal Government, with input from the State, is ultimately responsible for the selection of disposal sites, there is no assurance that the proposed site will be selected as a disposal site for the contamination remaining at the former tailings site.

As explained in Chapter 8, it is assumed that the empty portion of an existing tailings pond at the suggested disposal site can be used for disposal of the contaminated materials at the former site. Therefore, the procedure for disposing contaminated materials would involve placing them in the pond, and placing cover materials to a depth of at least 3 m. Low permeability soils for use as cover materials are available at distances of from 5 to 10 mi from the disposal site. The stabilized disposal site would be gently sloped and contoured to minimize the potential for water erosion. A 0.3-m-thick layer of riprap or gravel would be placed over the cover material to protect against surface erosion.

The suggested disposal site is accessible by means of a combination of paved and gravel roads. The condition of these roads is good, and they will not require upgrading.

9.2.4 Costs

As shown in Table 9-1, the estimated cost for cleanup of the Naturita site and disposing of contaminated materials at Ranchers Exploration and Development Corporation's disposal site is $8,200,000. The cost includes scraping 0.5 ft of topsoil from the windblown areas, removing 2 ft of soil from the mill area and 3 ft of soil from the former tailings and ore storage areas, decontaminating or demolishing the mill buildings, hauling the debris and contaminated materials to the disposal site, stabilizing the contamination with 3 m of cover material, contouring the pile, placing 0.3 m of gravel or riprap cap on the disposed material for erosion control, backfilling all affected areas with clean fill material to natural grade, and establishing vegetative cover at and around the former tailings site. Also included are health physics and radiological monitoring services at the cleanup and disposal sites.

9.3 ANALYSES OF COSTS AND BENEFITS

9.3.1 Health Benefits

The remedial action alternatives considered in this chapter have associated health impacts that would be avoided as a result of the action. These avoided health effects are referred to as health benefits. In Chapter 3, the estimated number of health effects was determined for the former Naturita tailings area in its present condition. In order to estimate the number of health benefits attributable to a particular remedial action, the effect of that remedial action on radon exhalation from the contaminated area 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 flux was assumed to be reduced from the present value (as conservatively calculated) of 100 pCi/m^2-s, to the required flux of less than 2 pCi/m^2-s for Option I. In the other option, radon flux was assumed to be reduced to zero by the removal of the tailings. Since health effects are proportional to radon flux, the present health effects rate was estimated to be reduced by 98% with stabilization in-place and by 100% with tailings removal. This small difference is well within the limits of error in the measurements.

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 were calculated and plotted in Figure 9-2. Option I yields the greater health benefit per unit cost.

9.3.2 Land Value Benefits

A good portion of the property surrounding the Naturita site is under control of the U.S. Bureau of Land Management. There are four private land owners adjacent to the site. The estimated market value of the land (excluding improvements or mineral values) varies from less than $50/acre to almost $1,200/acre; hence, after the contaminated materials are cleaned up and disposed of at the proposed disposal site, the value of the approximately 37 acres of contaminated land owned by Ranchers Exploration and Development Corporation could increase from a current estimated value of $200/acre to a possible $1,000/acre for a total increase of about $30,000. This increase in land value is minimal in comparison with the cost of remedial action.

The value of the surrounding land is not presently depressed and would be virtually unaffected by remedial action at the site.

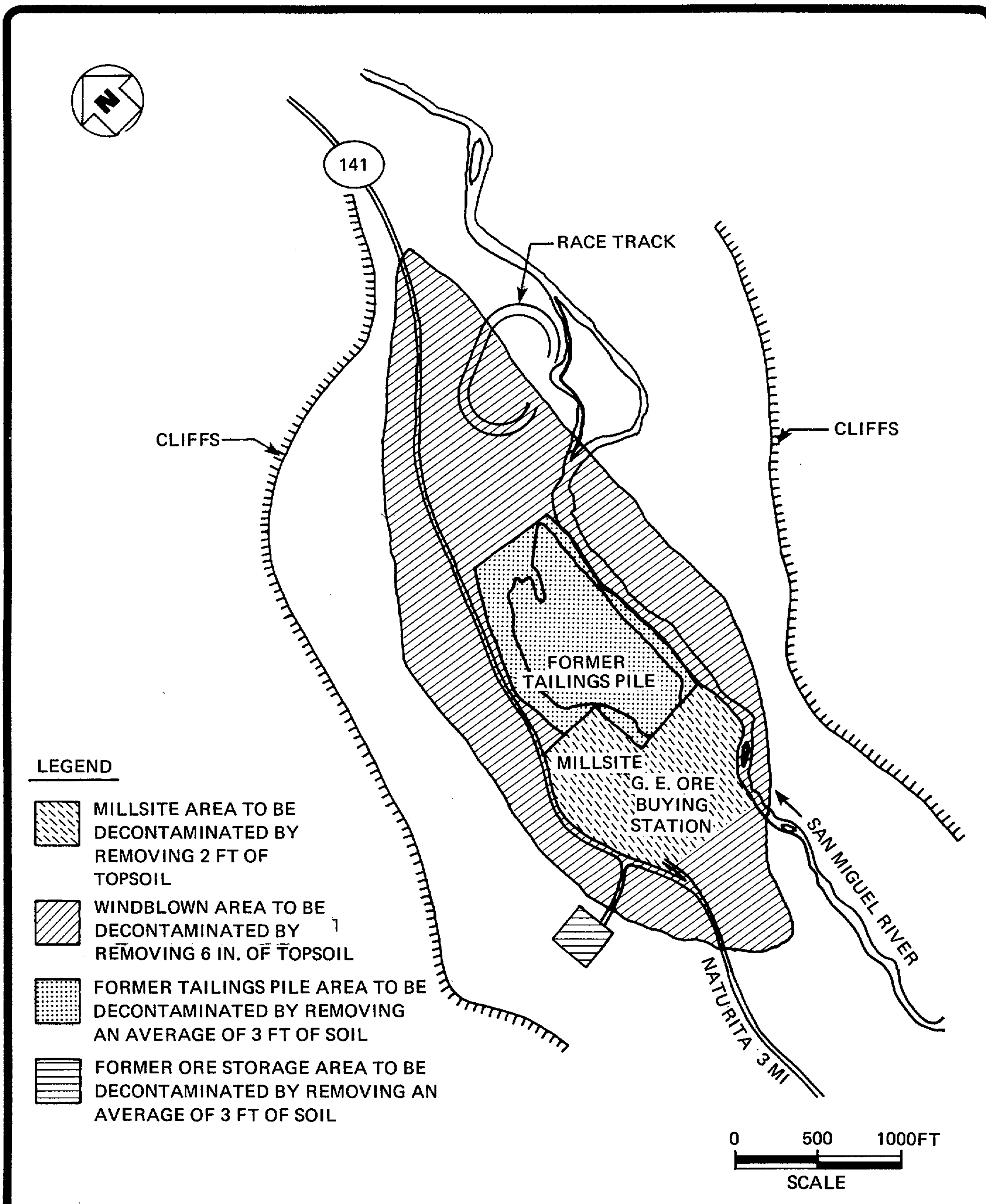

FIGURE 9-1. AREA DECONTAMINATION PLAN

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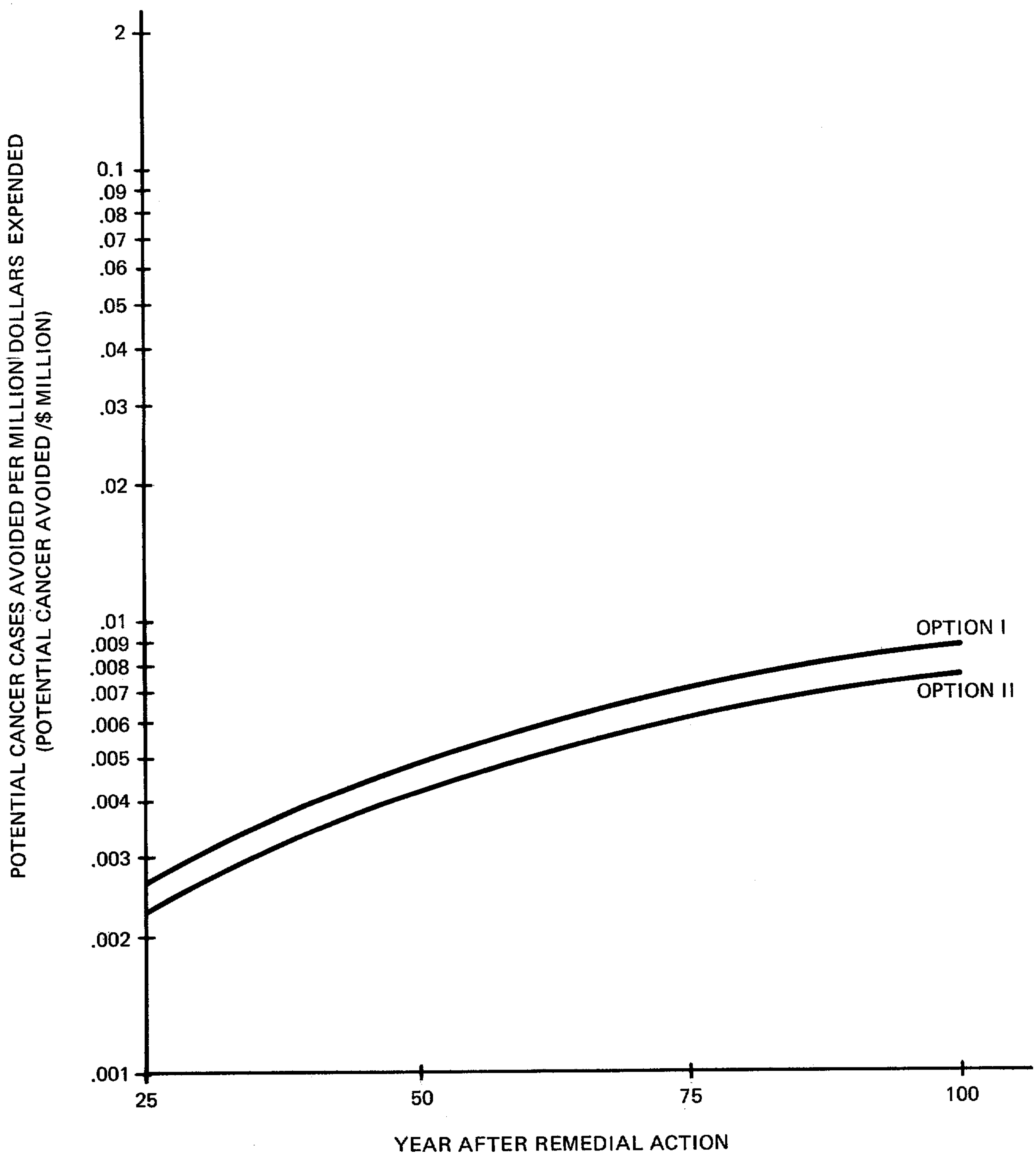

FIGURE 9-2. POTENTIAL CANCER CASES AVOIDED PER MILLION DOLLARS EXPENDED

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TABLE 9-1

SUMMARY OF STABILIZATION AND DISPOSAL COSTS[a]

		Option I	Option II
1.	Tailings Site Costs	2.5	1.6
2.	Off-Site Remedial Action	0.2	0.2
3.	Windblown Area Remedial Action	1.5	1.5
4.	Transportation		
	A. Capital Costs	--	0.3
	B. Haul Costs	--	0.6
5.	Disposal Site Costs	--	0.8
6.	Total Cleanup[b] (sum of lines 1 through 5)	4.2	4.9
7.	Engineering, Design, and Construction Management (30% of line 6, except line 4B)	1.3	1.4
8.	Total[b] (sum of lines 6 and 7)	5.5	6.3
9.	Contingency (30% of line 8)	1.7	1.9
10.	GRAND TOTAL[b]	7.2	8.2

[a]Costs are in millions of 1980 dollars.

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

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TABLE 9-2

POTENTIAL CANCER CASES AVOIDED
AND COST PER POTENTIAL CASE AVOIDED

A. Number of Potential Cancer Cases Avoided

Options:	I	II
Option Cost (million $)	7.2	8.2
Years After Remedial Action		
25	<0.019	0.019
50	<0.034	0.034
75	<0.049	0.049
100	<0.063	0.063

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

Options:	I	II
Option Cost (million $)	7.2	8.2
Years After Remedial Action		
25	379	432
50	212	241
75	147	167
100	114	130

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GLOSSARY

GLOSSARY

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

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

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

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

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

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

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

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

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

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