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ENGINEERING ASSESSMENT OF INACTIVE URANIUM MILL TAILINGS

GREEN RIVER SITE
GREEN RIVER, UTAH

AUGUST 1981

PREPARED FOR

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

CONTRACT NO. DE-AC04-76GJ01658

BY

Ford, Bacon & Davis Utah Inc.
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SINCE 1894

DISCLAIMER

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FORD, BACON & DAVIS UTAH INC.
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 December 1977, entitled "Phase II - Title I Engineering Assessment of Inactive Uranium Mill Tailings, Green River Site, Green River, Utah," which was authorized by DOE, Grand Junction, Colorado, under Contract No. E(05-1)-1658.

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

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

ABSTRACT

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

Radon gas released from the 123,000 tons of tailings at the Green River site constitutes the most significant environmental impact, although windblown tailings and external gamma radiation also are factors. The five alternative actions presented in this engineering assessment range from millsite decontamination with the addition of 3 m of stabilization cover material (Option I), to removal of the tailings to remote disposal sites and decontamination of the tailings site (Options II through V). Cost estimates for the five options range from about $4,300,000 for stabilization in-place, to about $9,600,000 for disposal at a distance of about 30 mi.

Three principal alternatives for the reprocessing of the Green River tailings were examined:

(a) Heap leaching

(b) Treatment at an existing mill

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

The cost of the uranium recovered would be about $1,800/lb by heap leach and $1,600/lb by conventional plant processes. The spot market price for uranium was $25/lb early in 1981. Therefore, reprocessing the tailings for uranium recovery is extremely impractical economically.

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

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

Prior to 1975, the studies of radiation levels on and in the vicinities of these sites were limited in scope. The data available were insufficient to permit assessment of risk to people with any degree of confidence. In addition, information on practicable measures to reduce radiation exposures and estimates of their projected costs was limited. The purposes of these recent studies performed by FB&DU have been to 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 Green River site:

(a) Exhalation of radon gas from the tailings

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

(c) Land contamination from windblown tailings

(d) Hydrology and contamination by water pathways

(e) Potential health impact

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

Investigation of these and other factors originally led to the evaluation of three potential practicable remedial action alternatives. Since that time, some remedial action alternatives have been judged unacceptable 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 tailings on site with a 3-m cover

(b) Option II - Disposal about 5 mi northeast of Green River, Utah, 4.5 mi northeast of tailings pile

(c) Option III - Disposal about 7 mi southeast of Green River, Utah, 7 mi southeast of tailings pile

(d) Option IV - Disposal 2 mi north of Woodside, Utah, 30 mi northwest of tailings pile

(e) Option V - Disposal at Sager's Flat, 6 mi east of Thompson, Utah, 30 mi east of tailings pile

1.1.1 Background

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

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

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

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

On May 5, 1975, ERDA, the successor to AEC, announced that Ford, Bacon & Davis Utah Inc. of Salt Lake City, Utah, had been selected to provide the architect-engineering (A-E) services for Phase II. ERDA's Grand Junction, Colorado, 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. The Phase I report on the Green River site appears as Appendix I to Reference 4.

terms of a contract with FB&DU. The contract was effective on June 23, 1975. The Salt Lake City Vitro site was assigned as the initial task, and work began immediately. The original work at the Green River site was performed in July and October of 1976, and the original Phase II - Title I Engineering Assessment was published in December 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 September 1, 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 Green River site.

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

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

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

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

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

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

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

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

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

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

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

    (1) Gamma radiation

    (2) Radon

(3) Radon daughter concentrations

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

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

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

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

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

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

Not all of these items received attention at the Green River site.

1.2 SITE DESCRIPTION

1.2.1 Location and Topography

The Green River millsite and tailings pile are located in the east-central portion of Utah, in Grand County. The site is 1 mi east of the city of Green River and 70 mi west of the Utah-Colorado border. The city of Green River is situated in Emery County on the west side of the Green River. The Green River is 0.5 mi west of the tailings, and the valley in which the tailings are located is about 4,080 ft above sea level. Mesas and steep cliffs that reach elevations of 6,400 ft border the valley on the north. The climate is arid and vegetation is sparse. The site and its relationship to the surrounding area are shown in the aerial photograph, Figure 2-1.

1.2.2 Ownership and History of Milling Operations and Processing

Union Carbide Corporation built the mill in 1958 and operated it until shutdown in 1961. During the 3 yr of operation, the mill processed 183,000 tons of ore with an average grade of 0.29% U_3O_8, generating an estimated 137,000 tons of tailings. Most of the ore came from the Temple Mountain Mine area, some 60 mi southwest of the site. Upgraded concentrate was sent to Rifle, Colorado, for further processing. Union Carbide still owns the mill and tailings site.

1.2.3 Present Condition of the Site

The tailings pile is generally rectangular in shape and covers approximately 9 acres. Figure 2-4 is a descriptive map of the site. The tailings reach an average depth of 7 ft. Although the pile has been stabilized with 6 in. of earth, its slightly sloping surface is eroding in places. A cross-section of the pile is shown in Figure 2-5.

Some diking and riprap have been placed around the north and east edges of the pile to protect it from the runoff waters of Browns Wash, which parallels the north side of the site. The tailings are enclosed by a barbed-wire fence that requires and receives maintenance. The mill buildings have been leased from time to time but are presently vacant.

1.2.4 Tailings and Soil Characteristics

The tailings are of finely-ground sand, white to pink in color. They have a bulk density of about 92 lb/ft^3. An estimated 14,000 tons of the tailings were washed away in a flash flood, leaving about 123,000 tons still on the site. Table 2-1 indicates the quantities and weights of the tailings and contaminated materials.

The ground beneath the tailings consists of alluvial material and the Mancos Shale Formation.

1.2.5 Geology, Hydrology, and Meteorology

The Green River tailings pile and millsite are located on a slope between an upper abandoned river terrace and the present flood plain of the Green River and its local tributary, Browns Wash. The tailings rest upon the upper terrace deposits, the alluvium of the flood plain, and upon Mancos Shale bedrock. Approximately 10 to 25 ft of Mancos Shale underlie the tailings area and separate it from the Dakota Sandstone and older sedimentary units. Figure 2-6 is a simplified stratigraphic column.

The surface waters adjacent to or near the site consist of Browns Wash, which borders the site on the north, and the Green River, which is 0.5 mi downstream from the tailings site. Browns Wash is an intermittent stream which drains an area of 80 sq mi that includes the site. Significant flooding occurs in Browns Wash, and such floods have undercut the stream bank and eroded tailings at the site. Contamination of the Green River conceivably could occur by the tailings being transported in flood waters from Browns Wash, but to date there has been no change in the quality of the Green River waters. In general, ditches, roads, and natural topography limit the water flowing onto the pile to the precipitation that falls on the site. However, some sections of the protective dike appear inadequate to divert flows, and waters from the south and southeast of the pile have flowed onto the pile. The dike at the north of the pile prevents some runoff from reaching Browns Wash but the dikes on the north and west sides do not meet, and it appears there has been runoff from the northwest corner.

The confined ground water system of the area is protected from contamination by the thin sequence of impermeable Mancos Shale that underlies the site and by the low annual precipitation of the area, which makes the percolation of waters through the pile virtually impossible. The Dakota Sandstone is a potential aquifer at Green River, but is not tapped because of its poor water quality and because of the availability of surface waters associated with the Green River. The unconfined aquifers in the Green River area consist of waters within the recent flood plain alluvium and associated older terrace deposits. The millsite is located at the southern edge of the river's flood plain. The sources of the Green River city water supply are upstream; therefore, there is little potential for contamination of unconfined ground waters and no potential for contamination of local domestic water supplies.

High intensity rainfall such as thunderstorms can be expected in the Green River area. These storms have caused the flooding of Browns Wash and have caused extensive erosion of the pile. Average annual precipitation totals 6 in., and average annual evaporation totals approximately 60 in. Erosion of tailings from the pile has been relatively minor except for that due to the flooding of Browns Wash.

1.3 RADIOACTIVITY AND POLLUTANT IMPACTS ON THE ENVIRONMENT

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

1.3.1 Radiation Exposure Pathways, Contamination Mechanisms, and Background Levels

The major potential environmental routes of exposure to man are:

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

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

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

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

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

1.3.1.1 Radon Gas Diffusion and Transport

Measurements of radon flux from the tailings made in 1976 using the charcoal canister technique(3) ranged from 32 to 130 pCi/m^2-s on the tailings pile. The latest (1980) measured fluxes ranged from 60 to 180 pCi/m^2-s, with a mean flux estimated to be about 95 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 in 1976 with continuous radon monitors supplied by ERDA at five locations in the vicinity of the Green River tailings pile. The locations and values of the radon measurements are shown in Figure 3-5. No correlation was found between radon concentration and distance from the pile. The lowest concentration off the pile was 0.9 pCi/l at a distance of 0.08 mi, while the highest concentration was 2.3 pCi/l at a distance of 3.4 mi.

Four 24-hr measurements of atmospheric radon indicated an average background concentration of 1.5 pCi/l for the Green River area.

1.3.1.2 Direct Gamma Radiation

The range of natural gamma background rates in the Green River area was between 4 and 12 μR/hr, averaging 8 μR/hr as measured 3 ft above ground with an energy-compensated Geiger Mueller detector.(4) Above the surface of the tailings pile, gamma radiation rates were measured as high as 96 μR/hr. At the former ore stockpile area, gamma radiation reached a maximum of 220 μR/hr.

1.3.1.3 Windblown Contaminants

Background gamma radiation rates were reached within 400 ft to the north, east, and west of the pile, and within 1,100 ft south of the pile. The results of the survey of windblown contaminants around the tailings pile are shown in Figure 3-13. There is generally close correlation between the 10 μR/hr line described in Reference 1 and the estimated 5 pCi/g boundary presented herein.

Surface soil samples taken west of the site access road contained only background levels of ^{226}Ra (1.4 pCi/g). To the north and east, at distances of 0.25 mi, soil samples had radium concentrations of 3.5 and 2.5 times average radium background concentration. To the south the radium concentration dropped to less than twice background at 0.4 mi. Three soil samples taken at least 0.5 mi from the site showed an average ^{226}Ra concentration of about 2.1 pCi/g.

1.3.1.4 Ground and Surface Water Contamination

The Green River flows within 0.5 mi of the Green River tailings pile. Browns Wash is a major drainage channel for the area around the pile that drains into the Green River, but it is dry during part of the year. An analysis of a shallow ground water sample from Browns Wash downstream from the tailings pile showed ^{226}Ra concentration to be less than 10% of the limit in the EPA Interim Primary Drinking Water Regulations.(5)

1.3.1.5 Soil Contamination

The leaching of radium into the subsoil beneath the tailings extends from 2 to 3 ft below the tailings-soil interface before reaching the average background level of radium concentration in local soil samples (1.4 pCi/g).

1.3.2 Remedial Action Criteria

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

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

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

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

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

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

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

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

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

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

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

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

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

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

1.3.3 Potential Health Impact

Radon gas released from the pile and the subsequent inhalation of radon daughters account for most of the total dose to the population from the Green River site under present conditions. The gamma radiation exposure from the pile is virtually zero since there are no individuals who live or work within 0.2 mi of the pile, where gamma radiation is above background.

Gamma radiation can be reduced effectively by shielding with any dense material. However, experience has shown that it is very difficult to control the movement of radon gas through porous materials. Once released from the radium-bearing minerals in the tailings, the gaseous radon diffuses by the path of least resistance to the surface. The radon has a half-life of about 4 days, and its daughter products are solids. Therefore, part of the radon decays en route to the surface and leaves daughter products within the tailings piles. If the diffusion time can be made long enough, then, theoretically, virtually all of the radon and its daughter products will have decayed before escaping to the atmosphere. Calculations using the theoretical techniques of Kraner, Schroeder, and Evans[6] earlier indicated that 13 ft of earth cover would be required to reduce the radon diffusion from the Green River 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 tailings pile in the vicinity within 2 mi of the Green River site is less than 1×10^{-6} per person per year, or less than 1% of the average lung cancer risk due to all causes for Utah residents (1.25×10^{-4}).(10)

The 25-yr health effects were calculated for three population projections using the present population of 1,180 in the 0- to 2-mi area. The results for pile-induced radon and background radon for this area were as follows:

25-Year Cumulative Health Effects within 2 Miles of Edge of Pile

Projected Population Growth	Pile-Induced RDC	Background RDC
1.0% constant growth rate	0.013	2.0
2.5% declining growth rate*	0.015	2.3
6.0% declining growth rate*	0.018	2.8

Pile-induced radon daughter health effects are less than 1% of the background radon daughter health effects for residents within 2 mi of the tailings site. The exposure and consequent risk will continue as long as the radiation source remains in its present location and condition.

1.3.4 Nonradioactive Pollutants

There are other potentially toxic materials in the tailings. Chemical analyses of samples from drill holes in the Green River tailings pile showed barium and lead in concentrations between 70 and 130 ppm. The highest selenium concentration was 231 ppm and the arsenic concentration was 2 ppm.

Two water samples from a drill hole on the pile and from a hole between the pile and Browns Wash were obtained and chemically analyzed. The selenium, lead, chromium, and arsenic concentrations were well above the EPA Interim Primary Drinking Water Regulations. These samples could have been contaminated during the drilling process and therefore may not be representative of the ground water quality. Analysis of two samples from Browns Wash, upstream and downstream from the tailings, showed heavy metal concentrations to be well below the limits in the EPA Interim Primary Drinking Water Regulations. Only the vanadium concentration increased slightly in the downstream sample.

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

1.4 SOCIOECONOMIC AND LAND USE IMPACTS

The Green River site is located slightly over 1 mi from the city of Green River and within 0.5 mi of the unincorporated community of Elgin. There are several occupied and unoccupied homes and mobile homes in Elgin and some commercial development along the highway to Green River. The White Sands Missile Test Range and Headquarters controls most of the land uses near the site and includes several large buildings and approximately 72 mobile home units. None of the residential units are officially occupied on a permanent basis, although a few are used intermittently. The remaining area near the tailings site is vacant and is used as part of the missile test area.

Virtually all the land within 0.5 mi of the site is owned by Union Carbide Corporation, and much of it is leased to the Federal Government. The Federal Government administers the missile testing site. The 80 acres of Union Carbide property is valued at approximately $60/acre. The presence of the tailings restricts the use of the actual tailings area. However, there appears to be no competing use for the site except as an extension of the missile range. Any loss of agricultural or grazing land is negligible. In short, if the tailings were not present, it appears there would be virtually no change in land uses and values in the surrounding area.

1.5 RECOVERY OF RESIDUAL VALUES

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

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

(a) The amount of tailings present

(b) Concentrations of residual values

(c) Projected recovery

(d) Current market price of recovered values

(e) Proximity to processing mills

Three principal alternatives for the reprocessing of the Green River tailings were examined:

(a) Heap leaching

(b) Treatment at an existing mill

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

The cost of the uranium recovered would be about $1,800/lb and $1,600/lb of U_3O_8 by heap leach and conventional plant processes, respectively. The spot market price for uranium was $25/lb early in 1981. Therefore, reprocessing the tailings for uranium recovery is extremely impractical economically.

1.6 MILL TAILINGS STABILIZATION

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

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

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

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

1.7 OFF-SITE REMEDIAL ACTION

A mobile scanning unit, operated by the AEC under interagency agreement for the EPA, was used to perform a gamma radiation survey of the Green River area prior to 1973. A subsequent field survey identified only one off-site location where tailings use was confirmed. The cost of remedial action for this location has been estimated to be $74,000, exclusive of engineering and contingency allowances. Cleanup of the off-site windblown tailings surrounding the pile and of water-eroded tailings in Browns Wash from the railroad bridge to the road bridge was considered necessary. The total remedial action cost for off-site structures and for decontamination of off-pile open lands has been estimated to be $348,000, exclusive of engineering and contingency allowances.

1.8 DISPOSAL SITE SELECTION

In this report, four of the alternative remedial action options include moving the Green River tailings to a disposal site. The corresponding four disposal sites were selected on the bases of their hydrology, meteorology, geology, ecology, economics, and proximity to population centers. Since the responsibility for disposal site selection lies with the Federal Government, with input from the State, the disposal sites evaluated in this report must be considered only as tentative.

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

1.9 REMEDIAL ACTIONS AND COST-BENEFIT ANALYSES

1.9.1 Remedial Action Options

The remedial action options examined include stabilization of the tailings pile in its present location, and removal of all radioactive materials to an area where these materials could be isolated from the public. The options for which cost estimates were made include stabilization on the present site with 3 m of cover material, and the removal of tailings to four possible disposal locations. The options are summarized in Table 1-2.

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

Option I represents remedial action activities to stabilize the pile more completely in its present location with the addition of a 3-m depth of cover. Erosion of the tailings would be controlled more completely and radon exhalation would be reduced to less than 2 pCi/m^2-s above background. The site would be available for restricted use only.

Four sites were evaluated for possible disposal of the Green River tailings, and cost estimates for disposal at each site were made. Their locations are given in Figure 8-1 and Table 8-1.

The Northeast Green River and the Southeast Green River sites have the advantage of being close enough to the Green River tailings to limit transportation costs. However, cover material would have to be hauled 4 to 6 mi to either site.

The disposal location 2 mi north of Woodside, Utah, and the Sager's Flat site 6 mi east of Thompson, Utah, are situated close to highway or rail transportation facilities. The main disadvantages of these sites are the long distances from the tailings site, scarcity of cover material, and, in the case of the Woodside site, the necessity of hauling the tailings through the city of Green River.

1.9.2 Cost-Benefit Analyses

As summarized in Table 9-1, the total costs for the five remedial action options vary from about $4,300,000 to about $9,600,000. Each of these options would have associated health and monetary benefits. The options are identified by number in Paragraph 1.1.

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

TABLE 1-1

SUMMARY OF CONDITIONS NOTED AT TIME OF 1980 SITE VISITS

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

TABLE 1-1 (Cont)

	Condition of Tailings[a]	Condition of Structures On Site[b]	Mill Housing[c]	Adequate Fencing, Posting, Security	Property Close to River or Stream	Houses or Industry within 0.5 Mi	Evidence of Wind or Water Erosion	Possible Water 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	4,300	The pile would be stabilized in place with 3 m of local earth cover. Natural vegetation would be established or a 0.3-m cover of riprap would be provided. On- and off-site contaminated materials would be cleaned up as necessary.	A-H	X,Y,Z
II	6,800	The tailings, contaminated soil, and rubble would be removed by truck to Northeast Green River, located about 4.5 mi from the tailings site. The tailings site would be decontaminated as in Option I and released for unlimited use.	A-G,I	--
III	6,900	Same as Option II, except tailings removed to Southeast Green River, located about 7 mi from the tailings site.	A-G,I	--
IV	8,100	Same as Option II, except tailings removed to 2 mi north of Woodside, Utah, located about 30 mi from the tailings site.	A-G,I	--
V	9,600	Same as Option II, except tailings removed to Sager's Flat, located 6 mi east of Thompson, Utah, and about 30 mi from the tailings site.	A-G,I	--

TABLE 1-2 (Cont)

Notes

1. All options include on-site remedial action.

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

Definition of Benefits

A. Better security, decontamination at off-site structures and open lands
B. Erosion in existing cover better controlled
C. Pile protected from flooding in Browns Wash
D. Pile protected from upslope flooding
E. Gamma radiation reduced to near-background levels
F. Minimum maintenance required
G. Radon exhalation reduced to 2 pCi/m^2-s
H. Site available for restricted use only
I. Site available for unrestricted use

Definition of Adverse Effects

X. Stabilized pile remains close to the Green River
Y. Some security and maintenance required
Z. Tailings remain close to the populated area

CHAPTER I 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, Green River Site, Green River, Utah"; GJT-14; Ford, Bacon & Davis Utah Inc.; Dec 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 Green River, Utah"; Oak Ridge National Laboratory; ORNL 5459; 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 (Nov 1980).

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

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

CHAPTER 2

SITE DESCRIPTION

CHAPTER 2

SITE DESCRIPTION

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

2.1 LOCATION

The Green River millsite, shown in Figure 2-1, is approximately 1 mi southeast of the town of Green River, Utah, in Grand County. The site is about 50 mi northwest of Moab, Utah, and approximately 70 mi west of the Utah-Colorado border. The site is in Section 15, Township 21 South, Range 16 East, Salt Lake Meridian, at 38 deg 59 min north latitude and 110 deg 08 min 20 sec west longitude.

2.2 TOPOGRAPHY

The site is located in the Gunnison Valley approximately 0.5 mi east of the Green River at an elevation of 4,080 ft above sea level. The valley is bordered on the north by the Book Cliffs, which reach elevations of 6,400 ft, and on the south by the San Rafael Valley. The area is characterized by cliffs, mesas, and the Gray Canyon of the Green River. The climate is arid and vegetation is sparse, with few trees except those near the Green River.

The tailings pile covers approximately 9 acres. The mill area is adjacent to and southwest of the tailings. Figure 2-2 is a topographic map of the tailings area and millsite.

2.3 OWNERSHIP

The Union Carbide Corporation built, owned, and operated the mill from its inception in 1958, and the mill and tailings site remain under their ownership. Present land ownership at the Green River site is shown in Figure 2-3, which has been adapted from the site description and ownership map prepared for DOE[1] and published in the Federal Register.

2.4 HISTORY OF MILLING OPERATIONS AND PROCESSING[2]

The plant was operated from March 1958 to January 1961 for the upgrading of ore from the uranium mines at Temple Mountain, Utah. During its 3-yr operation, 183,000 tons of ore averaging 0.29% U_3O_8 were fed to process in the Green River plant, generating an estimated 137,000 tons of tailings. The upgraded "ore concentrate" was shipped by rail to Rifle, Colorado, for further processing.

The ore was sandstone loosely cemented with clay and asphaltic material, with part of the uranium intimately associated with the carbonaceous minerals. After crushing and grinding, the ore was screened, with minus-35 mesh material going to flotation and the plus-35 mesh material joining the flotation concentration to form a carbonaceous concentrate. The flotation tailings were separated into sand and slime fractions. The sands were leached with acid, the leached slurry washed, and the spent sands discarded to the tailings area. The recovered slimes and pregnant solution then joined with a portion of the initial slime fraction. Any excess acid was neutralized with ammonia. This mixed product plus the remainder of the primary slimes were then dewatered and dried for shipment to the Rifle plant.[3]

2.5 PRESENT CONDITION OF THE SITE

The tailings pile rests against a natural embankment to the south and slopes gently toward Browns Wash on the north, as shown in Figure 2-2. Main line tracks of the Denver and Rio Grande Western Railroad are also to the north, a few hundred feet from the edge of the tailings, and also north of Browns Wash. Some riprap protection has been placed at the north and east edges of the pile, and small dikes have been constructed on the north, east, and west sides. Earth from the embankment on the south of the pile was removed and placed on the tailings as a stabilization cover averaging about 6 in. thick. This cover was not contour-graded and as a result there is evidence of surface erosion on the pile. About 15% of the pile surface area is covered with natural vegetation in the form of weeds native to the area. The pile has not been irrigated.

The dikes on the north and west sides of the tailings are not connected. Therefore, water draining off the pile does not collect at the northwest corner of the pile, but instead enters Browns Wash at this point. Gamma readings downgrade from the tailings showed little or no contamination of the wash itself, however, suggesting that runoff from the pile is of little erosional significance.

The fences around the tailings and mill area are in need of repair, and the gate at the northwest corner of the tailings has no lock. Access to the site is therefore not limited. Radiation warning signs are prominently displayed on the fence and gate, however, and there is little evidence of trespassing.

A copper-sheathed communications cable 2 in. in diameter is buried in the tailings at a depth of 2.5 to 3.5 ft, parallel to the north fence line and 20 ft from the fence. Its location is shown in the descriptive map of the site, Figure 2-4. This cable is part of the nearby military installation associated with the White Sands Missile Range. The cable also runs through the millsite. Its presence has no detrimental effect on the site and it should not interfere with remedial action at the site.

At the time of the 1980 field survey, the mill buildings were not occupied, although they have been leased to others, such as Celesco, a government contractor, since the closing of the mill.[4]

2.6 TAILINGS AND SOIL CHARACTERISTICS

The types, volumes, and weights of contaminated materials present on the site are summarized in Table 2-1. Approximately 123,000 tons of tailings remain on the site after about 14,000 tons of the tailings were removed by a flash flood prior to 1965. The tailings are predominantly fine sands, white to pink in color. The slime fraction was shipped to Rifle, Colorado, together with a flotation concentrate, for further processing. Physical properties and pH of the tailings are given in Table 2-2. The bulk density is about 92 lb/ft^3 and the pH of the tailings (Table 2-2) is in the neutral range. Assay results of composite tailings samples are shown in Table 5-1.

A cross-section of the tailings pile is shown in Figure 2-5. The average thickness of the tailings is 7 ft. The tailings pile is located on alluvial material and Mancos Shale.

2.7 GEOLOGY, HYDROLOGY, AND METEOROLOGY

2.7.1 Geology

The Green River site is located on a slope between an upper abandoned river terrace and the present flood plain of the Green River and its local tributary, Browns Wash.[5] The tailings rest upon the upper terrace deposits, the alluvium of the flood plain, and Mancos Shale bedrock. The lowest member of the Mancos Shale is known as the Tununk Shale, and 10 to 25 ft of this rock unit underlie the site. Underlying the Tununk Shale are the Dakota Sandstone and older sedimentary units. A simplified stratigraphic column of the rock formations is shown in Figure 2-6.

At the millsite the strata dip very gently (1 to 5 deg) toward the north. Although the Mancos Shale is relatively thin beneath the tailings, it may act as a barrier to the downward and upward migration of ground waters.

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 Green River tailings site is contemplated at this time.

The tailings pile is situated along the southern bank of Browns Wash, an intermittent stream that drains an area of more than 80 sq mi east of the site, as depicted in Figure 2-7. Approximately 2,000 ft upstream of the pile, Browns Wash crosses under a 42-ft railroad crossing with a clearance of 12 ft. A gauging station is located 0.2 mi upstream of the bridge. Significant flooding occurs in Browns Wash, such as the floods of 1959 and 1968 when approximately 6,000 ft^3/sec of water flowed past the present location of the pile. The maximum flow depth was approximately 10 ft, and the 1968 flood waters caused considerable streambed erosion, undercutting of the bank, erosion of the tailings themselves due to failure of the bank, and inundation of sections of the pile. Such flows can be expected in the future. Unless the wash is rechanneled and the bank protected, undercutting of the bank and consequent erosion of the tailings, even though they are above the flood level, can be expected to occur during either an intermediate regional flood (100-yr flood) or a more severe standard project flood. The Green River is 0.5 mi downstream of the site. Contamination of the Green River could occur by physical transport of the tailings by flood waters of Browns Wash into the river, but there is no evidence of change in the quality of the Green River waters due to the tailings to date, as discussed in Chapter 3.

The dikes on the north and west sides of the tailings pile are not continuous and might not contain the pile runoff nor preclude contamination of Browns Wash. Therefore, if the pile is stabilized in place, the dikes need to be enlarged, improved, and provided with heavy riprap protection to limit the potential for erosion of the pile by flood waters.

2.7.3 Ground Water Hydrology

Some of the tailings lie directly upon the Tununk Shale Member of the Mancos Shale. The Mancos Shale is relatively impermeable, is not a major aquifer, and serves as a confining layer over the Dakota Sandstone, preventing downward migration of contaminants. Although the Dakota Sandstone is a potential aquifer, it is not tapped at Green River because of its poor water quality and because of the availability of surface waters associated with the Green River.

The unconfined aquifers in the Green River area consist of waters within the recent flood plain alluvium and associated older terrace deposits. The flow gradients of local ground waters are shown in Figure 2-8. The millsite is at the southern edge of the flood plain, and the source of the Green River city water supply is located upstream; therefore, there is little potential for unconfined ground water contamination and no potential for contamination of local domestic water supplies. There is no evidence of seepage of waters along the edges of the pile.

Recent[6,7] 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[6] 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 in selecting stabilization methods. Since the pile is 0.5 mi from the Green River, there may not be a source of water to drive the phenomenon described above.

2.7.4 Meteorology

High-intensity rainfall such as thunderstorms can be expected in the Green River area from July through October. These storms have caused flooding of Browns Wash and have caused erosion of certain sections of the pile. Average annual precipitation totals 6 in. and average annual evaporation totals approximately 60 in. A rainfall of a 24-hr duration totaling 1 in. has a probability of occurring once every 2 yr. A 24-hr rainfall of 2.3 in. could be expected once every 100 yr. A high-intensity cloudburst at the site would result in erosion of cover material and tailings from the site.

Meteorological data for Green River gathered at the airport west of town for the 2-yr period of 1975 to 1976 are summarized in Table 2-3. These data indicate little or no wind over half of the time at Green River, with infrequent strong winds coming from the south, southwest, north, and northwest. The average wind speed at Green River is 4.2 mi/hr.

FIGURE 2-1. AERIAL PHOTOGRAPH OF SITE

360-14 12/77

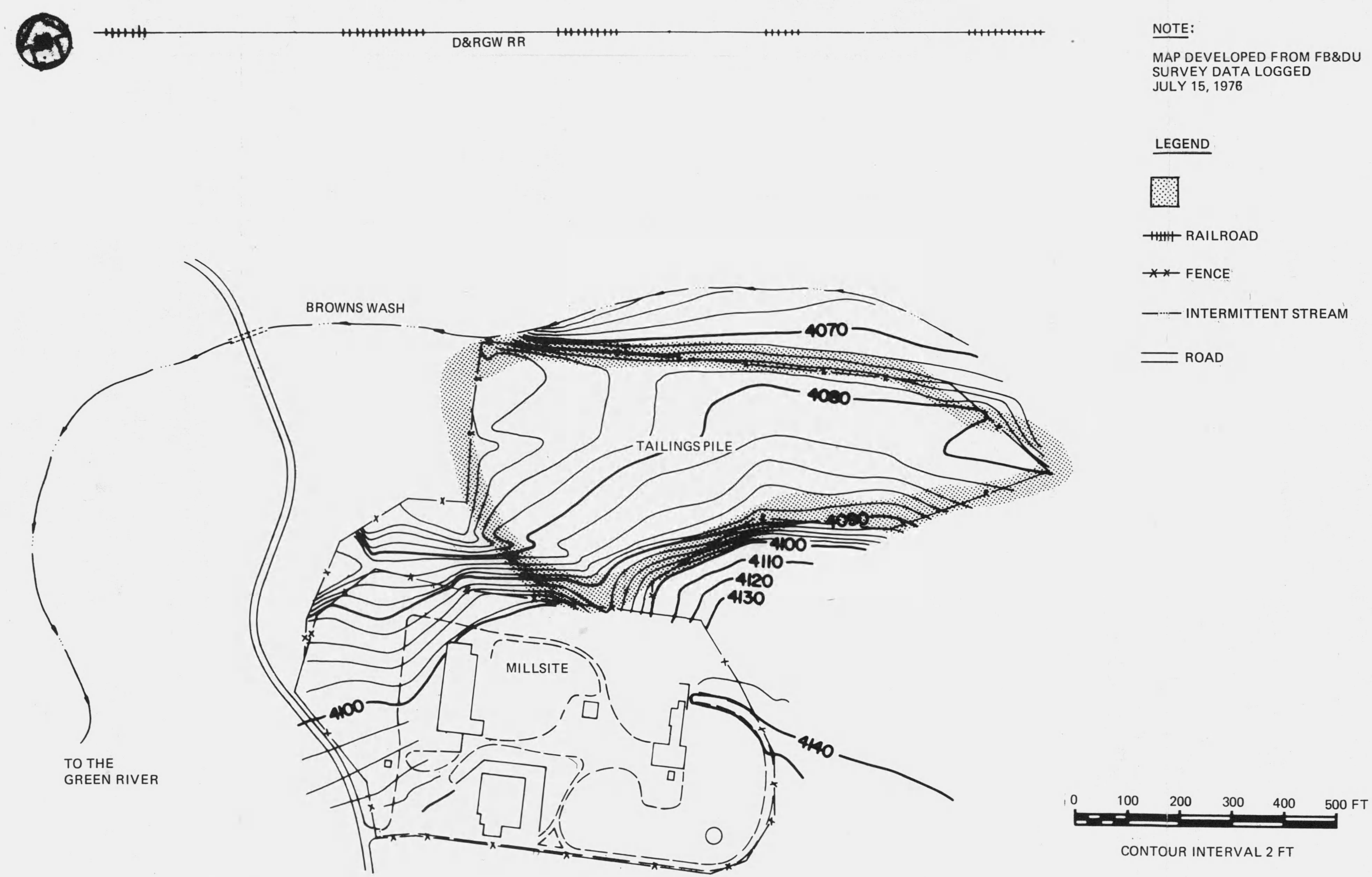
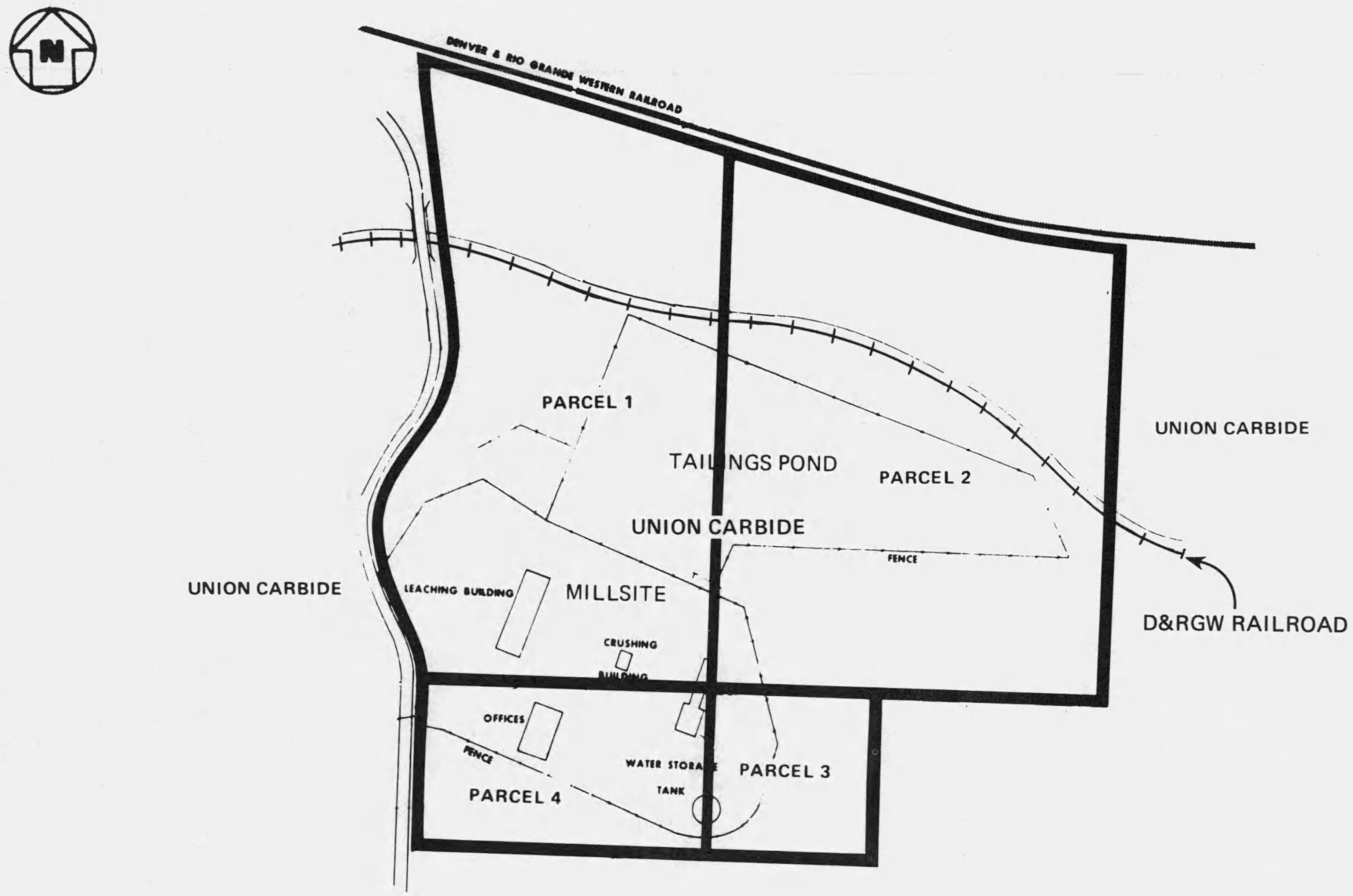


FIGURE 2-2. TOPOGRAPHIC MAP

360-14 12/77



GREEN RIVER SITE
(PARCELS 1 THRU 4)

PARCEL 1

THAT PORTION OF LAND LOCATED IN THE S.W. 1/4 OF THE S.E. 1/4 SECTION 15, T21S, R16E, SALT LAKE MERIDIAN, LYING ADJACENT TO AND EAST OF A COUNTY ROAD FROM ELGIN TO THE GREEN RIVER MISSILE SITE, AND SOUTH OF THE D.&R.G.W. RAILRAOD R/W.

PARCEL 2

THAT PORTION OF LAND LOCATED IN THE WEST 800 FT OF THE S.E. 1/4 OF THE S.E. 1/4 OF SECTION 15, T21S, R16E, SALT LAKE MERIDIAN LYING SOUTH OF AND ADJACENT TO THE D.&R.G.W. RAILROAD R/W.

PARCEL 3

THAT PORTION OF LAND LOCATED IN THE WEST 300 FT, OF THE NORTH 1/2 OF THE NORTH 1/2 OF THE N.E. 1/4 OF THE N.E. 1/4 OF SECTION 22, T21S, R16E, SALT LAKE MERIDIAN.

PARCEL 4

THAT PORTION OF LAND LOCATED IN THE NORTH 1/2 OF THE NORTH 1/2 OF THE N.W. 1/4 OF THE N.E. 1/4 OF SECTION 22, T21S, R16E, SALT LAKE MERIDIAN, LYING EAST OF AND ADJACENT TO A COUNTY ROAD FROM ELGIN TO THE GREEN RIVER MISSILE SITE.

CONTAINS 39 ACRES (MORE OR LESS).

NOTE: ADAPTED FROM REFERENCE 1

FIGURE 2-3. LAND OWNERSHIP AND SITE DESIGNATION MAP

360-14 1/81

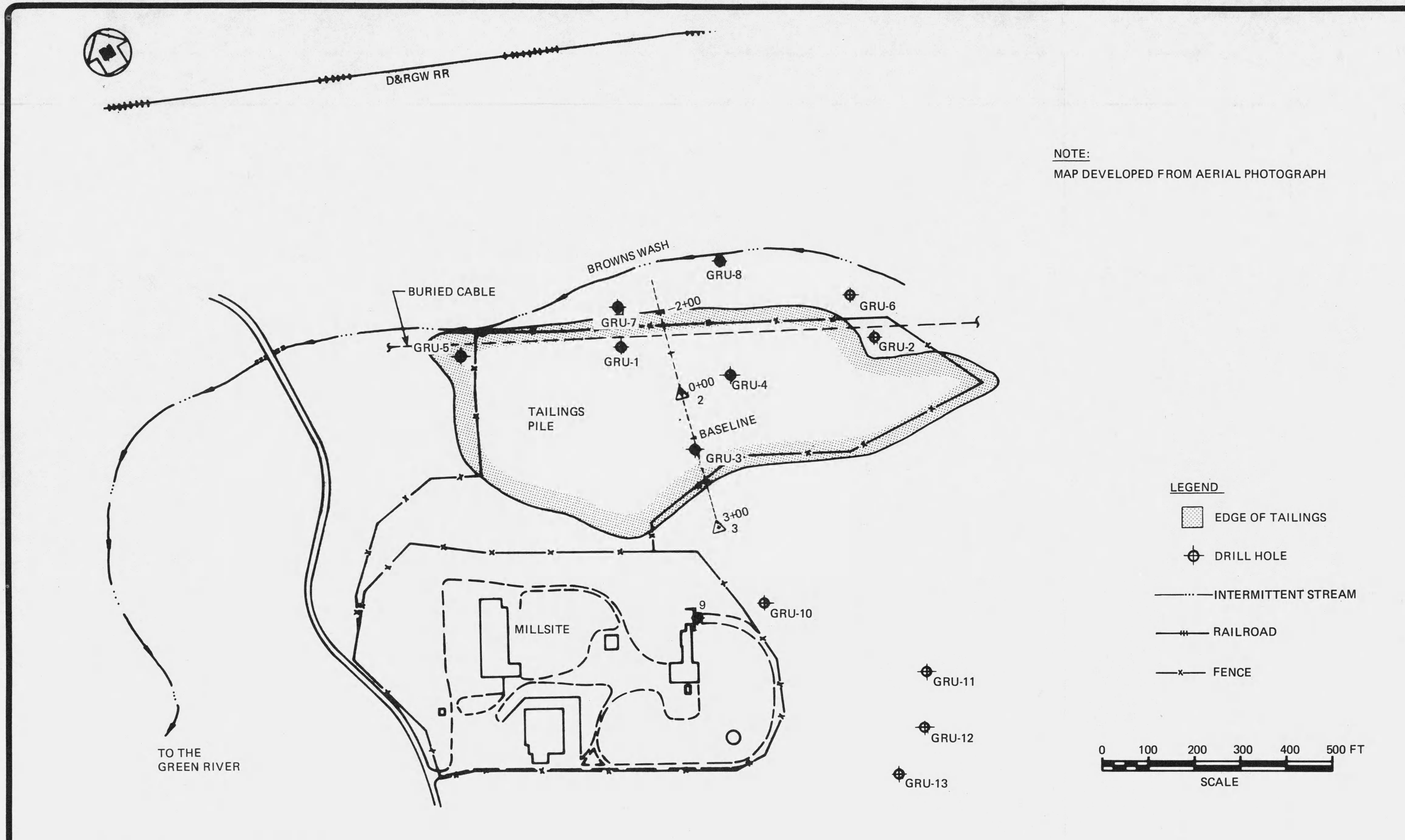


FIGURE 2-4. DESCRIPTIVE MAP

360-14 12/77

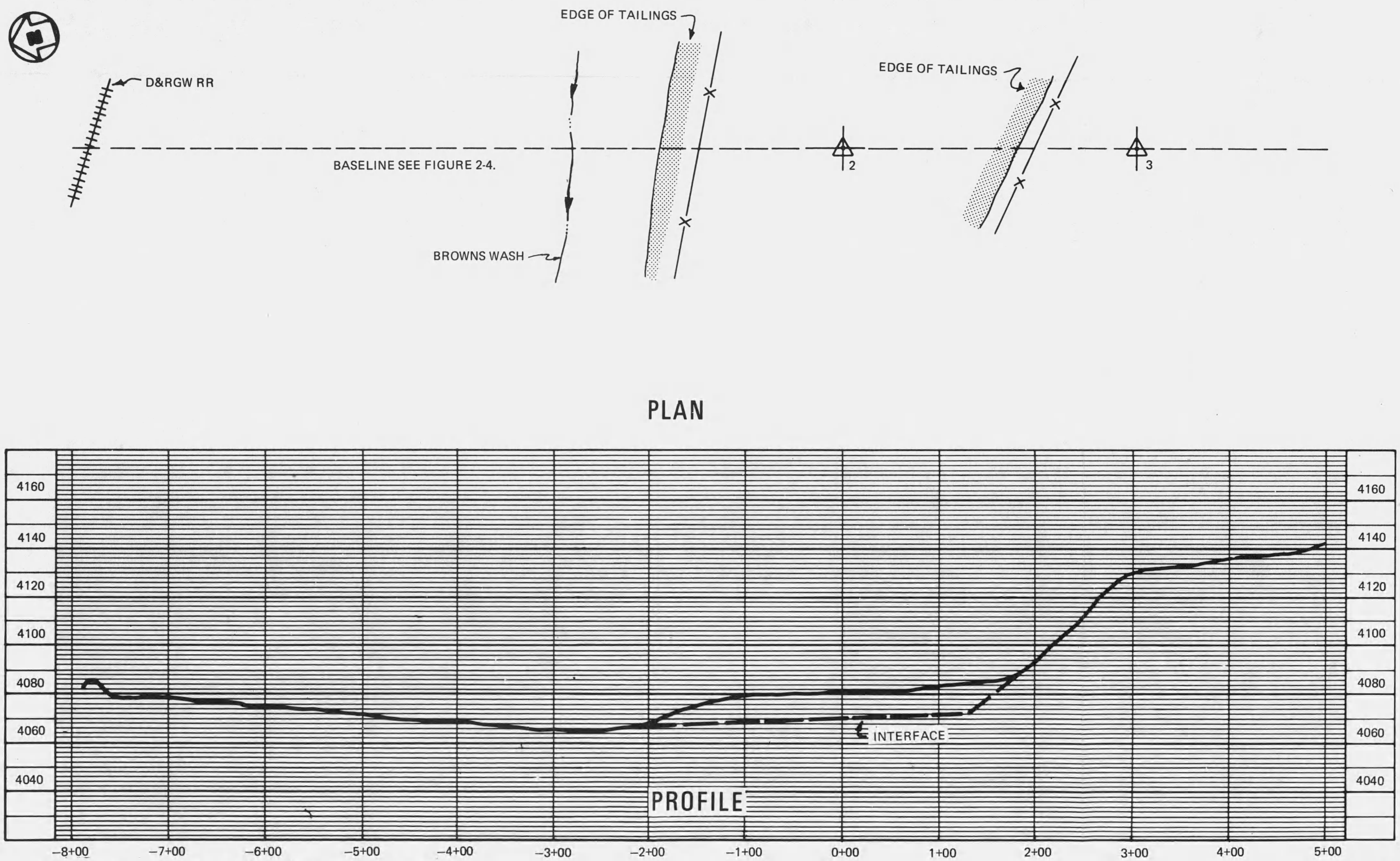


FIGURE 2-5. CROSS-SECTION THROUGH PILE

360-14 12/77

SYSTEM	FORMATION	THICKNESS (FT)	CHARACTER	POSITION OF THE TAILINGS
CRETACEOUS	MANCOS SHALE	2,000-5,000	UPPER PART; UNDIFFERENTIATED: GRAY SHALES; FORMS VALLEYS, AND SLOPES; AQUICLUDE	
			FERRON SANDSTONE MEMBER; SANDSTONES AND SANDY SHALES; FORMS LEDGES; POTENTIAL AQUIFER	
			TUNUNK SHALE MEMBER: DARK GRAY SHALES; FORMS VALLEYS; AQUICLUDE	GREEN RIVER TAILINGS ←
	DAKOTA SANDSTONE	0-200	GRAY AND BROWN SANDSTONE, SHALE AND CONGLOMERATE; CAPS MESAS AND FORMS CLIFFS; LOW QUALITY AQUIFER	
	BURRO CANYON FORMATION	50-250	BLUFF CONGLOMERATIC SANDSTONE AND MAROON AND GREEN MUDSTONES; FORMS SLOPES, SANDSTONES FORM CLIFFS, LOW QUALITY, POTENTIAL AQUIFER	
JURASSIC	MORRISON FORMATION	300-500	BRUSHY BASIN MEMBER; VARICOLORED SHALES, SOME SANDSTONE; FORMS SLOPES; SANDSTONES YIELD WATER	
			SALT WASH MEMBER: LIGHT COLORED SANDSTONE, RED MUDSTONE, OCCASIONAL LIMESTONE; URANIUM HOST ROCK; 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	
OLDER SEDIMENTARY ROCKS				

FIGURE 2-6. SIMPLIFIED STRATIGRAPHIC COLUMN

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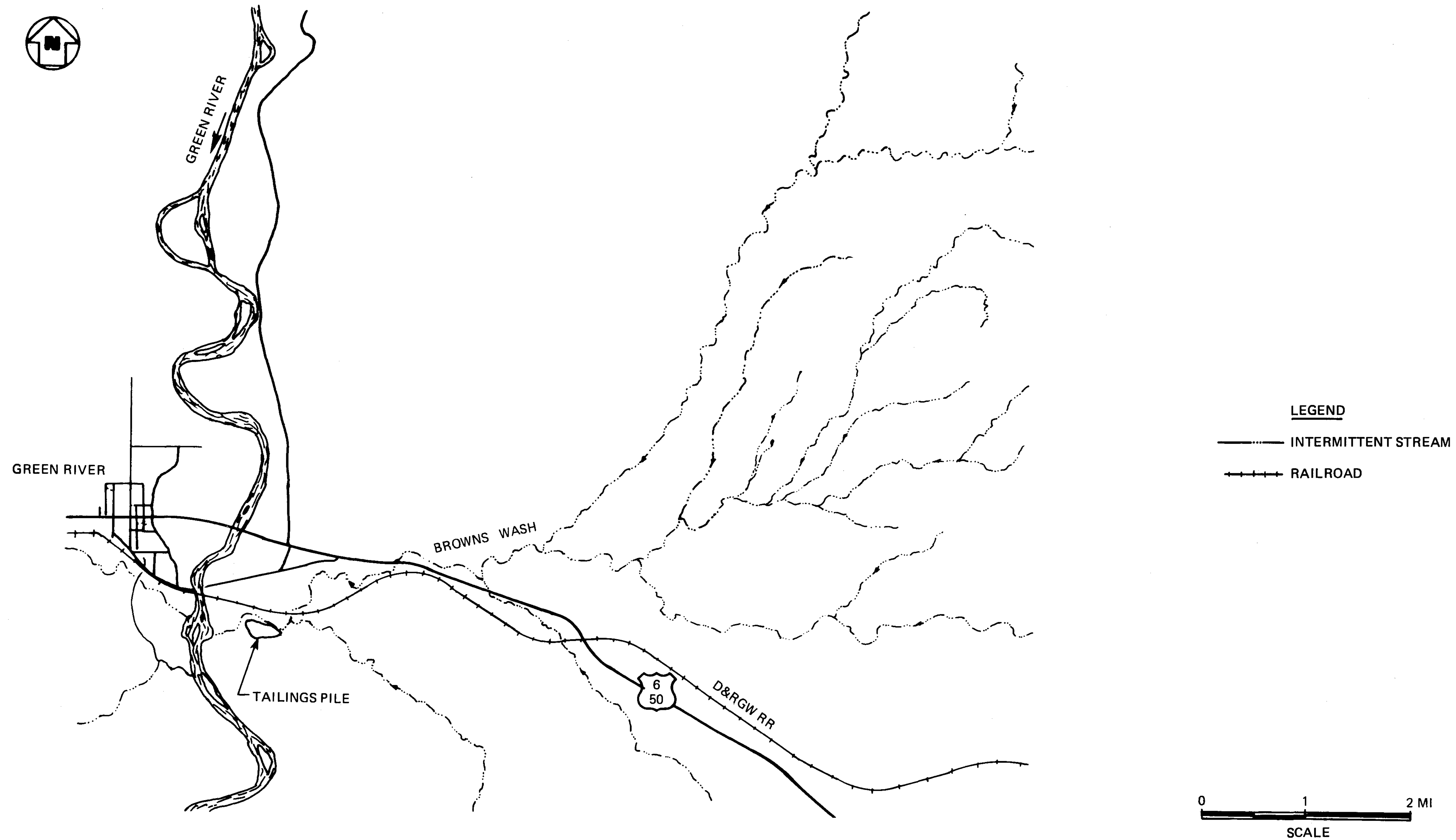

FIGURE 2-7. SURFACE DRAINAGE

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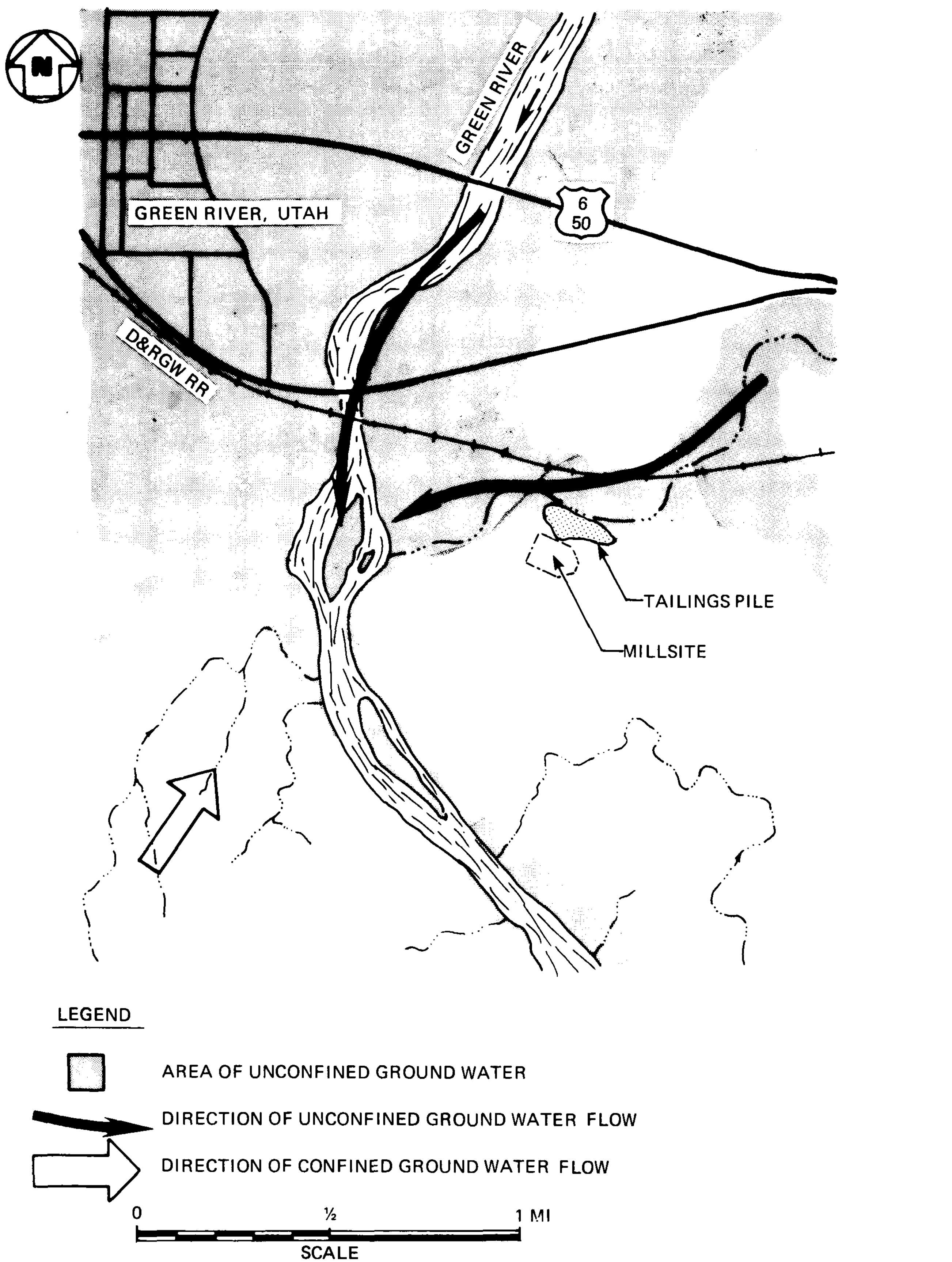

FIGURE 2-8. DIRECTION OF GROUND WATER FLOW

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TABLE 2-1

CONTAMINATED MATERIALS AT GREEN RIVER SITE

Material	Volume (yd^3)	Weight (tons)
Tailings	100,000	123,000[a]
Existing Stabilization Cover	8,000	11,500[a]
Riprap	500	800[a]
Contaminated Soil in Mill Area	50,500[c]	68,100[b]
Contaminated Subsoil beneath Tailings	43,600[d]	58,800[b]
Contaminated Soil in Windblown Area	21,000[e]	28,300[b]
Contaminated Soil in Area of Elevated Radium Content	6,500[f]	8,800[b]
TOTAL	230,100	299,300

[a]For tailings, indicated weight is dry weight, exclusive of moisture. For others, weight is based on average existing field densities, which include moisture.

[b]Weight based on an assumed density of 100 lb/ft^3.

[c]Volume based on 10.4 acres contaminated to an average depth of 3 ft.

[d]Volume based on 9 acres contaminated to an average depth of 3 ft below the tailings interface.

[e]Volume based on 26 acres contaminated to an average depth of 0.5 ft.

[f]Volume based on 4 acres contaminated to an average depth of 1 ft.

TABLE 2-2

PHYSICAL PROPERTIES AND pH OF THE URANIUM TAILINGS

Sample Location*	Percent Moisture	Bulk Density (lb/ft^3)	pH (5% water by wt)
GRU No. 3 Composite 0.0 to 10.0 ft (dry)	3.44	91.7	6.50

*See Figure 2-4.

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TABLE 2-3

METEOROLOGY FOR GREEN RIVER
(CUMULATIVE DATA FROM 1975 THROUGH 1976)

Direction	Frequency (%)	Direction	Frequency (%)
N	3.4	S	3.2
NNE	2.4	SSW	3.7
NE	1.7	SW	5.6
ENE	1.4	WSW	2.3
E	1.7	W	1.9
ESE	2.7	WNW	1.9
SE	2.9	NW	3.2
SSE	2.6	NNW	2.0

Calm (wind speed between 0 and 2.3 mi/hr) 57.4% of the time.

Annual average wind speed - 4.2 mi/hr.

Pasquill Stability Class D for 50% of the time and E for 50% of the time.

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CHAPTER 2 REFERENCES

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2. "Phase I Reports on Conditions of Uranium Millsite and Tailings at Green River, Utah"; AEC; Grand Junction, Colorado; Oct 1974 (see Reference 4 below, ORNL-5459, Appendix I).

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

4. F.F. Haywood, et al.; "Radiological Survey of the Inactive Uranium-Mill Tailings at Green River, Utah"; ORNL-5459; Oak Ridge National Laboratory, Oak Ridge, Tennessee; Mar 1980.

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6. 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.

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CHAPTER 3

RADIOACTIVITY AND POLLUTANT IMPACT ON THE ENVIRONMENT

CHAPTER 3

RADIOACTIVITY AND POLLUTANT IMPACT ON THE ENVIRONMENT

The principal objective of the assessment in this chapter is to determine the magnitude and characteristics of the radiation emitted from the Green River uranium tailings pile and the resulting potential exposure to the population residing and working in the vicinity of Green River, Utah. In addition, this chapter briefly describes the potential radioactive and chemical pollutants and their pathways in the environment. The notations and abbreviations used are given in Table 3-1.

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

3.1 RADIOACTIVE MATERIAL CHARACTERISTICS

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

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

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

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

3.2 RADIATION EFFECTS

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

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

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

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

3.3 NATURAL BACKGROUND RADIATION

There are several sources of radiation that occur naturally in the environment. Natural soils contain trace amounts of uranium, thorium, and radium that give rise to radon gas and to alpha, beta, and gamma radiation. The average background value in nine off-site soil samples for each member of the uranium decay chain, assuming equilibrium, was 1.4 pCi/g.(1) The sample locations within a 100-mi radius of Green River 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 0.7 pCi/g of soil. Table 3-2 lists the major background radioactive sources. The background values of the radium and thorium chains vary with locations by factors of 7 and 5, respectively.

Figure 3-3 shows the locations and ^{226}Ra concentrations of four soil samples obtained during the 1980 field work; the samples were located approximately 1 mi in each major compass direction from the tailings site. The average ^{226}Ra concentration in these four samples was 2 pCi/g.

Background values of radon concentrations were measured at four locations using continuous radon monitors supplied by ERDA.(2) An average outdoor value of 1.5 pCi/l was obtained from the 24-hr samples for the vicinity of Green River. However, the range of the measurements extends from 0.9 to 2.3 pCi/l.

Background gamma ray levels, as measured 3 ft above the ground, also were determined at several locations within 0.3 mi of the site by using a calibrated and energy-compensated Geiger Mueller detector. A value of 8 μR/hr was established as the average background level, but the values ranged from 4 to 12 μR/hr.(1) Cosmic rays are part of the measured background radiation levels. The contribution from cosmic rays generally is dependent upon the altitude and is approximately 6 μR/hr in the Green River area,[3] or approximately 75% 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

Measurements of the radon exhalation flux from the tailings were made using the charcoal canister technique[4] and their locations and radon fluxes are shown in Figure 3-4. The values range from 32 to 180 pCi/m^2-s on the tailings pile. Measurements of the radon flux from the tailings made in 1980 are shown separately in Figure 3-4 and resulted in an area-weighted average flux of 95 pCi/m^2-s. The pile was dry at the time of the measurements. Radon flux depends primarily on the radium content of the tailings. However, reported values of radon flux at a sampling location may vary considerably from time to time due to such factors as soil moisture content, atmospheric pressure, atmospheric inversion or lapse conditions, and humidity.

Radon gas attributed to the pile, as predicted from the model calculations, is near the estimated background ^{222}Rn concentration at a distance of 0.3 mi from the site. A significant relationship between radon concentration data and distance from the pile was not obtained during this assessment. Measurement locations and corresponding 24-hr average radon concentrations including background are illustrated in Figure 3-5.

Variation of radon concentration at two locations during the measurement period and the concomitant weather conditions are shown in Figures 3-6 and 3-7. The sample location for Figure 3-6 is at the center of the tailings pile. Figure 3-7 illustrates the measurements 3.1 mi north of the pile. A diurnal variation of ^{222}Rn concentration is evident in both figures, indicating the presence of a source of ^{222}Rn greater than background near the measurement locations. Thus the higher-than-normal background values are not merely the result of a high instrument background count. These 24-hr measurements were obtained during atmospheric conditions normal for that time of year (October). Data were not recorded during wind or rainstorms.

Radon concentration measurements taken during this program generally indicated increased concentrations during the night, with reduced values during the day. The increase in concentration is probably the result of an inversion condition and reduced wind velocities. High winds tend to disperse the radon and generally do not result in significantly higher measurements of radon concentration downwind from the tailings pile.

The radon concentration measurements are plotted in Figure 3-8 as a function of distance from the edge of the tailings pile. Also shown in the figure are the FB&DU model predictions. Model calculations were performed with annual meteorology data to provide an additional estimate of the radon concentration in the vicinity of the pile. The FB&DU model first determines radon flux and the total radon releases from the pile with diffusion theory using radium soil concentrations, and pile configurations deduced from the drilling and survey data. Then the radon transport off pile is calculated by Gaussian diffusion.[5] The meteorology used for the model predictions was taken at Green River, Utah, for the period 1975 through 1976 and is presented in Table 2-3.

The high radon concentrations at great distances from the pile (3 mi) are indicative of sources of radon other than the pile. Therefore, the model results were used to calculate potential health effects resulting from radon diffusing from the tailings.

3.4.2 Direct Gamma Radiation

The external gamma radiation (EGR) levels, including background, measured on the tailings pile are shown in Figure 3-9. These measurements were taken with calibrated energy-compensated Geiger Mueller detectors.[1] The highest gamma radiation rates on the pile (96 μR/hr) were measured at the edges of the tailings pile where the cover has been eroded by water runoff. In the mill and ore storage areas, gamma radiation rates were measured from background to 220 μR/hr.

External gamma radiation levels away from the tailings pile were measured at 100-yd intervals and reached background levels about 0.1 mi to the east and west of the site. These measurements of EGR levels are shown in Figure 3-10. Where the wind has carried tailings toward the north, background levels of gamma radiation were reached at distances of 0.2 mi. The gamma measurements toward the south were taken on a traverse through the millsite and ore storage areas; therefore, it was concluded that the above background gamma radiation beyond 0.1 mi was mainly due to sources other than the tailings pile, such as ore storage or mill spills. The reduction of gamma radiation as a function of distance from the pile is shown in Figure 3-11.

3.4.3 Windblown Contaminants

Another pathway results from windblown tailings. Prevailing winds are from the south and southwest.

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

The iso-exposure lines extend toward the east to include the former ore storage area and windblown radioactive material, and toward the north where tailings have been carried into Browns Wash by wind and water erosion.

Measurements and data analyses were performed in 1980 to establish a boundary around the site with soil contaminated in excess of 5 pCi/g of ^{226}Ra. A lead-shielded scintillometer, NaI(Tl), was used. One end of the scintillometer was unshielded and directed toward the ground, where it was held about 1 in. above the ground surface. An unshielded reading was obtained. A 0.5-in.-thick lead shield was then placed over the unshielded end and a second reading was obtained. The difference between the unshielded and shielded readings, called the "delta", represents the surface exposure at that location due to wind-blown materials in the soil. A delta of about 400 counts/min with the instrument used has been estimated to indicate a soil concentration of about 5 pCi/g of ^{226}Ra. The deltas and the boundary of the region around the site that exceeds the 5-pCi/g concentration of ^{226}Ra are shown in Figure 3-13.

Ten traverses with the scintillometer were made along lines away from the site to determine the extent of windblown contamination, as shown in Figure 3-13.

The 5-pCi/g boundary was reached within 300 ft of the site on all traverses to the north and west of the site. To the east of the site, windblown contamination was found as far as 400 ft from the edge of the tailings. South of the site the 5-pCi/g boundary extends to 1,100 ft from the edge of the tailings. Elevated delta readings, indicating areas with high ^{226}Ra concentrations, were encountered along the traverses to the south. The 5-pCi/g boundary includes approximately 26 acres of windblown contaminated land, of which about 14 acres are located outside the designated site boundary.

Surface soil samples were taken in the area immediately surrounding the tailings.(1) The sample locations and ^{226}Ra concentrations are shown in Figure 3-14. All samples to the west of the site access road, including those from Browns Wash where it enters the Green River, were below the average background ^{226}Ra concentration of 1.4 pCi/g. A surface soil sample 0.25 mi east of the pile contained 2.5 times the average background concentration. At 0.4 mi south of the tailings pile a soil sample contained less than 2 times the average background radium concentration. Samples taken in Browns Wash indicated only background concentrations of radium, but north of the wash in a previously flooded area the radium concentration was 9 times the background value. At 0.25 mi north, the radium concentration was 3.5 times the average background concentration.

No air particulate measurements were performed at the Green River site.

3.4.4 Ground and Surface Water Contamination

Two surface water samples were taken from the vicinity of the Green River tailings pile and analyzed for ^{226}Ra, as shown in Figure 3-14.[1] The sample taken from Browns Wash downstream from the tailings pile contained 0.26 pCi/l. The other sample, taken from the Green River upstream from where Browns Wash enters the Green River, contained 0.25 pCi/l of ^{226}Ra.

Browns Wash is the major drainage path from the tailings pile to the Green River; therefore, water in Browns Wash would be the most readily contaminated surface water in the vicinity of the tailings pile. The water sample from Browns Wash contained less than 10% of the maximum acceptable limit of radium for drinking water; consequently, surface water contamination from the Green River tailings pile is not a radiological health hazard. The quality of the Green River with respect to ^{226}Ra was monitored from 1962 to 1964. The average ^{226}Ra level during this period downstream from the tailings pile was 0.08 pCi/l.[7]

3.4.5 Soil Contamination

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

Typical ^{226}Ra activity profiles in the Green River tailings and soil are shown in Figures 3-15 and 3-16. Figure 3-15 illustrates the ^{226}Ra profile at hole GRU-3 located toward the southern edge of the tailings. The profile was determined with the gamma probe and by analyses of soil samples taken from the drill hole. The analyses of samples from the drill hole indicated that radioactive contamination decreased to the average ^{226}Ra background concentration about 2.5 ft below the original surface. The gamma log showed that background concentration was reached at 3.5 ft below the tailings-soil interface.

Figure 3-16 is the profile of radium activity at hole GRU-5 at the northwest corner of the pile outside the fenced area. At that location, the gamma log indicated less than twice background radium concentration about 1 ft below the tailings-soil interface. Radium activity in the tailings ranged up to 220 pCi/g in the holes that were logged. In general, ^{226}Ra contamination in the soil reached depths of 2 to 3 ft before reaching twice the ^{226}Ra background concentration.

3.4.6 Off-Site Tailings Use

A mobile gamma survey located sites where the gamma radiation rate was above the background level. A follow-up survey was performed at these locations to determine the source of the radiation, and one tailings location was found. The results of these surveys are discussed in Chapter 7.

3.5 REMEDIAL ACTION CRITERIA

The Grand Junction criteria for remedial action were adopted as a basis for the engineering assessments that preceded the enactment of PL 95-604, the Uranium Mill Tailings Radiation Control Act of 1978. The criteria adopted applied to: (a) the cleanup of structures[8] where tailings are present, and (b) the cleanup of open land.

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

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

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

3.5.1 EPA Interim and Proposed Standards

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

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

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

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

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

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

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

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

Average annual indoor radon decay product concentration--including background (WL) 0.015

Indoor gamma radiation--above background (mR/hr). 0.02

3.5.2 NRC Regulations on Uranium Mill Tailings

In the NRC's final regulations for uranium mill licensing requirements (45 FR 65521), 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 the NRC proposed criteria as given above. However, they add the important further condition that the stabilization should be designed to provide reasonable assurance of remaining effective for at least 1,000 yr.

3.6 POTENTIAL HEALTH IMPACT

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

(a) Radon Diffusion - Inhalation of radon daughters from radon diffusion constitutes the most significant pathway and results in the largest estimated population dose.[1,9] Elevated concentrations were measured as far away as 3 mi, but they were not believed to be due to radon released from the pile. In order to estimate the health effects attributable to radon released from the pile, the model values were used.

(b) External Gamma Radiation - Gamma radiation above background is measurable to distances up to 0.2 mi from the pile, an area with very few inhabitants. People on site will receive some gamma exposure until the pile is covered with sufficient material to reduce the gamma radiation. Exposure to the local population within 0.2 mi of the pile has been evaluated and yields a 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 is a minor component of the total population dose at Green River and other tailings sites.[10,11] Added stabilization of the Green River tailings against wind erosion will eliminate any gradual accumulation of tailings off the site.

(d) Water Contamination - The ^{226}Ra activity in nearby shallow ground water does not indicate contamination from the tailings pile.

(e) Subsoil Contamination - Leaching of radioactive materials into the ground beneath the pile at the millsite is on the order of 2 to 3 ft.

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

Only the potential health effects from the inhalation of radon daughters (pathway a) are estimated quantitatively in this assessment because this pathway produces the most significant exposure.[9-11] Furthermore, the uncertainty in the estimates of the potential health effects from this pathway far exceeds the magnitude of the health effects from the other pathways.

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

3.6.1 Assumptions and Uncertainties in Estimating Health Effects

Since radiation exposure from ^{222}Rn progeny is expressed in terms of working levels (WL) and working level months (WLM), total population exposures as well as health risk estimates are based upon these units; i.e., person-WLM. Exposures and resulting health effects are often expressed in terms of rems; however, estimates of the WLM-to-rem conversion factor for internal lung exposure to alpha particles from ^{222}Rn progeny are observed to vary by over an order of magnitude.[12] Presently, there are significant differences of opinion related to the choice of an appropriate conversion factor. Consequently, disagreements of calculated health effects from RDC occur when these effects are based on the rem.

The BEIR-III[13] risk estimator for lung cancer is based only on the absolute model since the relative risk model is not considered valid.[14]

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

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.(15) Since exposure is considered proportional to the breathing rate, the exposure (and hence the excess risk) of the general population would be smaller by this same factor.

The cumulative risk estimator is obtained from the BEIR-III data adjusted for breathing rate by determining cancer risks for each year following an exposure. These risks are summed for the years between age at exposure and age 75. The contribution to the cumulative risk estimator from each age group is weighted by the respective fractions of the U.S. population found in those age groups.(16) 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:[17]

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

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

3.6.2 Health Effects

The health effects due to radon transport from the Green River site in its present condition were calculated using a radon flux of 160 pCi/m^2-s for the tailings pile. This value was calculated using diffusion theory and the tailings physical properties. Even though the calculated value for radon flux appears much larger than the measured values, it is considered a more defensible estimate of the radon release rate since measurements of radon flux to date have been made only at a few points in time and give no suggestion of the magnitude of annual variations. In the absence of this information, the conservative estimate was chosen as the basis for health effect calculations.

The transport of radon from the tailings pile was modeled using a Gaussian plume model, meteorology characteristics of the Green River area, and the population distribution surrounding the tailings pile as a function of the radius and direction from the center of the site. The pile was modeled as a vertical cylinder with an area equivalent to the surface area of the pile. The height of the equivalent pile was assumed to be 10 ft, a conservative estimate.

Total predicted outdoor ^{222}Rn concentration is shown in Figure 3-8, along with measured values, as a function of distance from the edge of the pile in the northeasterly direction. The predicted ^{222}Rn concentration at 0.13 mi from the edge of the pile is almost 1.2 times background levels. The predicted radon concentration appears to be conservative when compared with measured values.

Figure 3-17 shows the lung cancer risk per year from continuous exposure to radon as a function of distance northeast of the edge of the tailings pile. The curve shown in the figure represents the sum of the annual radiation-induced risk from the tailings pile, plus the average lung cancer risk per year from all causes for residents of Utah.(18) The curve shows that the risk for developing lung cancer from radon released from the pile is about 10% greater than the natural occurrence from all causes at a distance of about 0.1 mi from the edge of the site but declines to near the natural occurrence within 0.4 mi.

The population distribution within 2 mi of the edge of the pile was developed using the best available local statistics and other population information for the past decade. This distribution includes virtually all residents close enough to the pile to be exposed to any noticeable degree to radon released from the pile, as described in Chapter 4.

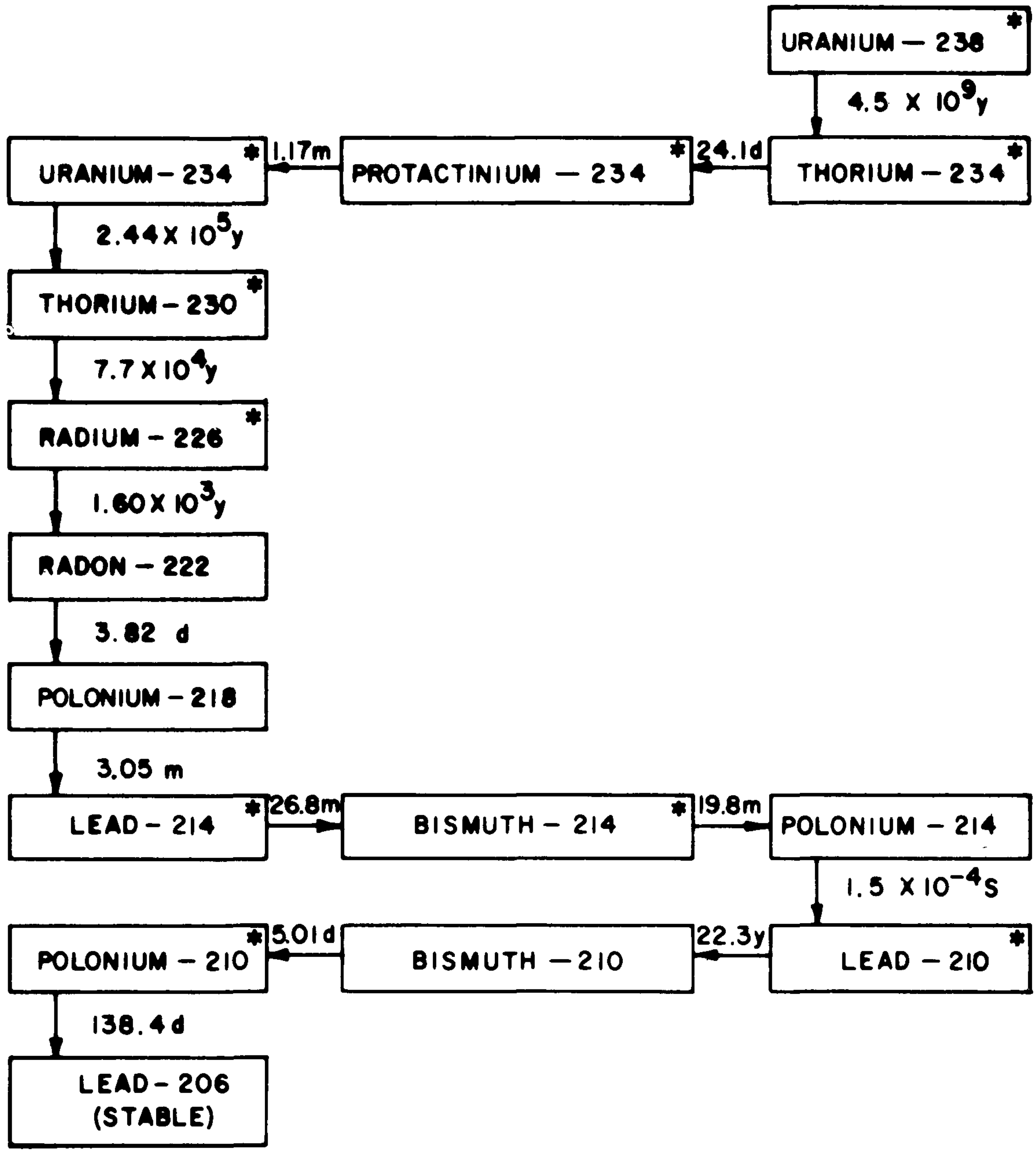
The three population projections used to estimate the cumulative health impacts attributable to the tailings pile are the 1 and 2.5% constant growth rates and the 6% declining growth rate, as discussed in Paragraph 4.2. All three growth projections assume that the population is distributed around the site in the same proportions as those reflected in Table 4-1.

Table 3-3 presents the estimated health impacts from the tailings pile for 0 to 2 mi from the edge of the pile, based on the estimated 1980 population distribution presented in Table 4-1. The cumulative health effects for the three growth scenarios considered for Green River are also included. In Table 3-3, the health effects from the pile radon are shown to be less than 1% of those caused by background radon for the vicinity within 0 to 2 mi of the edge of the pile.

3.7 NONRADIOACTIVE POLLUTANTS

The tailings pile contains other potentially toxic materials. Chemical analyses of samples from drill holes in the Green River tailings pile showed barium and lead in concentrations between 70 and 130 ppm. The highest selenium concentration measured was 231 ppm; arsenic ranged as high as 2 ppm. Vanadium was present in concentrations averaging 1,400 ppm.

Four water samples were taken from the vicinity of the Green River tailings pile and chemically analyzed. The analytical results are listed in Table 3-4 and the locations of these samples are shown in Figure 3-14. Two samples were obtained from drill holes on the tailings pile and just north of the pile at the edge of Browns Wash. The selenium, lead, chromium, and arsenic contents of the samples were well above the limits of the EPA Interim Primary Drinking Water Regulations. These samples were obtained from drill holes and could have been contaminated during the drilling. Two samples were taken from Browns Wash. The first sample was taken from ponded water in Browns Wash at the railroad bridge upstream from the tailings. The second sample was obtained from the water table in Browns Wash downstream from the tailings. All concentrations of heavy metals were within the limits of the EPA Drinking Water Regulations, and except for vanadium, increases in concentration downstream were not detected.



NOTE:
VERTICAL DIRECTION REPRESENTS ALPHA DECAY, HORIZONTAL DIRECTION INDICATES BETA DECAY. TIMES SHOWN ARE HALF LIVES. ONLY THE DOMINANT DECAY MODE IS SHOWN.
* ALSO GAMMA EMITTERS

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

360-14 12/77

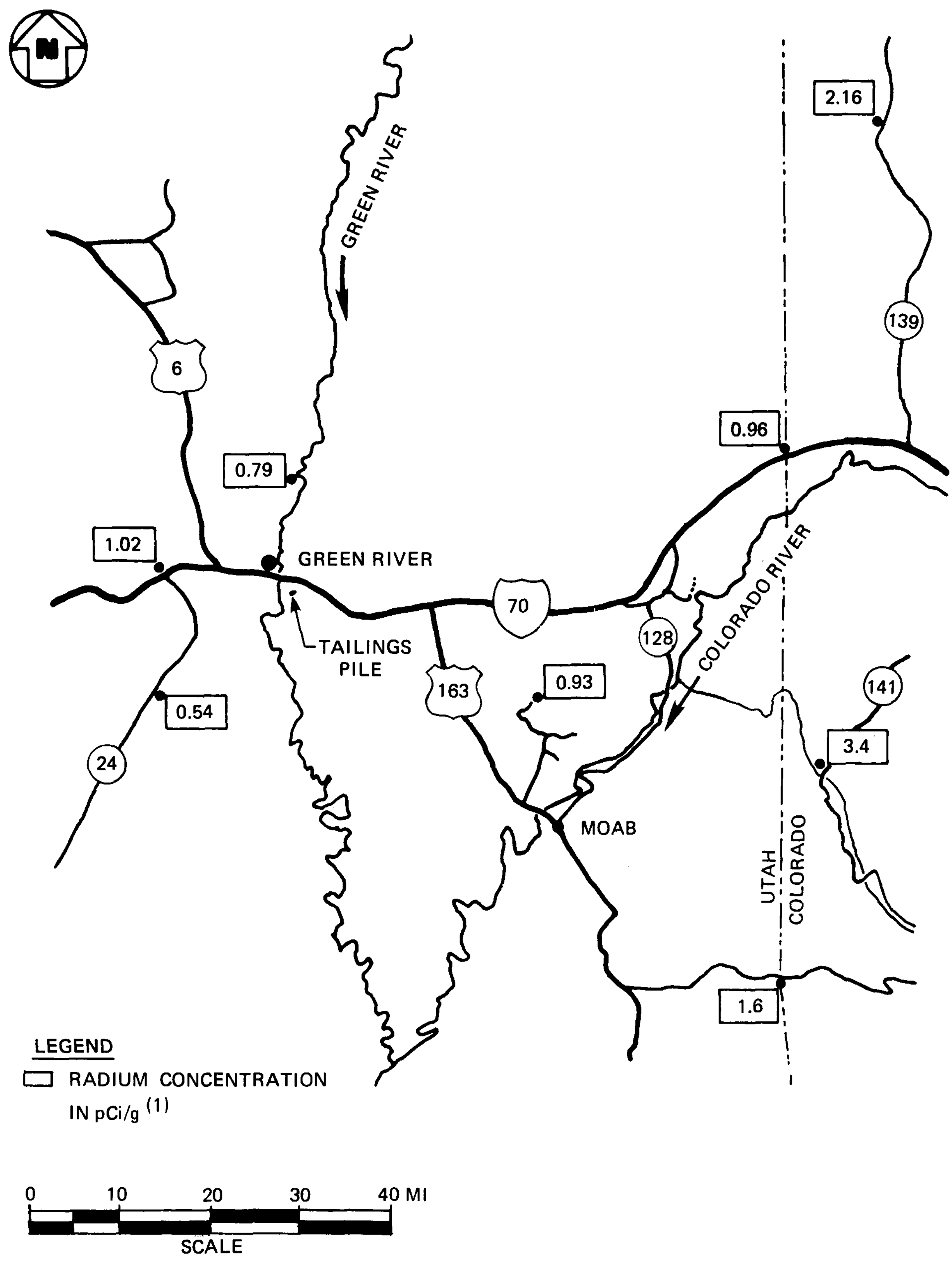


FIGURE 3-2. LOCATION FOR ^{226}Ra BACKGROUND SAMPLES

360-14 12/77

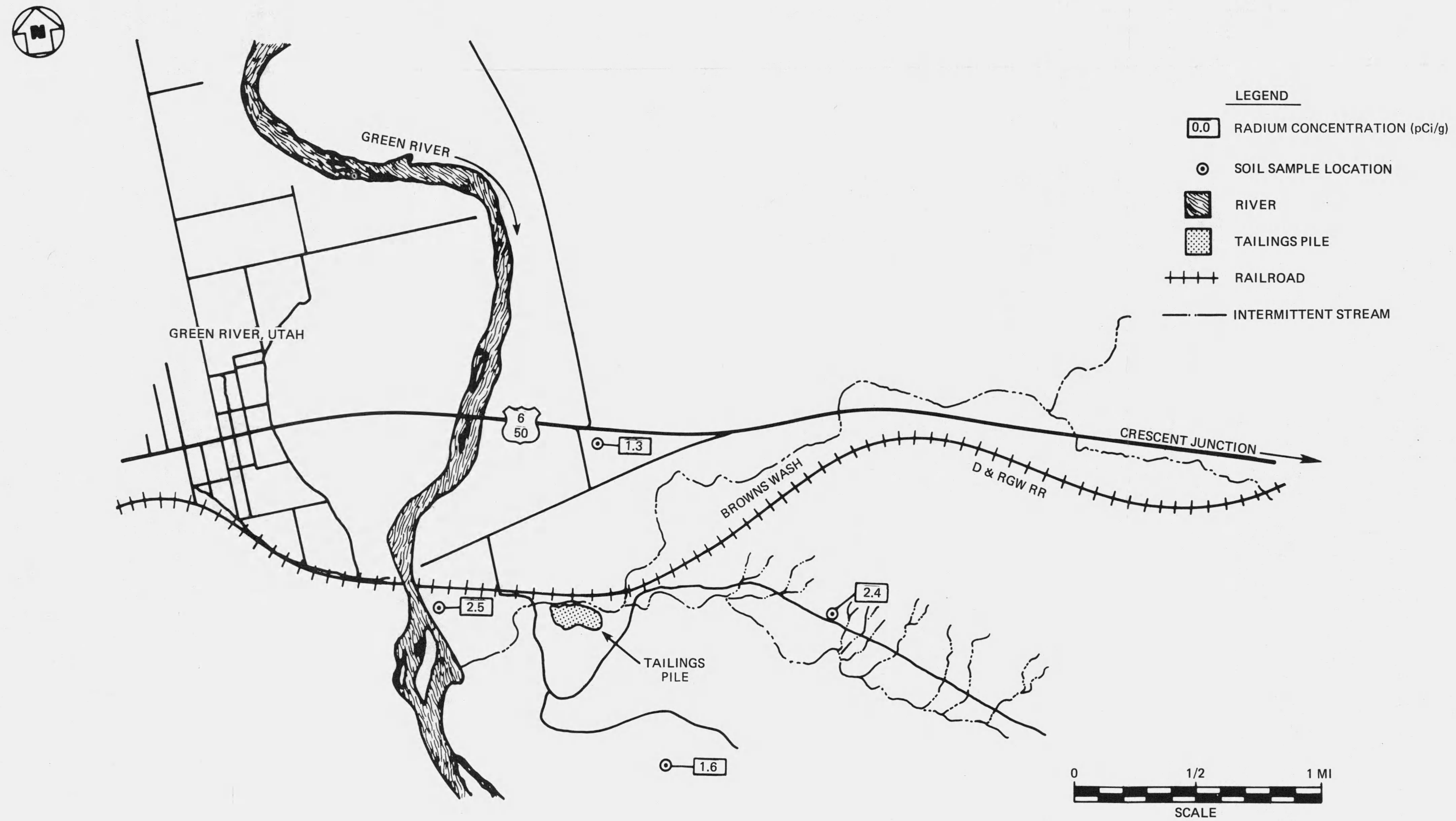


FIGURE 3-3. BACKGROUND SOIL SAMPLE LOCATIONS

360-14 REV 1/81

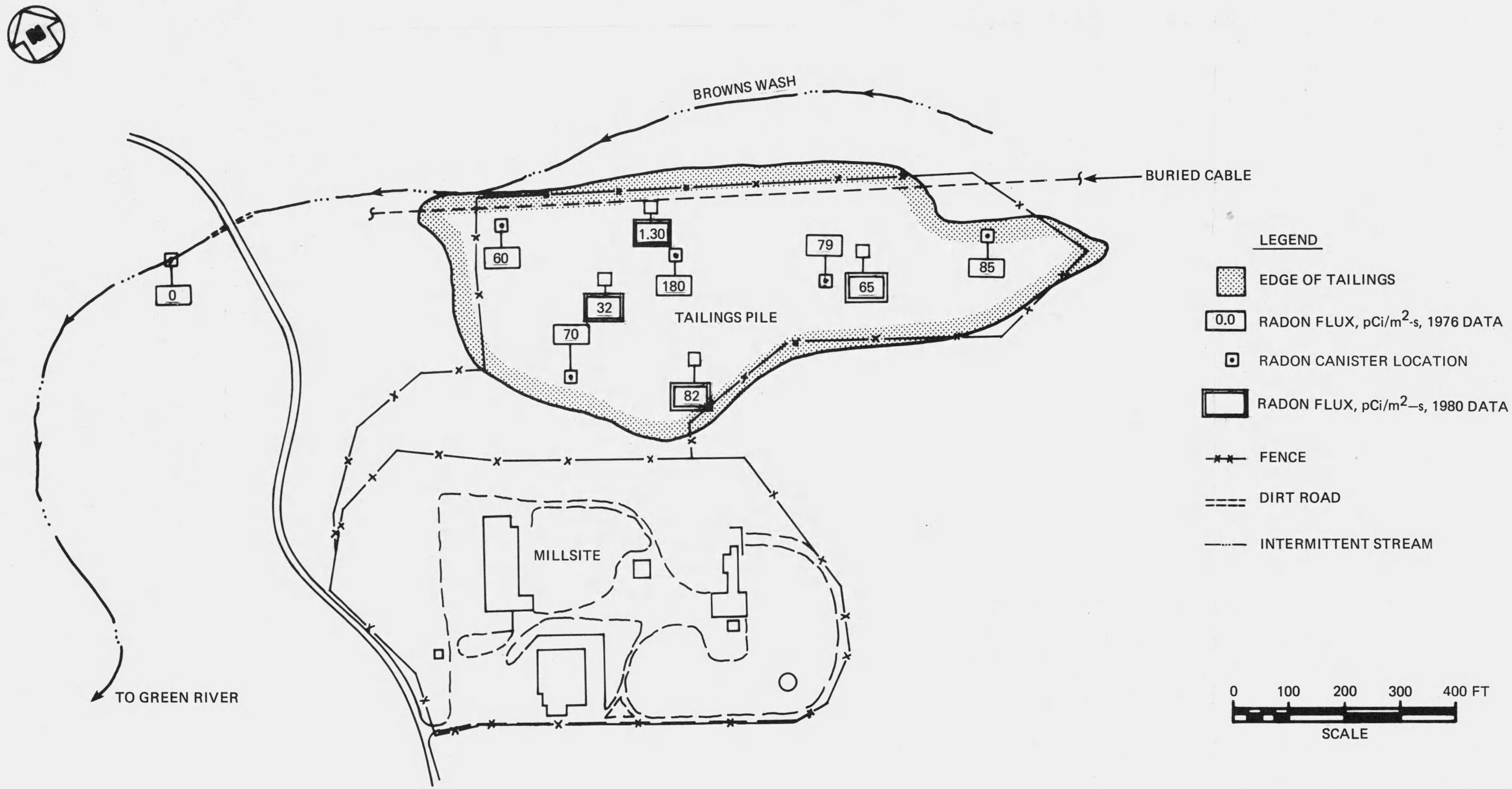


FIGURE 3-4. RADON CANISTER LOCATIONS AND FLUX VALUES

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SITE NO.	24 HR INDOOR (pCi / l)	24 HR OUTDOOR (pCi / l)	DATE	AVG WIND SPEED (KNOTS)	AVG WIND DIREC-TION	LOCATION
1	–	13.5	10/25/76	10	N	ON PILE
2	1.3	0.9	10/26/76	5	N	MILL BUILDING 0.08 MI S OF PILE
3	1.3	1.2	10/26/76	5	N	OFFICE BUILDING 0.4 MI NW OF PILE
4	2.0	1.7	10/27/76	2	NE	RESIDENCE 3.1 MI NW OF PILE
5	–	2.3	10/27/76	2	NE	3.4 MI E OF PILE

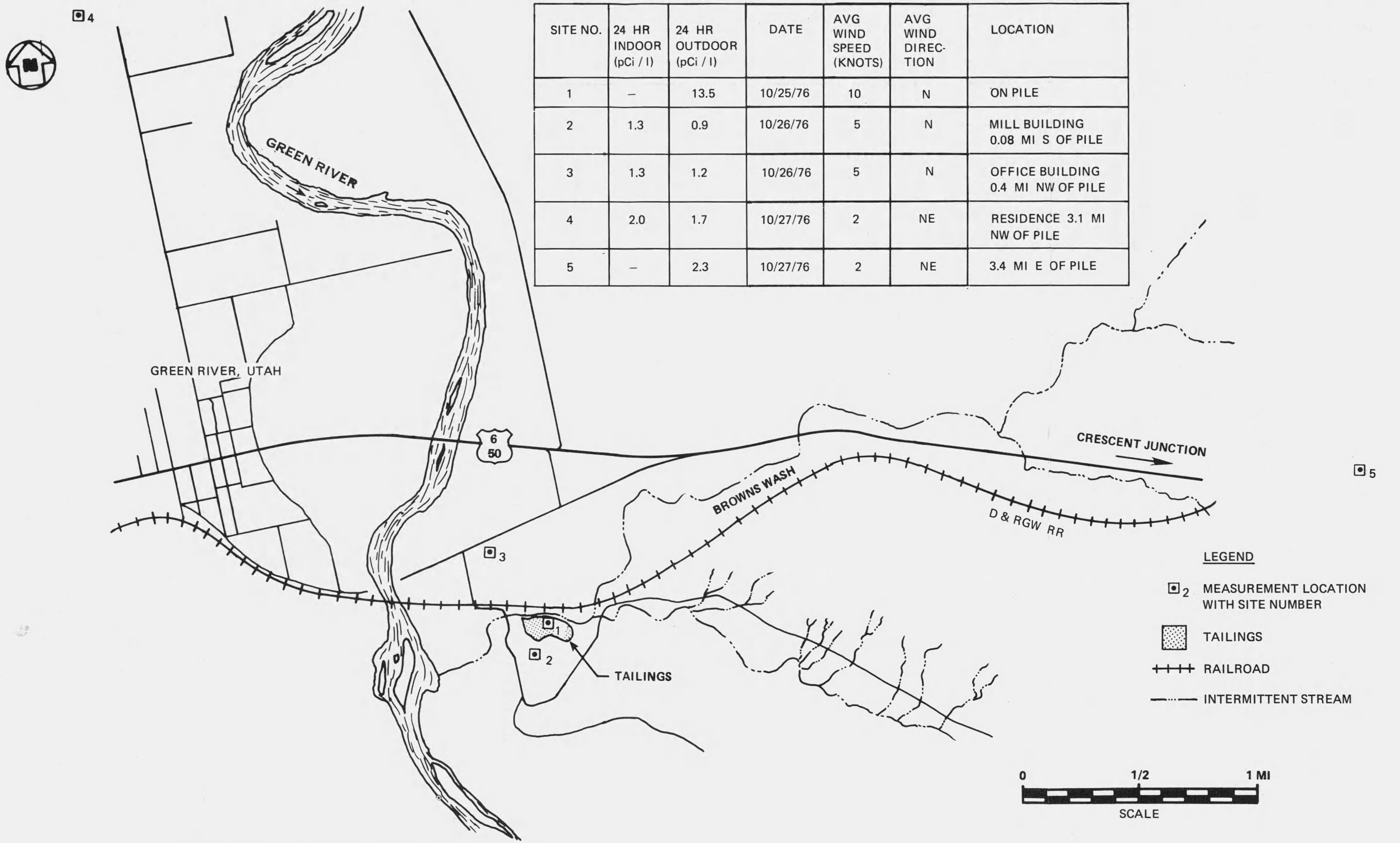

FIGURE 3-5. RADON CONCENTRATION IN VICINITY OF PILE

360-14 12/77

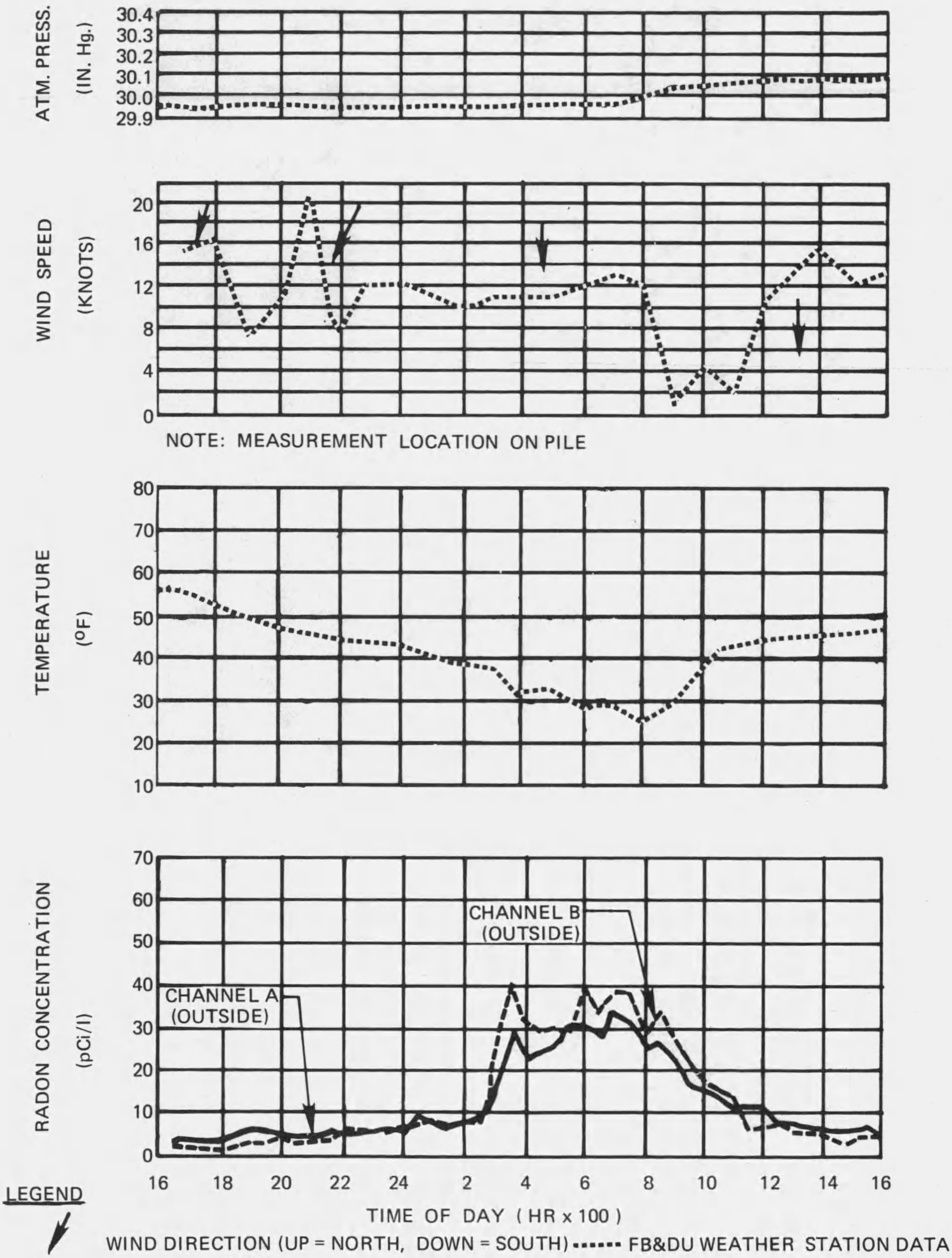

FIGURE 3-6. ^{222}Rn AND ATMOSPHERIC TRANSIENTS ON PILE ON OCTOBER 25, 1976

360-14 12/77

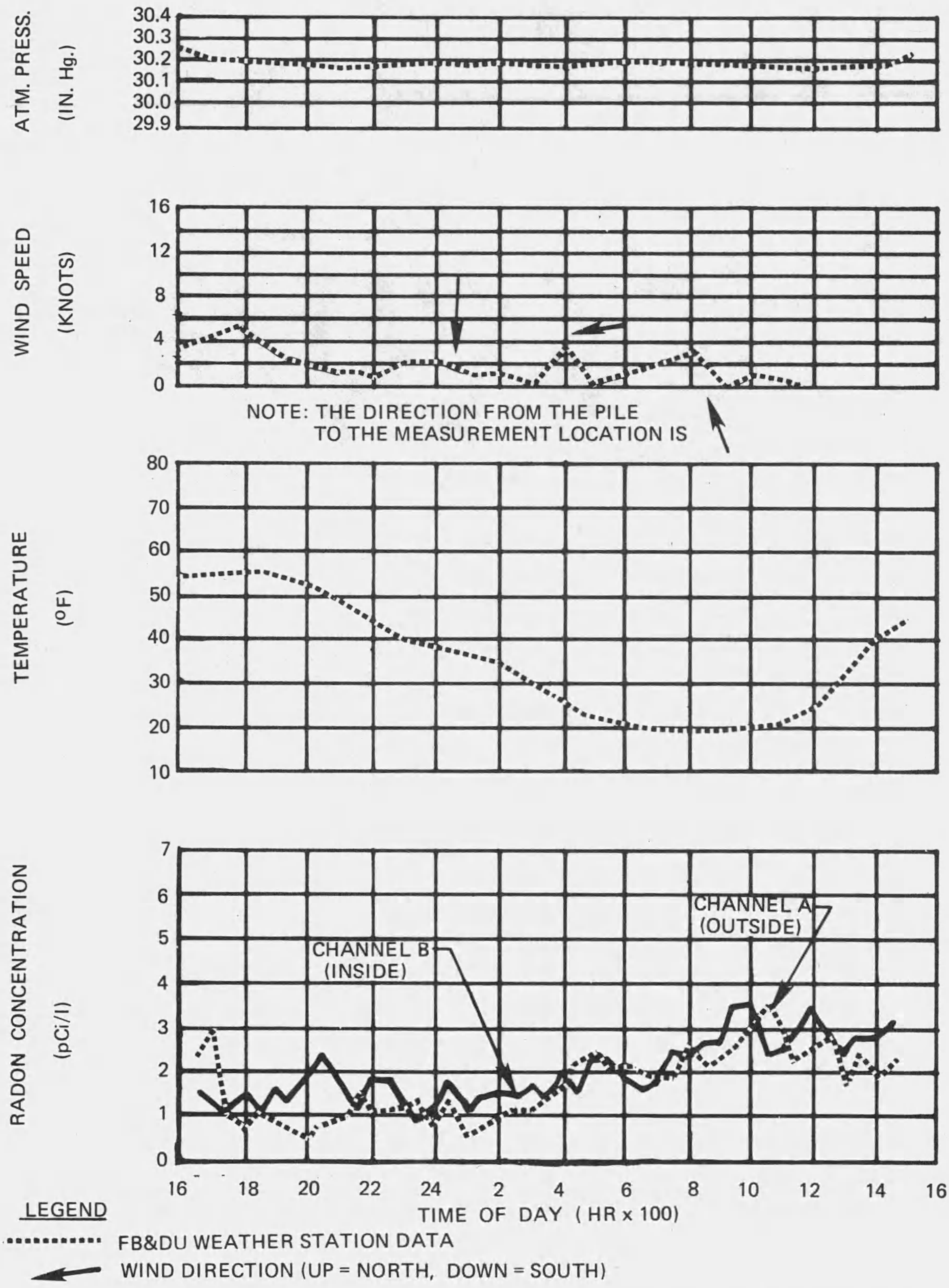

FIGURE 3-7. ^{222}Rn AND ATMOSPHERIC TRANSIENTS 3.1 MI N OF PILE ON OCTOBER 27, 1976

360-14 12/77

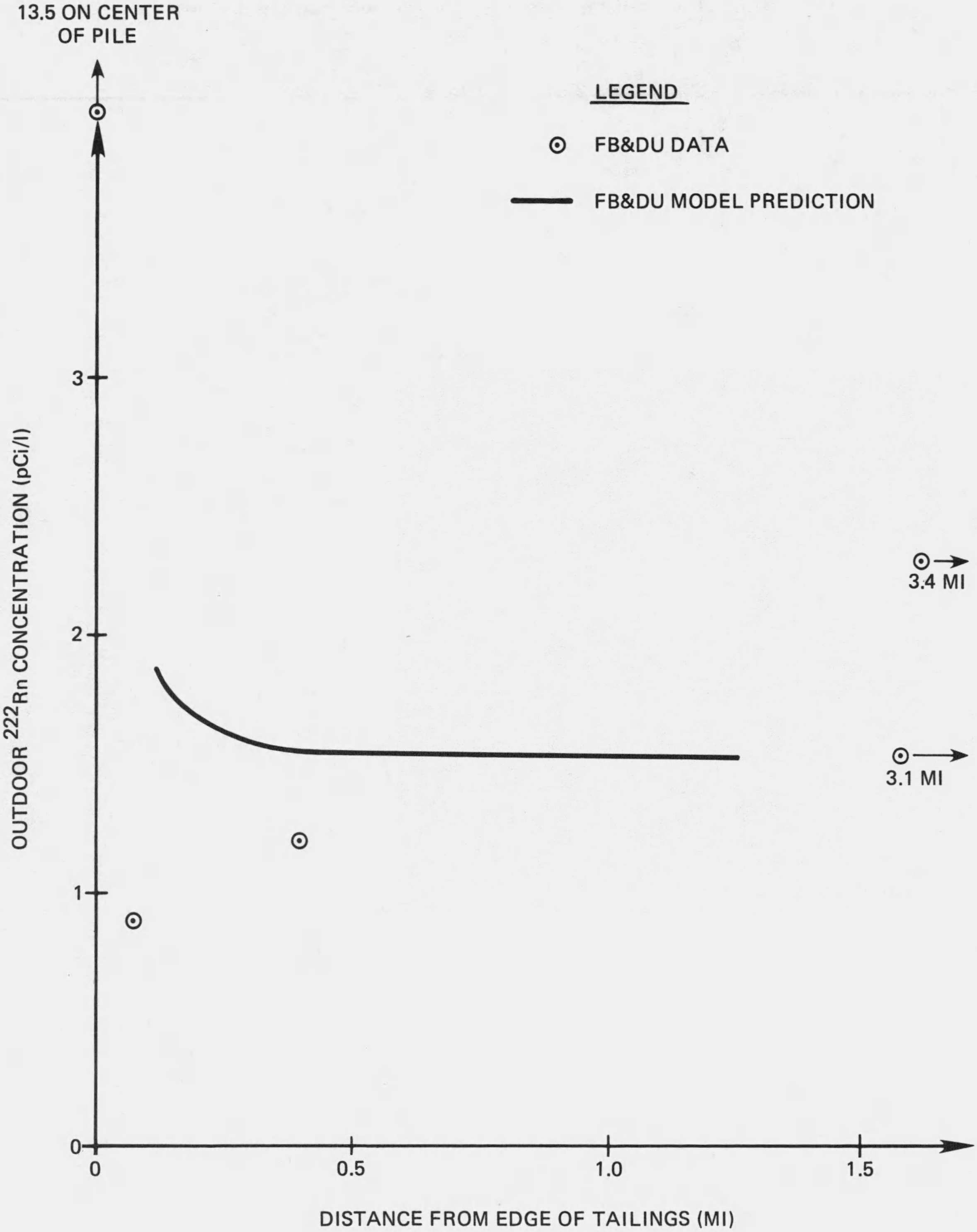

FIGURE 3-8. REDUCTION OF OUTDOOR ^{222}Rn CONCENTRATION WITH DISTANCE FROM THE TAILINGS PILE

360-14 REV 1/81

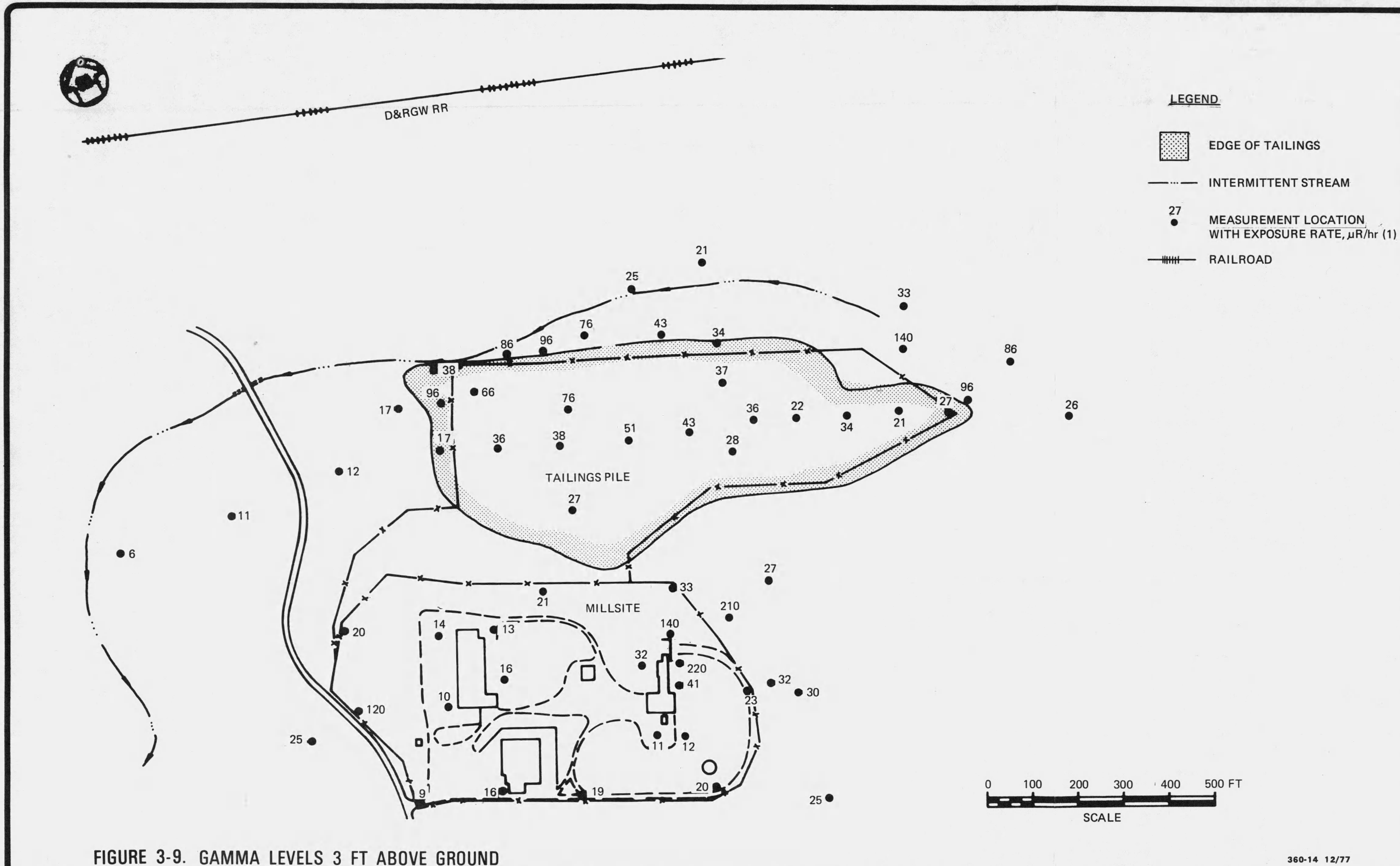

FIGURE 3-9. GAMMA LEVELS 3 FT ABOVE GROUND

360-14 12/77

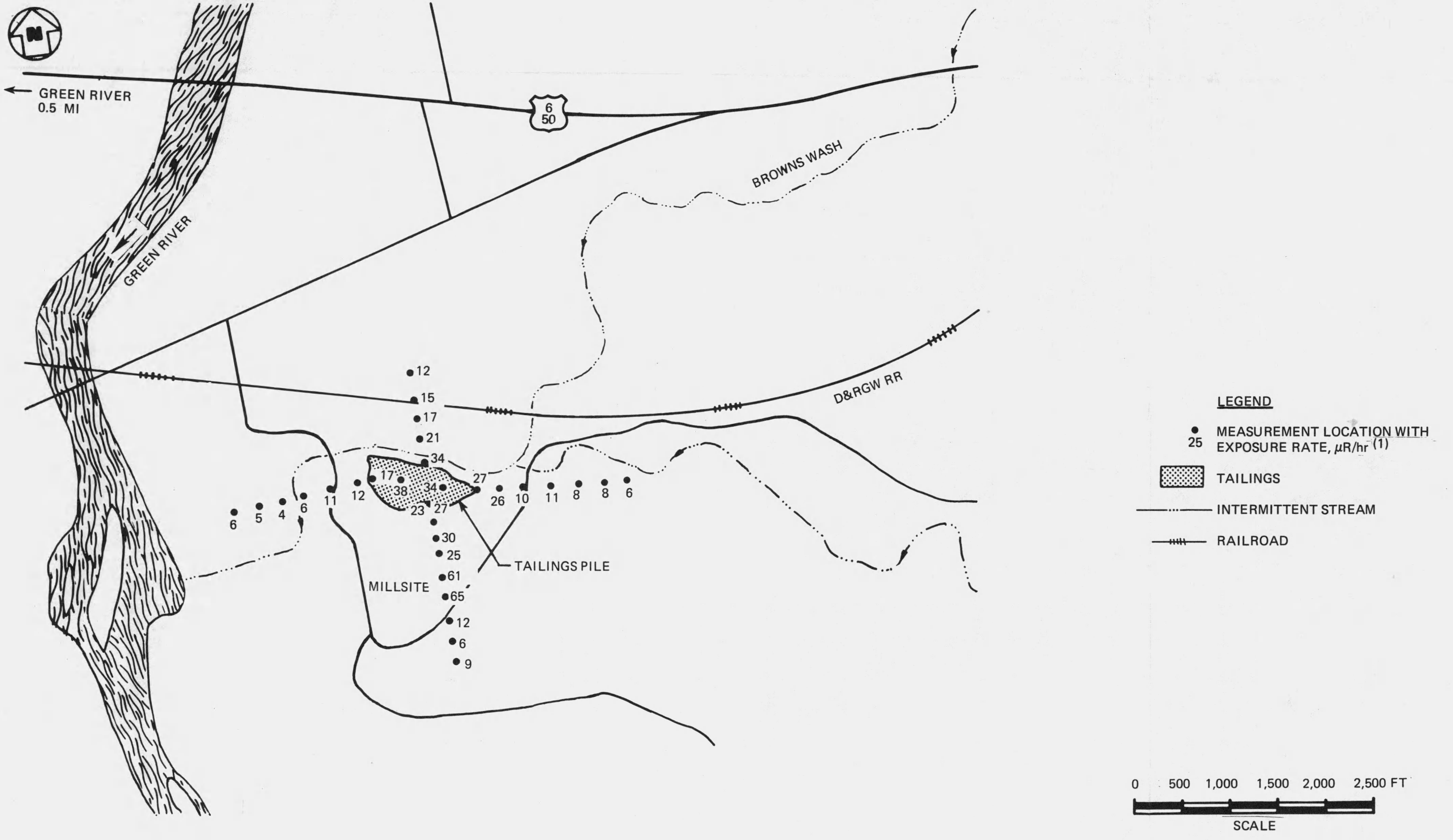

FIGURE 3-10. GAMMA LEVELS IN VICINITY 3 FT ABOVE GROUND

360-14 12/77

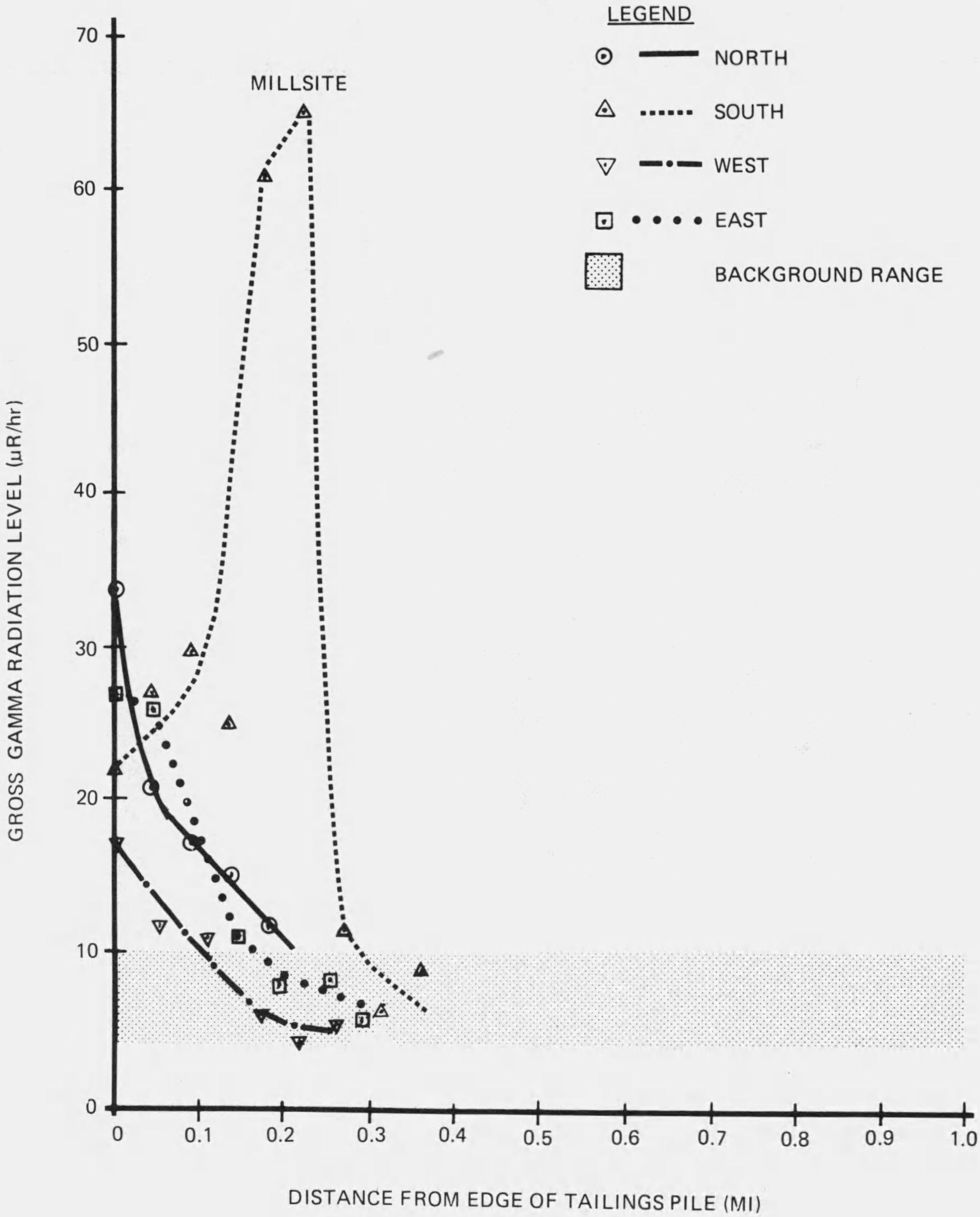

FIGURE 3-11. REDUCTION OF EXTERNAL GAMMA RADIATION LEVELS WITH DISTANCE FROM THE TAILINGS PILE

360-14 12/77

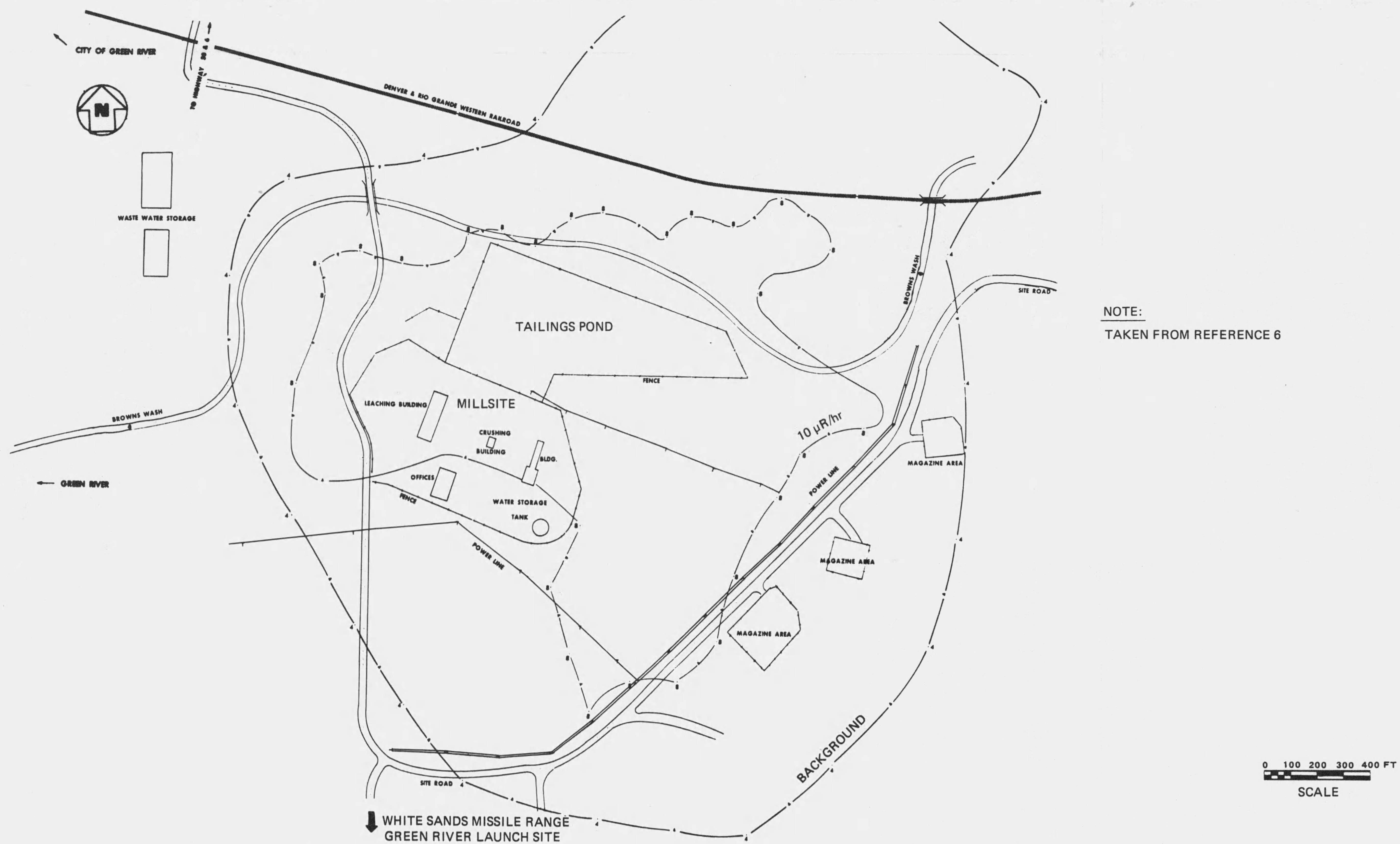

FIGURE 3-12. EPA GAMMA SURVEY SURROUNDING MILLSITE

360-14 12/77

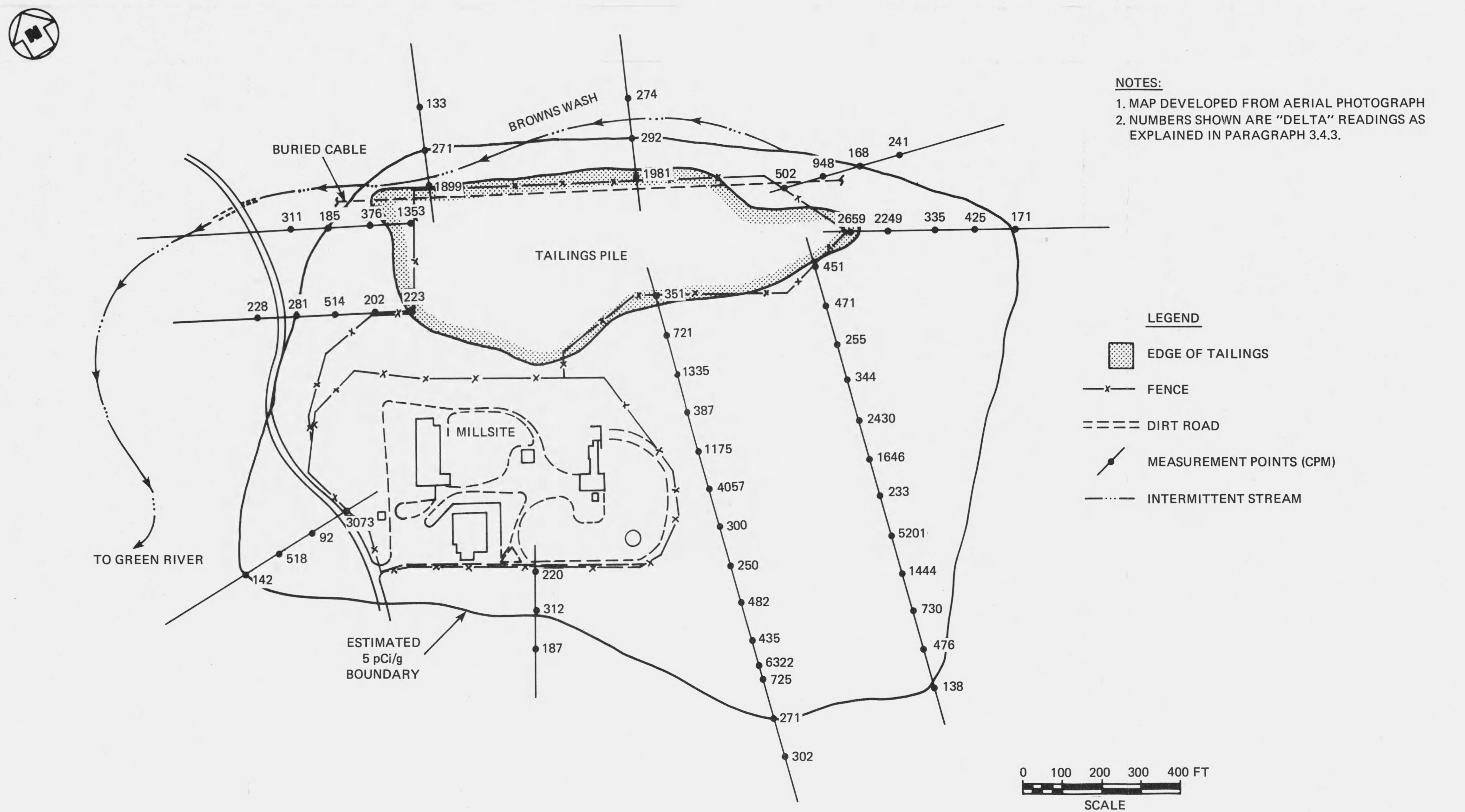

FIGURE 3-13. WINDBLOWN CONTAMINATION SURVEY

360-14 1/81

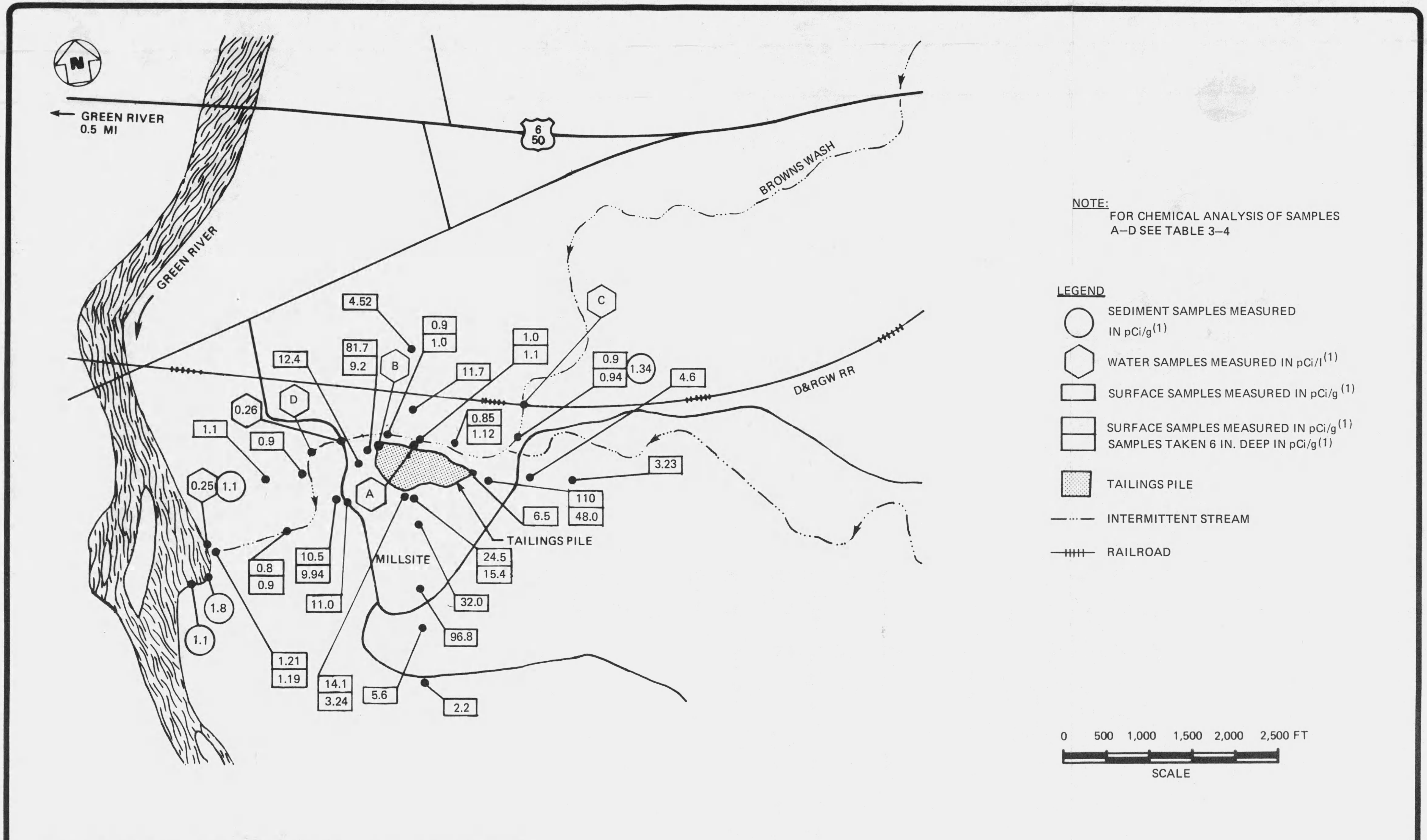

FIGURE 3-14. SURFACE AND SUBSURFACE RADIUM CONCENTRATIONS

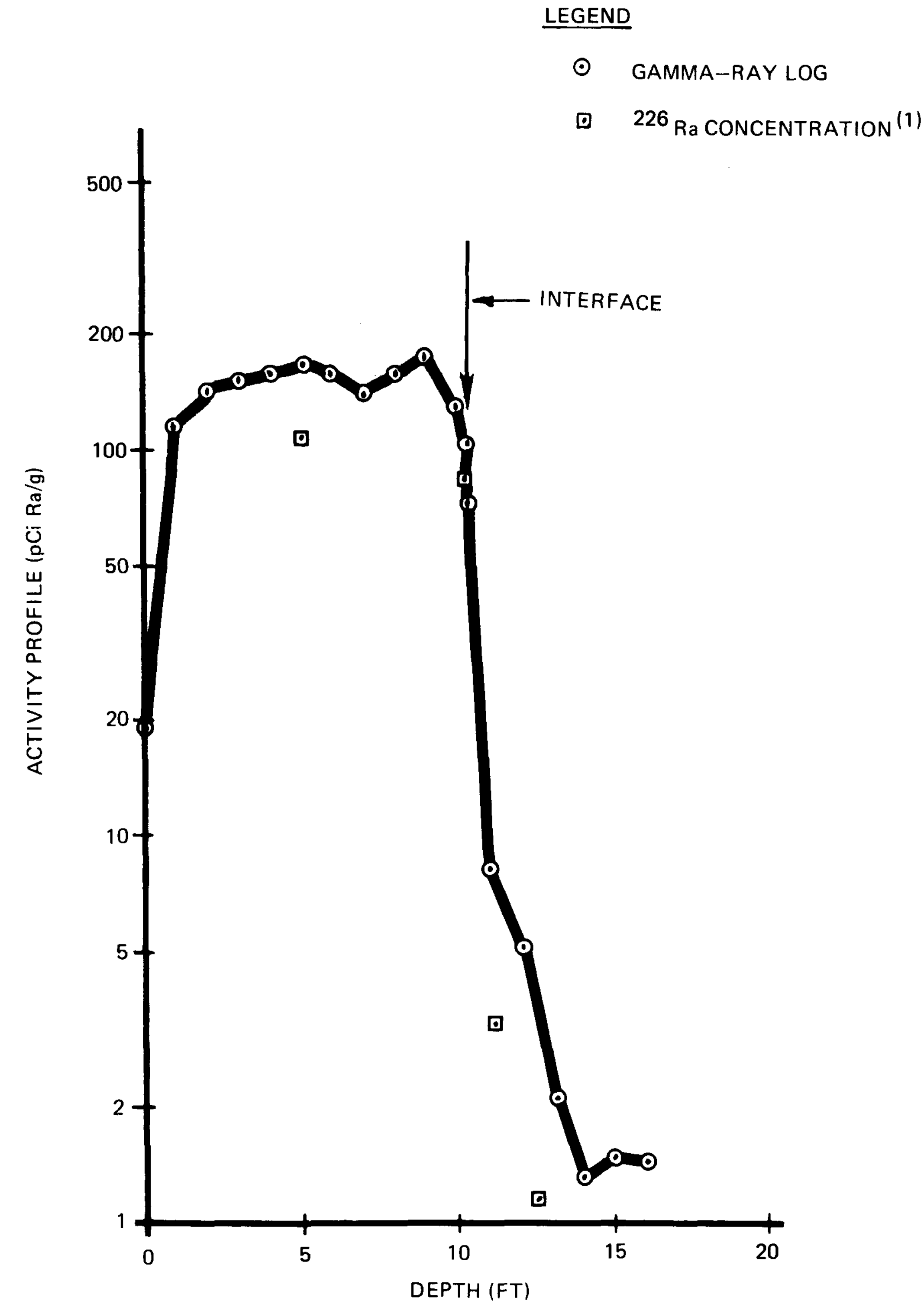

FIGURE 3-15. RADIOMETRIC PROFILE AT DRILL HOLE GRU–3

360-14 12/77

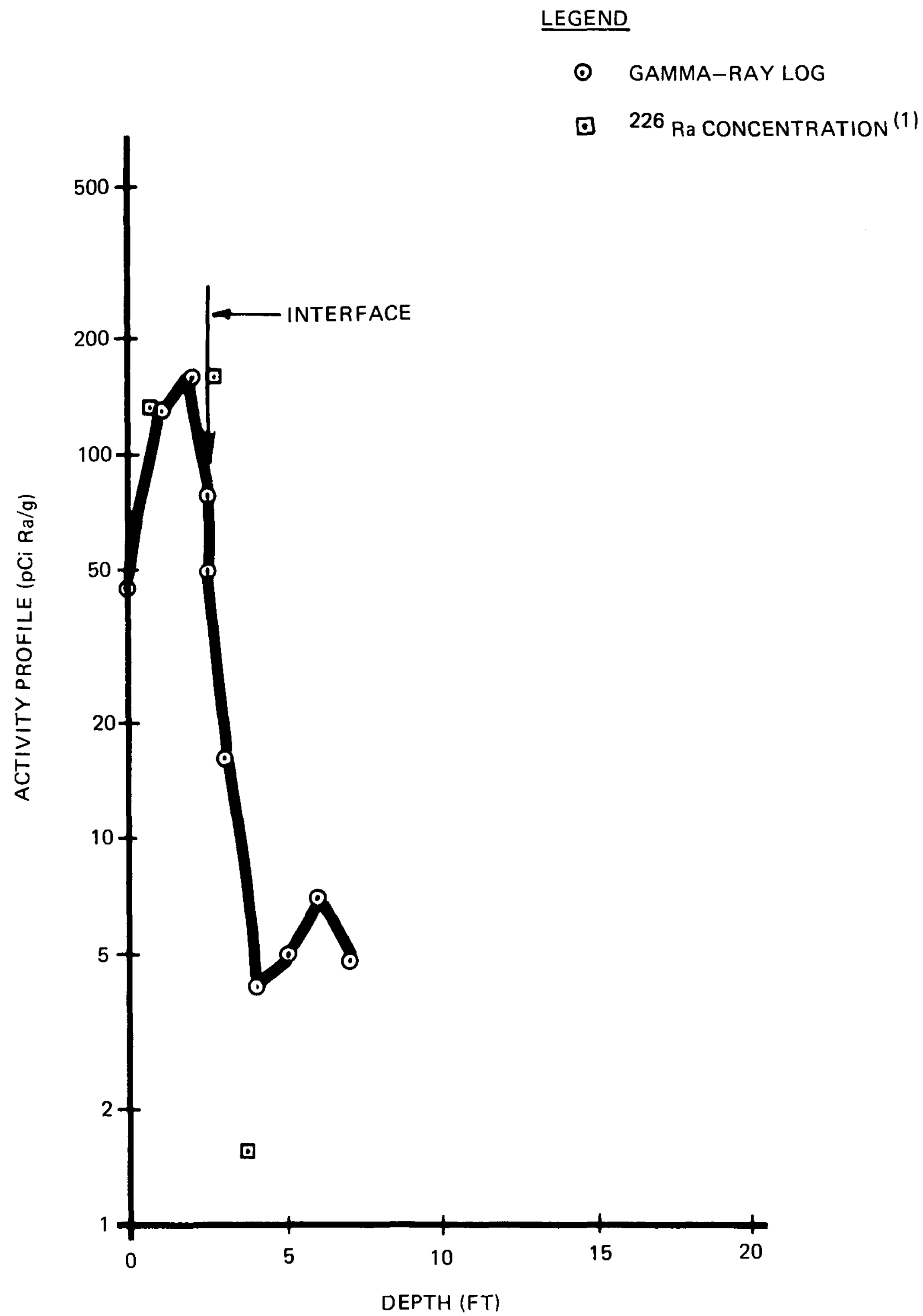

FIGURE 3-16. RADIOMETRIC PROFILE AT DRILL HOLE GRU–5

360-14 12/77

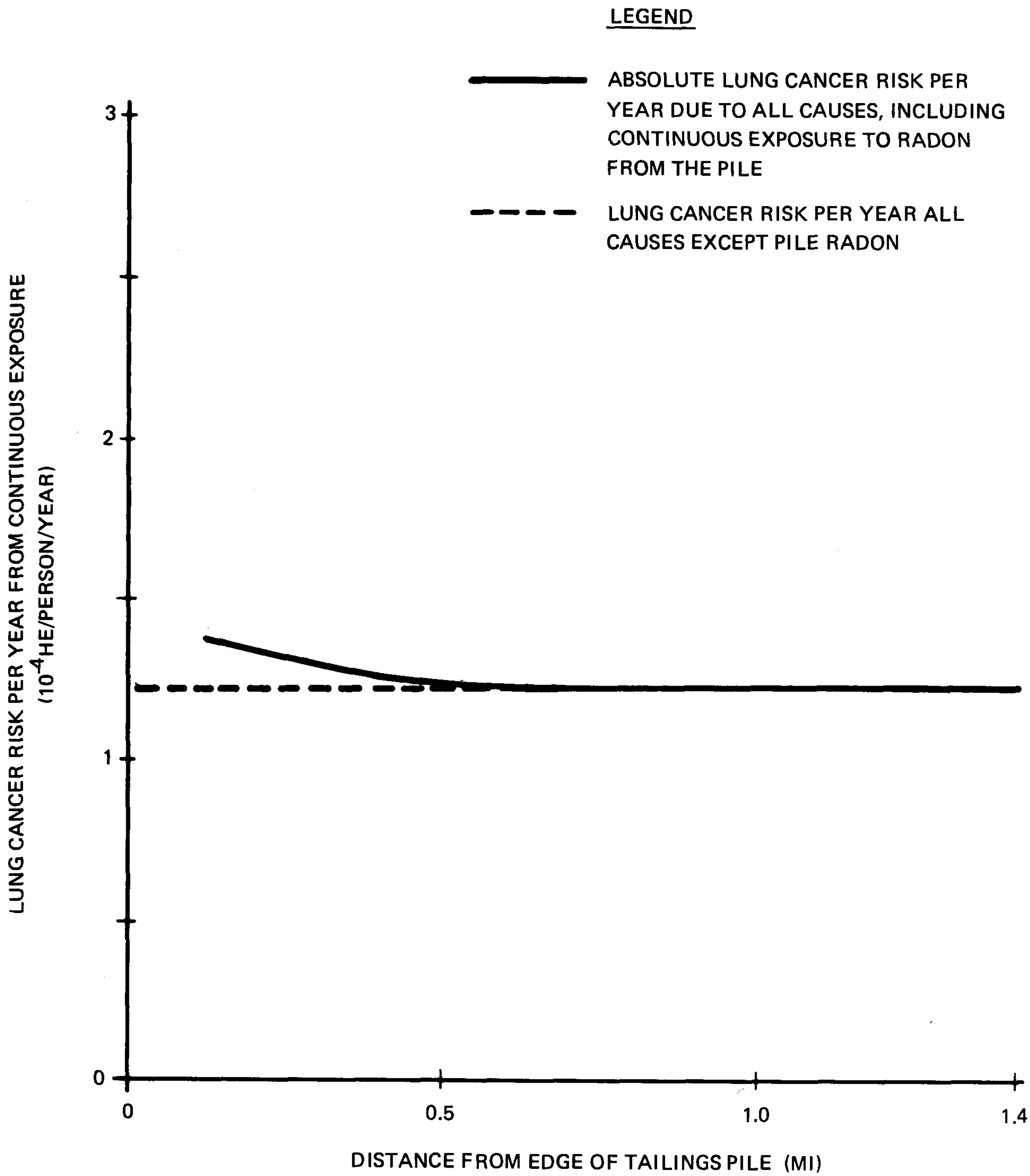

FIGURE 3-17. LUNG CANCER RISK FROM CONTINUOUS EXPOSURE TO RADON

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TABLE 3-1

NOTATIONS AND ABBREVIATIONS USED IN CHAPTER 3

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

Isotope Abbreviations:

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

Radiations:

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

TABLE 3-1 (Cont)

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

Note: Also see definitions of terms in Glossary.

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TABLE 3-2

BACKGROUND RADIATION SOURCES IN SOIL FROM EASTERN UTAH[1]

Isotope (Decay Chain)	Average Value (pCi/g)	Range (pCi/g)
^{226}Ra (^{238}U)	1.43 ± 0.95	0.54 - 3.4
^{232}Th (^{232}Th)	1.71 ± 0.39	0.26 - 1.19

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TABLE 3-3

ESTIMATED HEALTH IMPACT FROM GREEN RIVER TAILINGS
FOR AN AREA 0 TO 2 MILES FROM TAILINGS EDGE

Time Period	Population (Persons)	Total Pile-Induced RDC Health Effects/Yr	Background RDC Health Effects/Yr
1980	1,180	0.00043	0.067
2005 (1.0% constant growth rate)	1,510	0.00054	0.083
2005 (2.5% constant growth rate)	2,190	0.00082	0.13
2005 (6.0% declining growth rate)*	2,530	0.00092	0.14

Growth Projection	25-Yr Cumulative RDC Health Effects	
	Pile-Induced	Background
1.0% constant growth rate	0.013	2.0
2.5% constant growth rate	0.015	2.3
6.0% declining growth rate*	0.018	2.8

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

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TABLE 3-4

CHEMICAL ANALYSES OF GREEN RIVER WATER SAMPLES (mg/l)

Sample[a]	As	Ba	Cd	Cr	V	Fe	Pb	Se
A - Drill hole no. 8, Browns Wash	0.515	0.59	0.030	0.070	0.320	30.0	0.617	0.426
B - Drill hole no. 5, on pile	0.162	2.11	<0.001	0.136	0.140	140.0	0.107	6.572
C - Pond in wash, upstream from tailings	<0.001	0.089	<0.001	<0.001	0.007	0.192	--	<0.001
D - Wash downstream from tailings	<0.001	0.011	<0.001	<0.001	0.019	0.154	--	<0.001
EPA Interim Primary Drinking Water Regulations[b]	0.05	1.0	0.01	0.05	--	0.3[c]	0.05	0.01

[a] See Figure 3-14 for locations.

[b] Federal Register, Dec 24, 1975

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

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CHAPTER 4

SOCIOECONOMIC AND LAND USE IMPACTS

CHAPTER 4

SOCIOECONOMIC AND LAND USE IMPACTS

The Green River tailings and millsite are located in Grand County, Utah, approximately 1 mi southeast of the city of Green River in Emery County, Utah. The city of Green River is the major population center in the area. Interstate Highway 70, U.S. Highway 50, and U.S. Highway 163 connect Green River with other major Utah cities. The Grand County boundaries and major highways of the area are shown in Figure 4-1.

4.1 SOCIOECONOMIC BACKGROUND[1]

The city of Green River is a community shifting from an agricultural and mining base to tourism, construction, services, and public administration. At the present time, operations at the White Sands Missile Base south of the tailings site have been discontinued, and a crew of only 26 maintenance workers is employed there. The construction of Interstate Highway 70 is still in progress, and construction workers make up a considerable portion of the local labor force.

The uranium boom was in full force in Grand and Emery Counties during the 1950's; the population of Green River nearly doubled and the growth in both counties was dramatic. As uranium exploration and mining stabilized in the 1960's, the population growth slowed. In recent years the population has declined slightly. These fluctuations in population are in marked contrast to the steady growth in the population of the State of Utah as a whole. The median age of residents and their sex distribution differ from those of the state. The male population of Green River in 1970 was 53% versus 49% for the state, and the median age was 24.7 and rising versus 23 for the state.

Ethnically, the populations of the city of Green River, Grand County, and Emery County are predominantly Caucasian, with less than 0.5% classified as minorities. Educational attainment for the city, Grand and Emery Counties, and the state is high and relatively uniform (12.3 yr). During the uranium boom, the median income was above the state level; since then, however, the income levels have become more equal. In 1970 most workers were classified as professionals, craftsmen, farmers/farm laborers, and service providers. Farmers/farm laborers show a decline in both real numbers and percentage of the total. Mining has decreased in importance as an employer while the construction industry has become a larger employer. The construction boom may prove to be short-lived and may decrease in importance with the completion of Interstate Highway 70.

Green River is expected to experience moderate growth in the future due to tourist activities, increased uranium mining, and other mineral development.

4.2 POPULATION ESTIMATES

The 1980 preliminary census figures for Green River indicate that 1,100 people live within the city limits.(2) This figure is in close agreement with a population study prepared by the Southeastern Utah Association of Governments,(3) which estimates the population of Green River to be 1,140 people. The population of the unincorporated area of Elgin, located between 0.50 and 0.75 mi northwest of the tailings site, is estimated to be about 30 people.(2) In addition, 26 full-time workers are employed at the White Sands Missile Base and three people occupy mobile homes at the base. A summation of these population figures yields a base 1980 population of about 1,180 people residing or working within a 2-mi radius of the edge of the tailings pile. The number of workers close to the site was divided by a factor of 4 to account for the fact that they are at work near the site only 25% of the time. The estimated 1980 population distribution for the Green River area is shown in Table 4-1.

Several factors must be considered in determining population projections and future growth patterns for Green River. Employment opportunities fluctuate with the activities of the mining and construction industries and with the operations of the missile test base. The small population of Green River might expand by several hundred if an energy boom takes place in the area, but unsettled market conditions would adversely affect population growth. Prospects for long-term sustained population growth in the immediate area of the tailings are minimal.

Figure 4-2 illustrates three population projections for the area through the year 2005. The slowest growth rate shown, a 1% constant annual growth rate, is a continuation of the overall growth pattern experienced by Green River during the last decade. If this pattern continues, the population of the area will increase 1% every year from its present figure of 1,180 people to about 1,510 people by the year 2005. This growth scenario is considered as a lower bound on the growth rate of Green River.

The fastest growth rate presented in Figure 4-2 is a 6% declining annual growth rate. At this rate population growth would decline linearly from 6%/yr initially to zero growth by the year 2005. This pattern is suggested by the population projections of the Southeastern Utah Association of Governments(3) and is considered as an upper bound on the growth rate of Green River. If this scenario were experienced, the population would double in 18 yr and reach about 2,530 people by the year 2005.

The 2.5% constant annual growth rate curve presented in Figure 4-2 assumes that the population of the area will increase 2.5% every year until the year 2005. This growth scenario is considered to be a probable projection for the area. If this pattern were followed, the population of the area would reach about 2,190 people by the year 2005.

4.3 LAND USE

The Green River site is located just over 1 mi southeast of the city of Green River and within 0.5 mi of the community of Elgin. There are 12 occupied houses and trailers and several unoccupied residences in Elgin.

The White Sands Missile Test Range and Headquarters dominates most of the land use near the site. The headquarters location is shown in Figure 4-3. The military facility includes several large buildings, a headquarters building, a cafeteria, and approximately 72 mobile home units. None of the mobile homes are occupied on a permanent basis, although a few are used intermittently. Only three are occupied at the present time. Although operations at the missile range and headquarters have been discontinued, they may be resumed in the future.

There is some commercial activity along the major highways in the city of Green River. East of the Green River, which flows east of the city, there is a motel, a campground for trailers and mobile homes, and a drive-in movie lot. The remaining vacant area near the tailings site is used as part of the missile test area.

4.4 IMPACT OF THE TAILINGS ON LAND VALUES

Virtually all the land within 0.5 mi of the site is owned by Union Carbide Corporation, and most of it is leased to the Federal Government. The estimated value of the unimproved land at the site is $60/acre.(4) The presence of the tailings restricts the use of the actual tailings area. However, there appears to be no demand to use the land except as an extension of the missile range, for which purpose the Federal Government may purchase much of the land adjacent to the site. Any loss of agricultural or grazing land is negligible. In short, if the tailings were not present, it appears there would be virtually no change in land uses and values in the surrounding area.

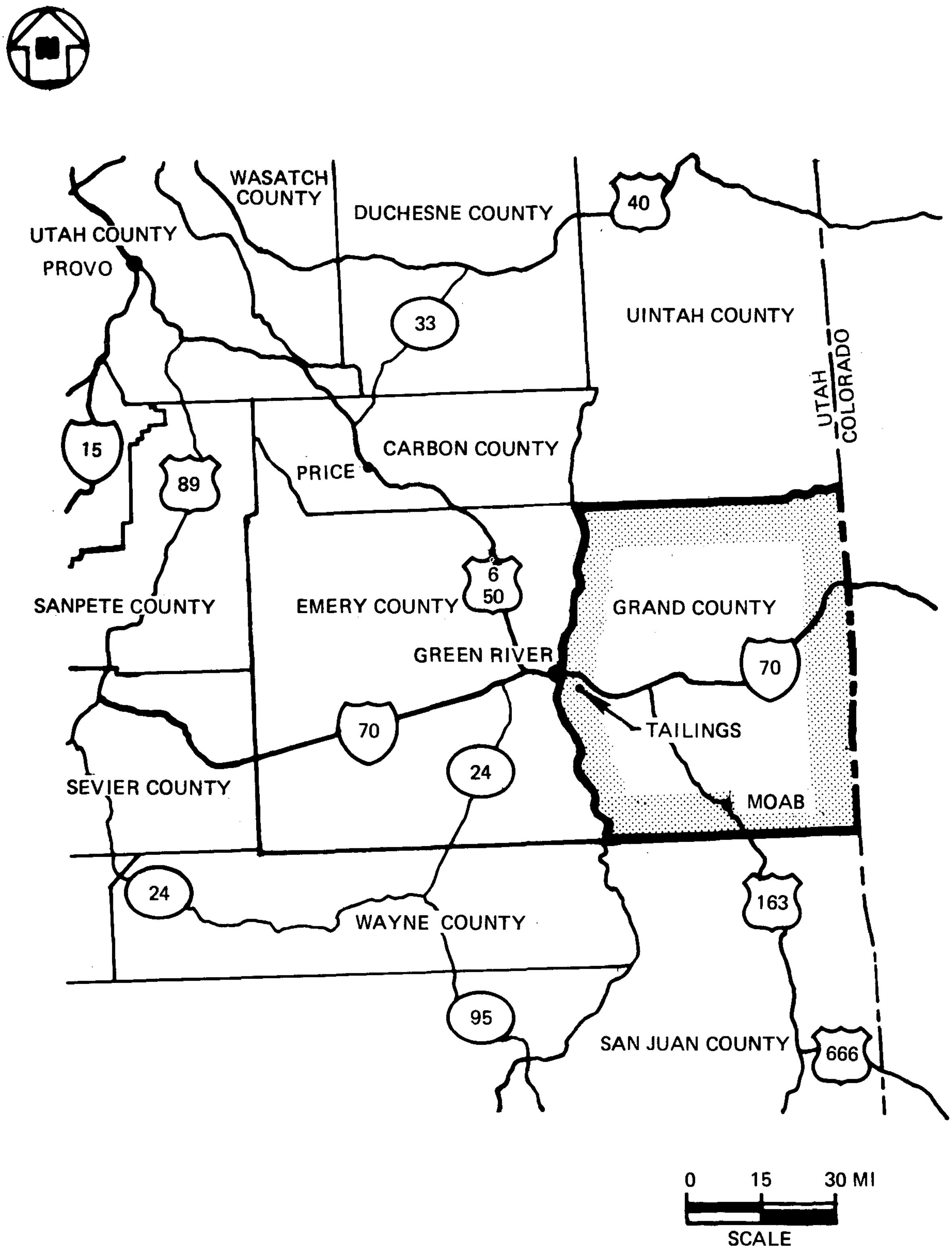

FIGURE 4-1. MAP OF GRAND COUNTY BOUNDARIES

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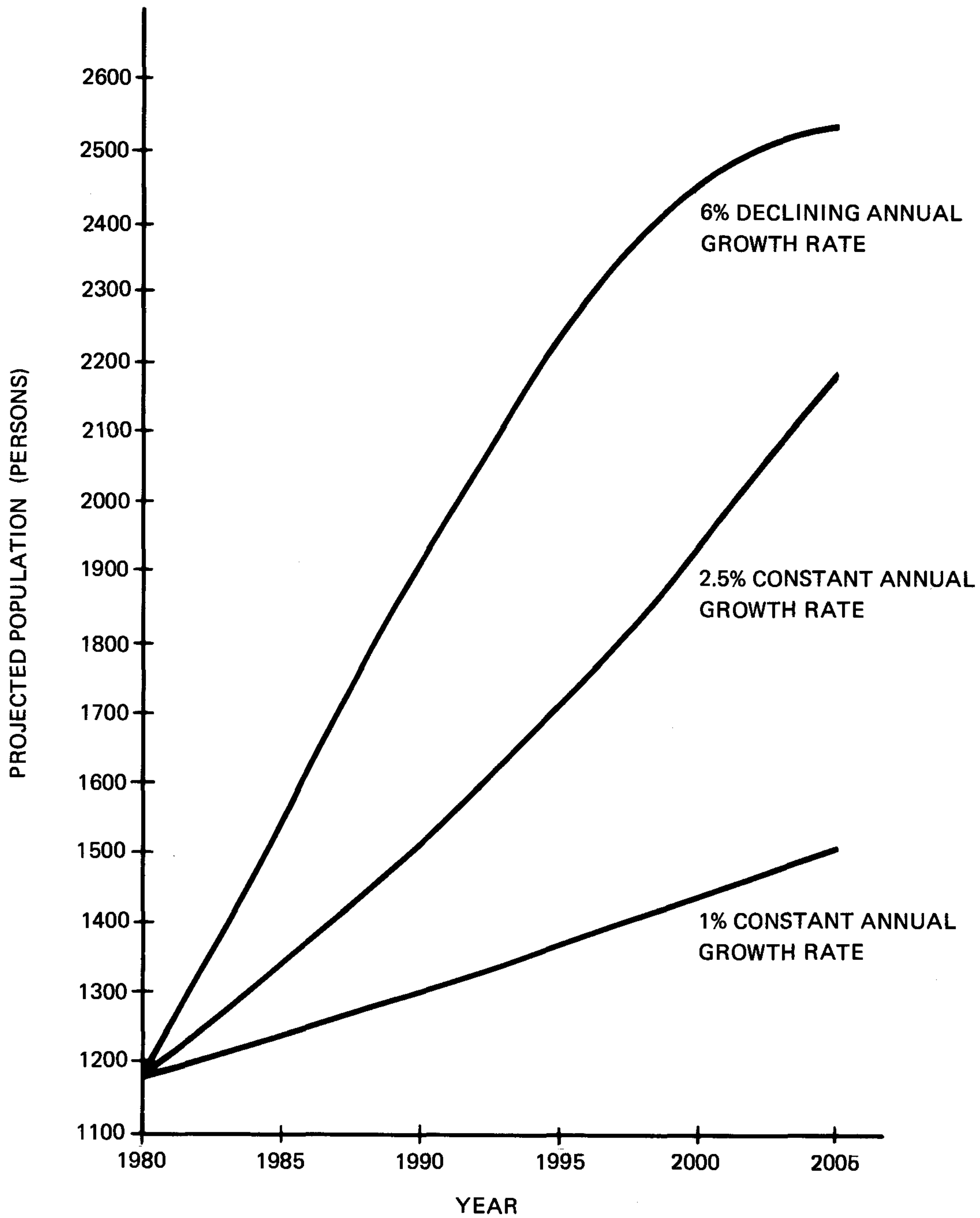

FIGURE 4-2. POPULATION PROJECTIONS

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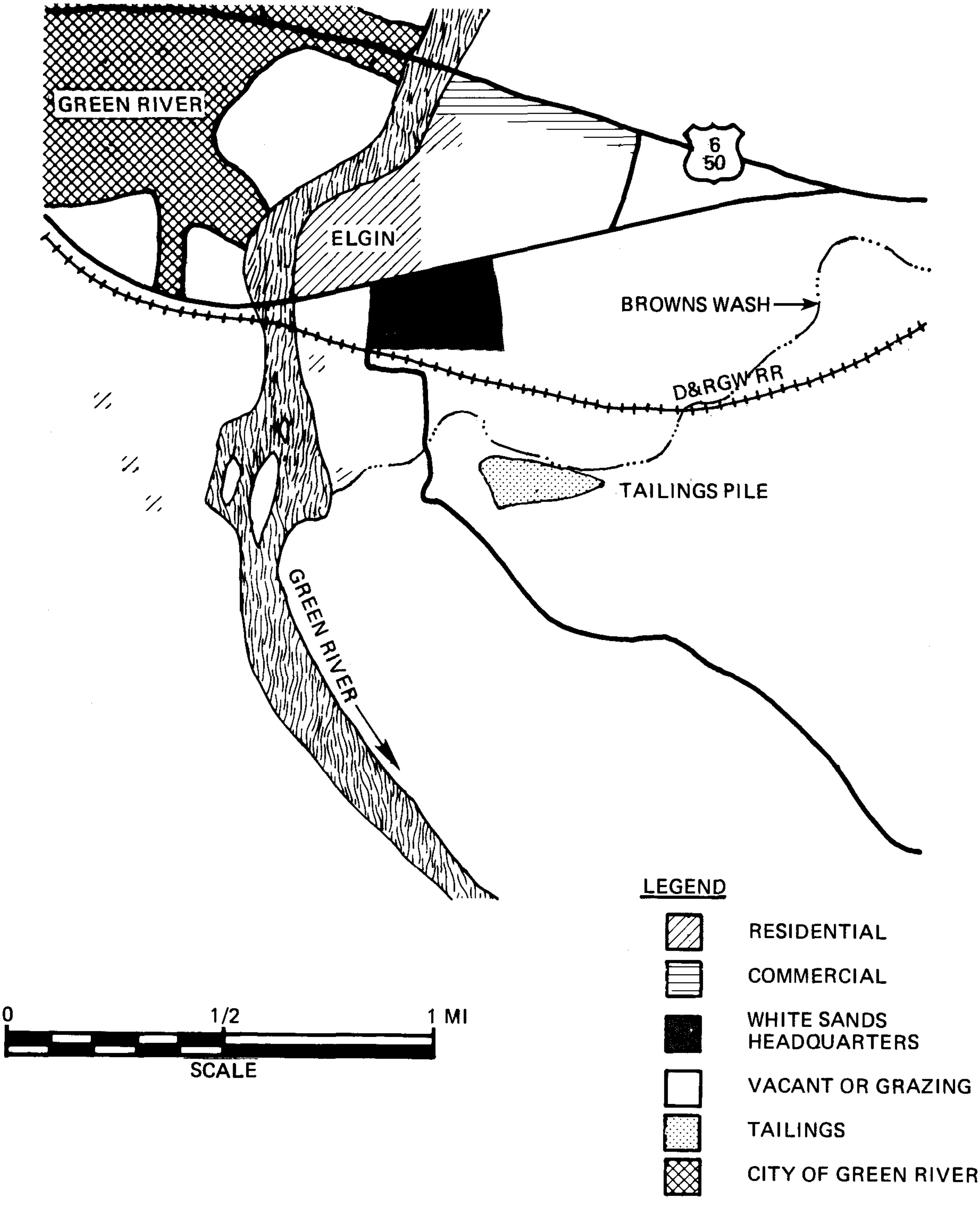

FIGURE 4-3. VICINITY LAND USE

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TABLE 4-1

ESTIMATED 1980 POPULATION DISTRIBUTION FOR GREEN RIVER, UTAH

	Radial Distance from Edge of Tailings Pile (mi)						
Direction	0.25	0.50	0.75	1.0	1.5	2.0	Total
W	0	0	0	20	0	0	20
WNW	0	2	0	20	30	0	52
NW	0	8	0	59	535	426	1,028
NNW	7	8	13	20	20	0	68
N	0	0	2	10	0	0	12
Total	7	18	15	129	585	426	1,180

CHAPTER 4 REFERENCES

1. J.L. England; "Baseline Data and Land Use Impact of the Green River, Utah, Uranium Tailings Site"; Center for Health and Environmental Studies, Brigham Young University; Provo, Utah; July 1977.

2. Green River City Officials; personal communication; Dec 10, 1980.

3. "Southeastern Utah Association of Governments Population Projections by County and City - Table III"; letter from the Southeastern Utah Association of Local Governments, dated July 3, 1980.

4. N. Stocks, Grand County Assessor; personal communication; Dec 17, 1980.

CHAPTER 5

RECOVERY OF RESIDUAL VALUES

CHAPTER 5

RECOVERY OF RESIDUAL VALUES

The Green River tailings pile contains only 123,000 tons of tailings. The uranium content, as derived from AEC records of plant operation, is 0.005% U_3O_8. Table 5-1 gives the assay results obtained on a composite sample taken in 1976.(1) The uranium content of this sample was only 0.006% U_3O_8, which is in reasonable agreement with the AEC records. There are no other metals present in significant concentrations in the tailings. As will be shown in the analysis that follows, the relatively small quantity of tailings present at this site together with the low uranium and vanadium content of the tailings make the possibility very remote that additional uranium can be recovered at a profit.

No amenability testing has been performed on Green River tailings to determine the recovery of uranium or vanadium that could be achieved in a reprocessing operation. In the absence of specific testing, the estimate of uranium recovery from retreatment of the tailings is based on the graph provided by DOE's Grand Junction Office, as shown in Figure 5-1. For the purpose of this chapter it is assumed that the uranium content of 0.005% U_3O_8 indicated by AEC records is correct. It is expected that recovery of uranium by a conventional process will be about 40% or 0.04 lb U_3O_8/ton of tailings. By pelletizing with acid and heap leaching, recovery would be about 30% or 0.03 lb/ton. By normal heap leaching the recovery would be about 23% or 0.02 lb. At November 1980 prices of $28/lb of U_3O_8 the total income from uranium recovery would be $0.60 to $1.20/ton processed. The ores processed at Green River contained a small amount of vanadium. The composite tailings sample contains 0.139% V_2O_5. At 40% recovery and a price of $3/lb of V_2O_5, the recoverable vanadium would be worth about $3.30/ton of tailings treated, which is well below the reprocessing cost.

5.1 PROCESS ALTERNATIVES

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

(a) Heap leaching

(b) Treatment at an existing mill

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

5.1.1 Heap Leaching

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

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

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

5.1.2 Treating in an Existing Plant

For reprocessing in an existing conventional plant to be economically feasible, a mill with significant excess capacity must be located reasonably close to the present tailings site. The mill must also have a tailings disposal site with sufficient capacity to handle the additional tailings and to allow for adequate long-term stabilization. In addition to the 123,000 tons of tailings, there is a substantial quantity of contaminated waste at the Green River site, including contaminated soil from windblown tailings and ore residues in the stockpile area.

The site has good access. Trucks could remove material from the site at rates up to 4,800 tons/day. At such a rate, all tailings and contaminated materials could be removed from the site in a few months. However, the nearest operating mill is about 50 miles away. The transportation costs would far exceed the value of the uranium and vanadium that could be recovered from the Green River tailings. However, if the Green River tailings could be consolidated into the pile at the active mill in Moab, Utah, the cost might compare favorably with stabilizing the tailings at Green River. Even if the tailings were delivered without charge to Moab, reprocessing at an existing mill does not appear to be economically favorable.

5.1.3 Treating in a New Plant

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

The Green River tailings would feed a 500 ton/day plant for about 1 yr. Normally, amortization of a plant is based on planned operation for 10 to 20 yr. While there is good potential for development of new reserves in the area which might be able to supply ore to feed such a plant, there are no production plans as yet.

5.2 GREEN RIVER RECOVERY ECONOMICS

The parameters discussed in this section determine the economic viability of reprocessing uranium mill tailings to recover residual mineral values.

5.2.1 Market for Uranium

The demand and price for uranium from 1976 to 1980 have gone through a rapid rise and fall cycle. Spot prices for uranium, as indicated by the exchange values reported by NUEXCO,[2] rose from \$30/lb of U_3O_8 in November 1975 to \$43/lb in November 1977 and essentially held constant until the end of 1979. The price dropped precipitously to \$28.50/lb of U_3O_8 by September 1980 and to \$25/lb early in 1981. Prices in individual long-term uranium sales contracts have varied over a broad range.

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

5.2.2 Escalation of Plant Construction Costs

The estimated construction costs of both heap leach plants and conventional mills without crushing and grinding facilities, as provided by the DOE Grand Junction, Colorado Office, were included as figures in the Phase II, Title I Engineering Assessment report.[1] The costs are adjusted to January 1977. Since then, relatively few plants have been built, and reported costs have been strongly influenced by new tailings control and stabilization requirements under NRC licenses. Recent estimates by R.B. Coleman of construction cost for conventional plants have been in the range of $13,000 to $30,000/ton of daily plant capacity.[4] In view of the many significant site-specific problems that can influence capital costs, for the purposes of this report it was decided to apply suitable escalation factors to the 1977 Grand Junction Office estimates, which are based on construction costs of many plants.

The Engineering News Record[5] publishes reports quarterly on various construction cost indexes. The following data are derived from this source:

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

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

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

From the above indexes, an increase in plant construction cost of 25% from January 1977 to mid-1980 has been applied as a conservative estimate. As indicated in Figure 5-2, the capital cost of a 500 ton/day heap leach facility would be about $4.8 million. As indicated in Figure 5-3, the cost for a conventional mill of similar capacity would be about $6 million. If these capital costs were to be amortized on the Green River tailings only, the unit costs would be $39 to $49/ton, or from $1,200 to $1,300/lb of U_3O_8 recovered.

5.2.3 Escalation of Plant Operating Costs

The operating costs of uranium mills appear to have risen much more steeply than construction costs. In the December 1977 engineering assessment report, the direct operating costs of a 500 ton/day facility were estimated at $3.25 and $5.80/ton for heap leach and conventional acid leach mills, respectively. However, R.B. Coleman(4) reports that 1980 operating costs of conventional mills are in the range of $8.70 to $18.40/ton.

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

Considering the differences in the plant designs, it is estimated that average mill operating costs have increased by a factor of 2.5 from the January 1977 data to mid-1980. This would result in operating costs for Green River tailings in a 500 ton/day conventional plant of about $17.50/ton, or

$440/lb U_3O_8 recovered (assuming 0.04 lb recovered/ton). For a heap leach plant of the same size the corresponding figures would be $13.75/ton and $690/lb recovered. In view of these operating costs, which far exceed the market price, no detailed analysis of optimum plant size is warranted. The 500 ton/day plant size is about the smallest that would be built today for an operation processing high grade ore.

5.2.4 Competitive Market Factors

The average grade of ore processed in conventional mills has decreased from 0.15% U_3O_8 in 1977 to 0.11% in 1979. Average recovery rate for the industry has been 91±1% during this period.(6) However, since tailings have been processed previously, the recoveries in reprocessing are likely to be much lower, as reflected in Figure 5-1. To produce a given quantity of uranium, about 20 times as much Green River tailings material would have to be processed as would when a mill is operating on ore of the average grade treated in 1979. Thus, the volume of tailings to be stabilized per unit of production is correspondingly greater. The fact that there are no mining costs is a substantial off-setting advantage. However, it is not sufficient to compensate for the low grade and small quantity of Green River tailings.

5.3 CONCLUSION

Processing the Green River tailings for the recovery of additional uranium in connection with the tailings stabilization operations either by heap leach or conventional plant processes is not practicable, nor is it likely to be practicable under any foreseeable conditions. Even if all the uranium could be recovered, an increase in prices by a factor of about 60 would be needed to make the reprocessing economically attractive. A comparison of costs by process method is given below.

	Conventional Plant		Heap Leach	
	$/ton	$/lb U_3O_8	$/ton	$/lb U_3O_8
Capital Cost	48.75	1,200	39.00	1,300
Operating Cost	17.50	400	13.75	500
Total	66.25	1,600	52.75	1,800

Even if reprocessing could occur at a new mill constructed primarily for processing newly-mined ore, so that the amortization of plant capital costs would not have to be accomplished with tailings alone, the operating costs appear to be greater than the current spot market price for U_3O_8 by a factor of not less than 10. Therefore, reprocessing the Green River tailings for uranium recovery is extremely impractical economically.

Since the economic analyses in this chapter were prepared, construction costs have continued to rise, while the spot market price for uranium has declined to about $25/lb of U_3O_8 early in 1981. These trends further reduce the economic attractiveness of tailings reprocessing.

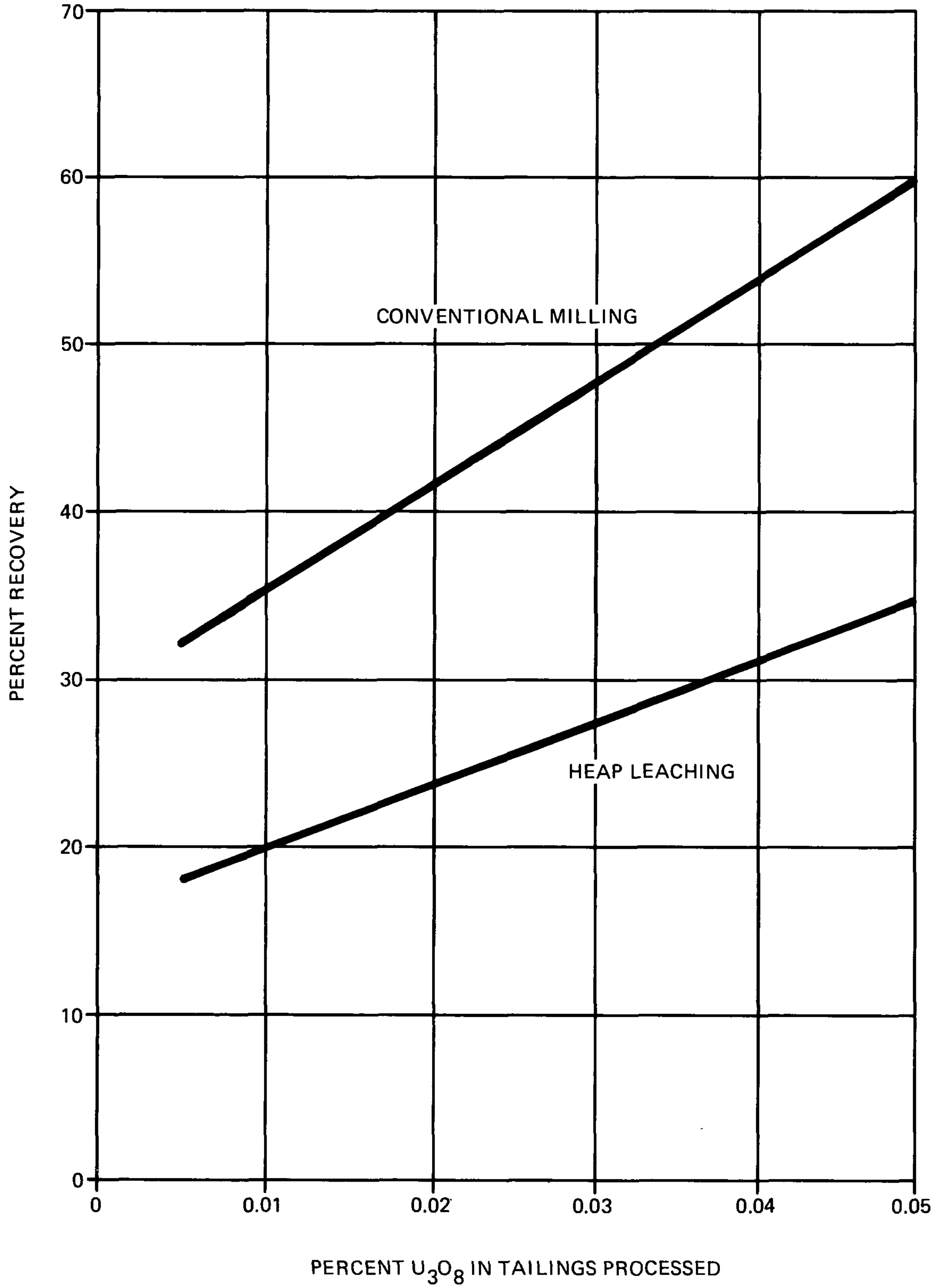

FIGURE 5-1. URANIUM RECOVERY FROM MILL TAILINGS AS A FUNCTION OF U_3O_8 CONTENT IN TAILINGS

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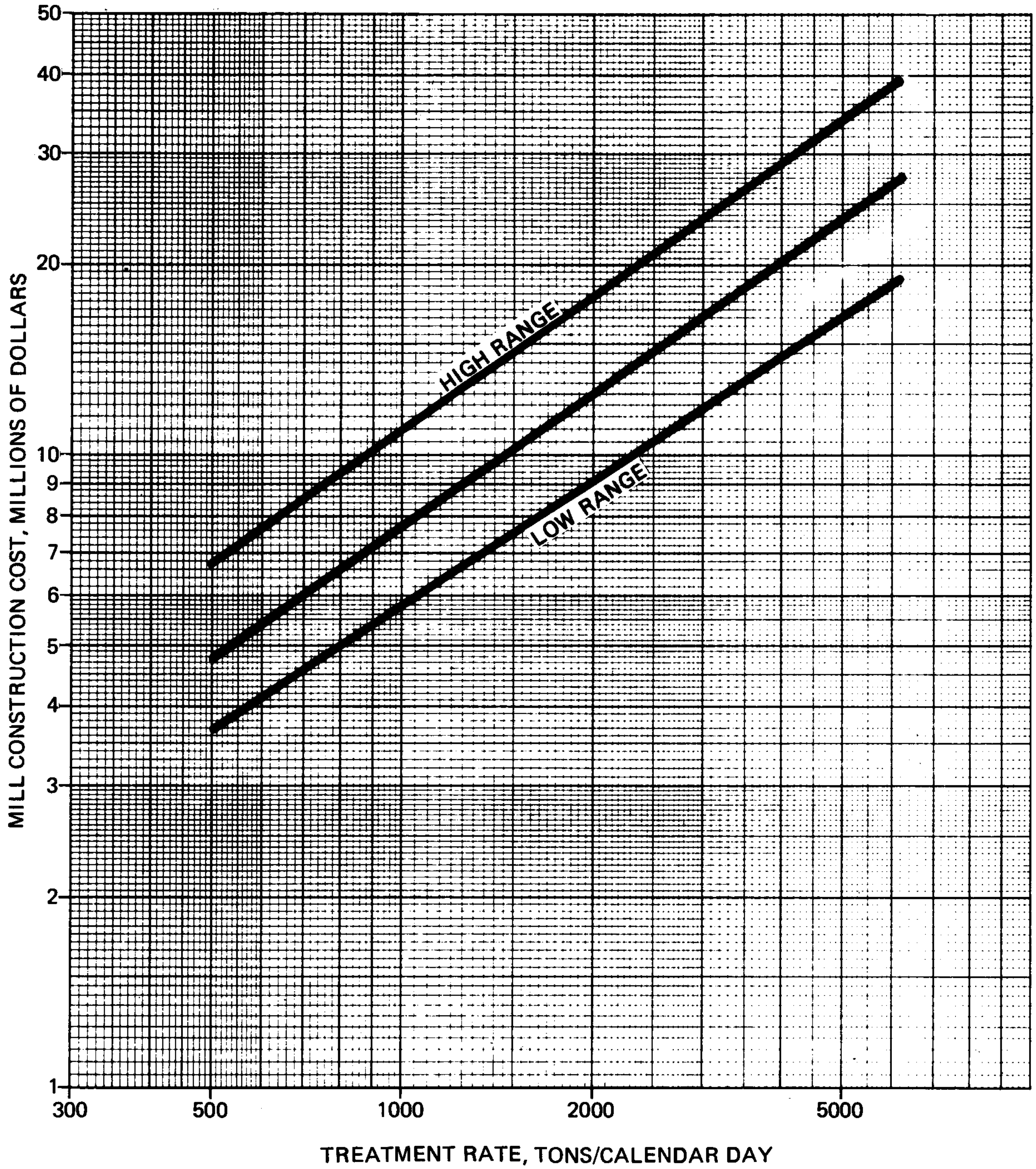

FIGURE 5-2. CONSTRUCTION COSTS OF HEAP LEACHING PLANT TO REPROCESS URANIUM MILL TAILINGS (COST ADJUSTED TO JULY 1980)

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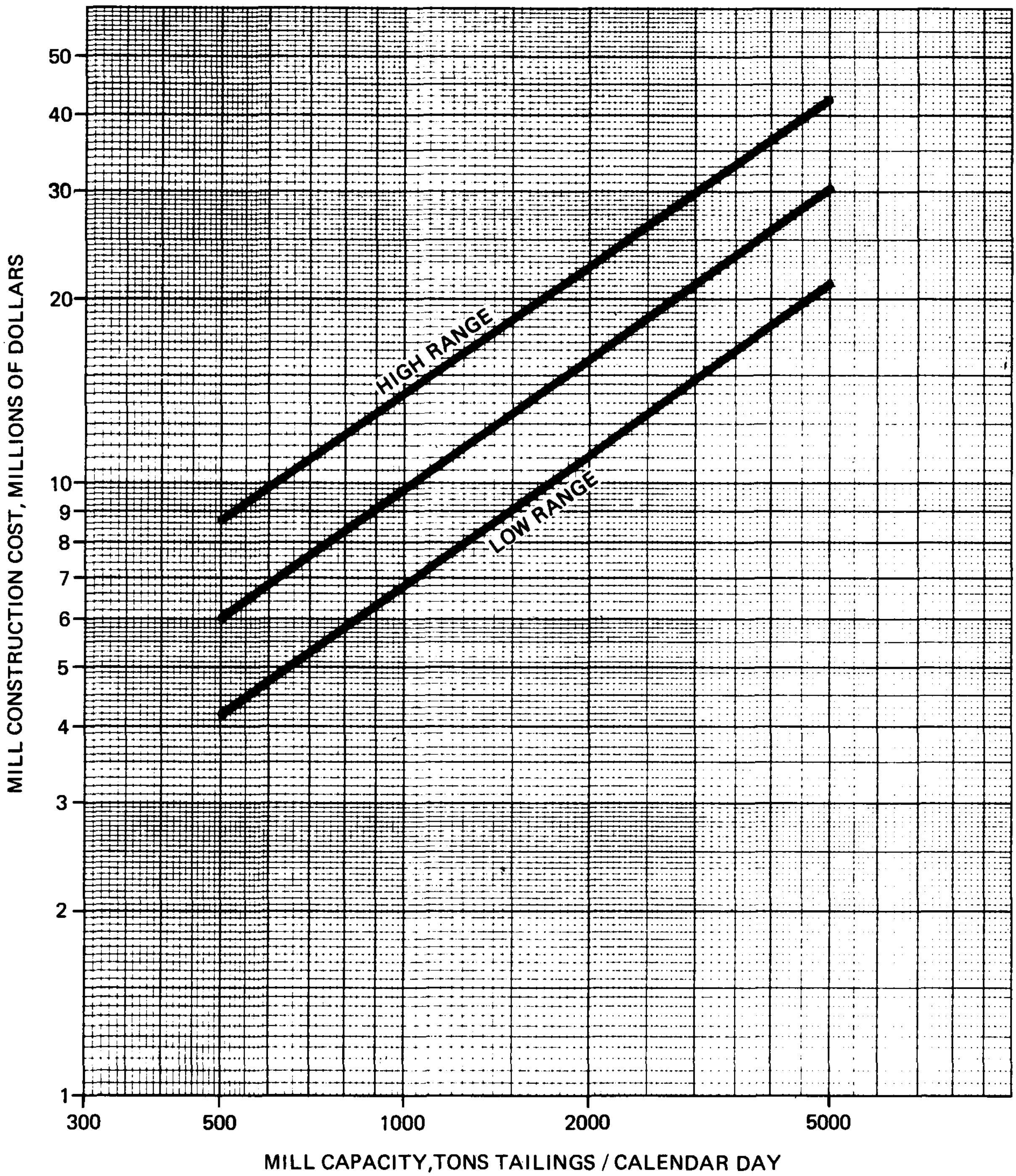

FIGURE 5-3. CONSTRUCTION COSTS OF A CONVENTIONAL URANIUM MILL TO REPROCESS TAILINGS W/O CRUSHING AND GRINDING FACILITIES OR TAILINGS STABILIZATION COSTS (COST ADJUSTED TO JULY 1980)

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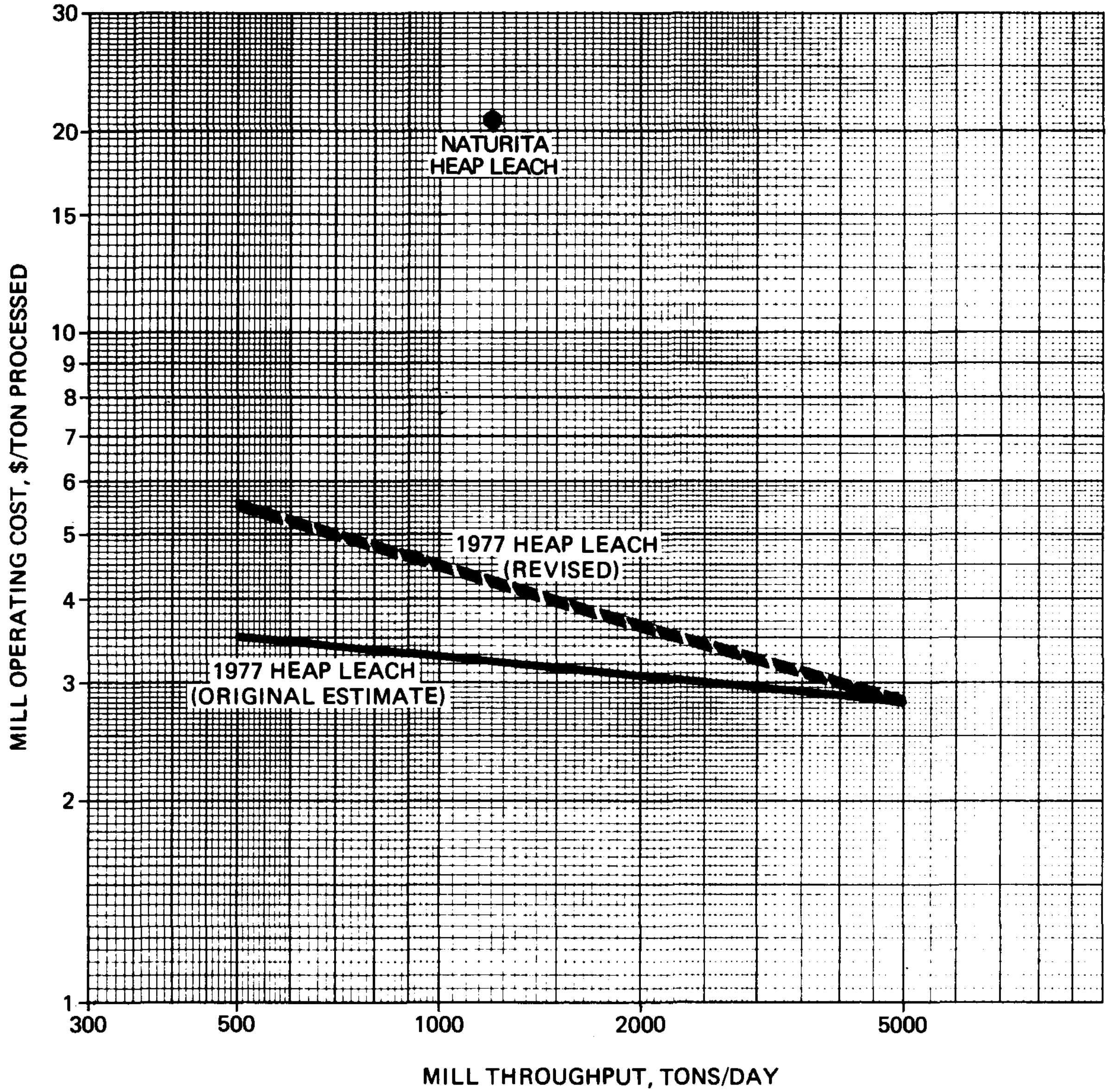

FIGURE 5-4. OPERATING COSTS OF HEAP LEACHING OF URANIUM MILL TAILINGS

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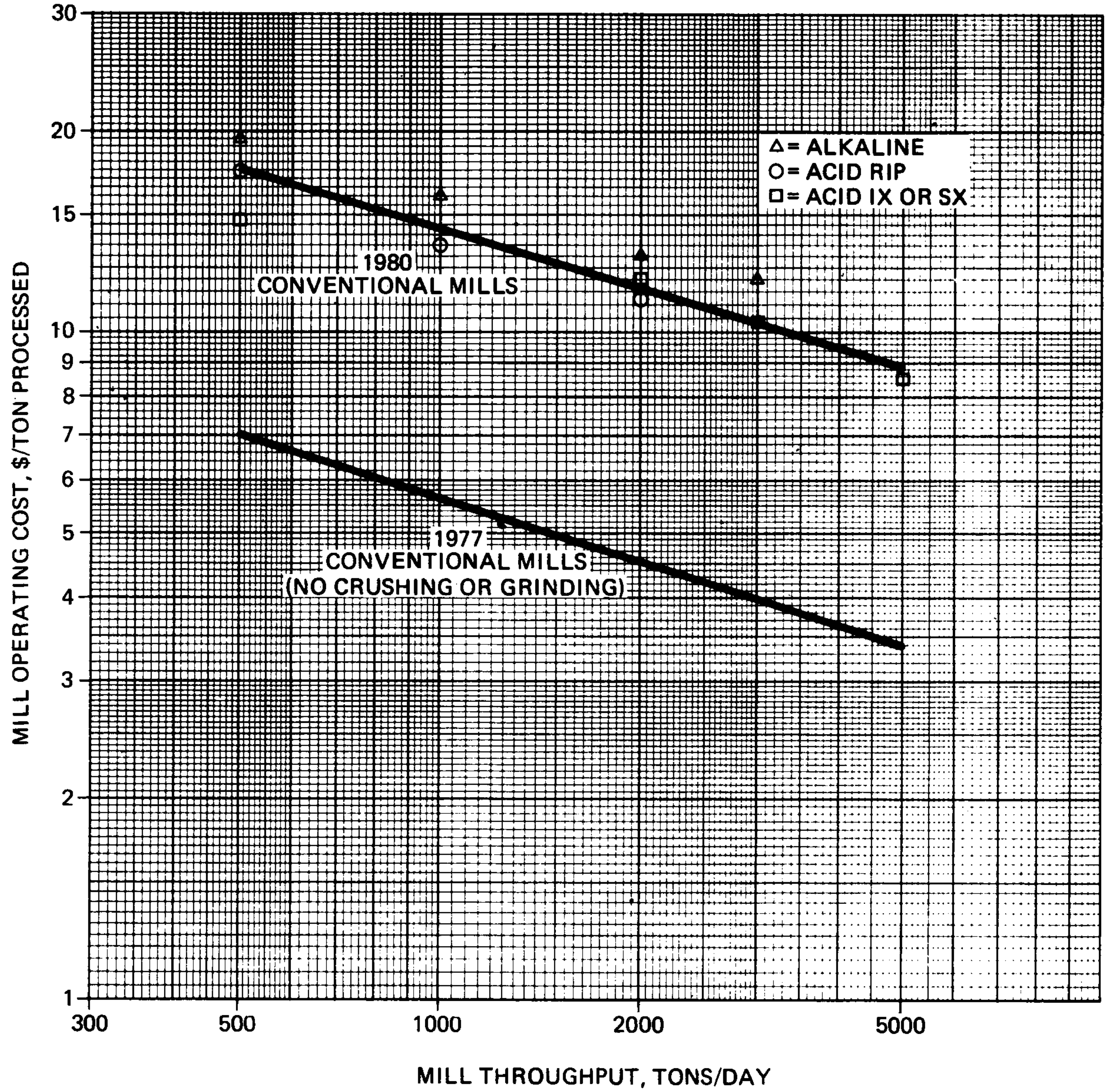

FIGURE 5-5. OPERATING COSTS OF CONVENTIONAL MILLING W/O CRUSHING AND GRINDING FACILITIES TO REPROCESS TAILINGS (COST ADJUSTED TO JULY 1980)

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TABLE 5-1

ASSAY RESULTS OF COMPOSITE GREEN RIVER TAILINGS

	Percentage by Weight			
Element	Atomic Absorption	Spectrographic	Chemical	AEC* Estimate
Aluminum	--	>1.0	--	--
Arsenic	0.000186	--	--	--
Barium	0.00733	--	--	--
Boron	--	--	--	--
Cadmium	0.000040	--	--	--
Calcium	--	>1.0	--	--
Chromium	0.00170	--	--	--
Cobalt	0.0056	--	--	--
Copper	0.0102	1.0-0.01	--	--
Cyanide	<0.000001	--	--	--
Gallium	--	--	--	--
Iron	0.1210	>1.0	--	--
Lead	0.0121	<0.01	--	--
Magnesium	--	>1.0	--	--
Manganese	--	1.0-0.01	--	--
Mercury	<0.00000011	--	--	--
Molybdenum	--	--	--	--
Nickel	--	<0.01	--	--
Potassium	--	>1.0	--	--
Selenium	0.0231	--	--	--
Silicon	--	>1.0	--	--
Silver	0.000007	--	--	--
Sodium	--	>1.0	--	--
Titanium	--	1.0-0.01	--	--
Uranium (U_3O_8)	--	--	0.006	0.005
Vanadium (V_2O_5)	--	1.0-0.01	0.139	--
Zinc	0.00208	--	--	--

*Calculated tailings assay based on plant operation

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TABLE 5-2

U.S. URANIUM SUPPLY AND MARKET SUMMARY

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

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

CHAPTER 5 REFERENCES

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

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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 Green River, precipitation averages about 6 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.

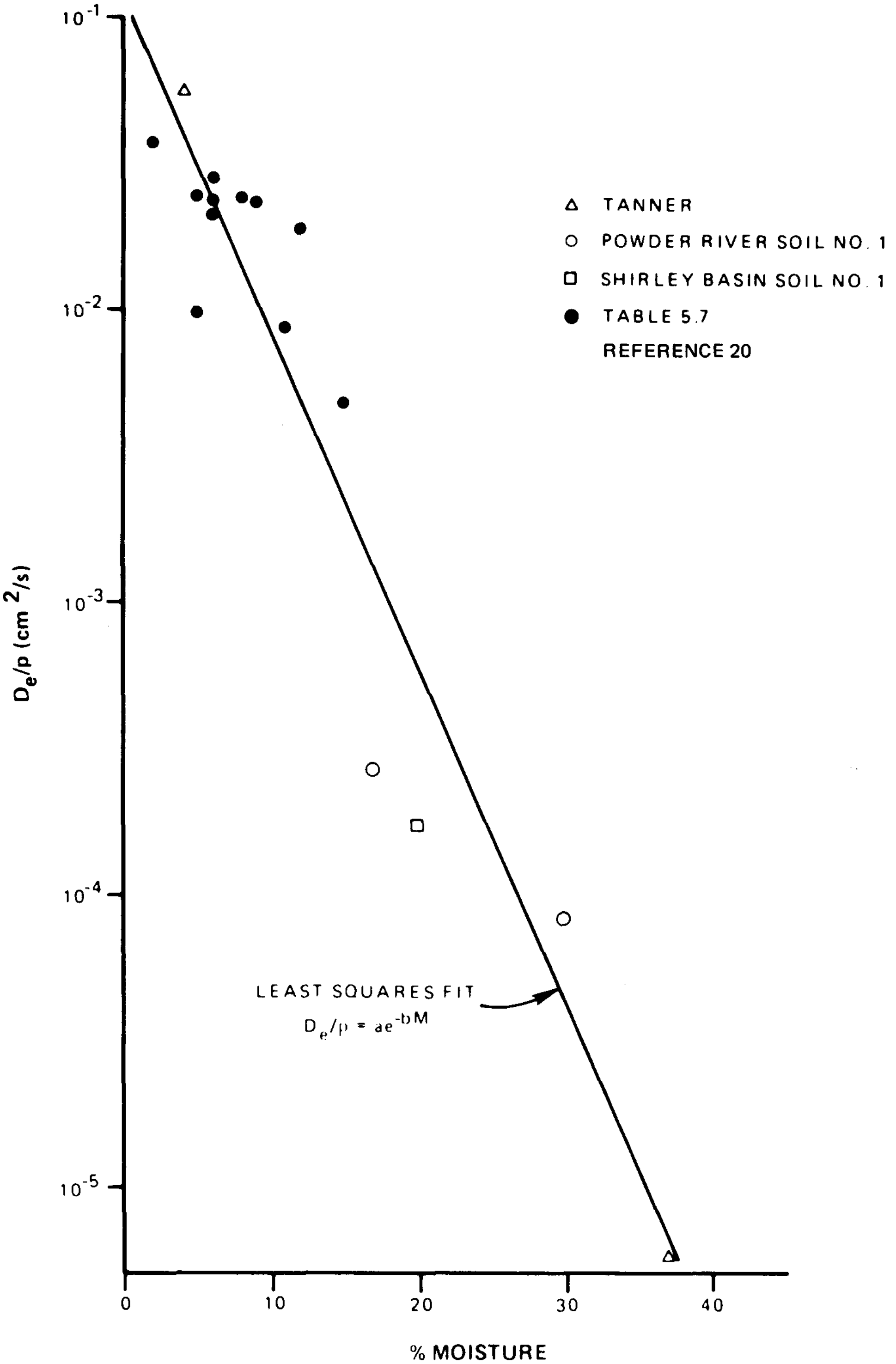

FIGURE 6-1. EXPONENTIAL MOISTURE DEPENDENCE OF THE DIFFUSION COEFFICIENT

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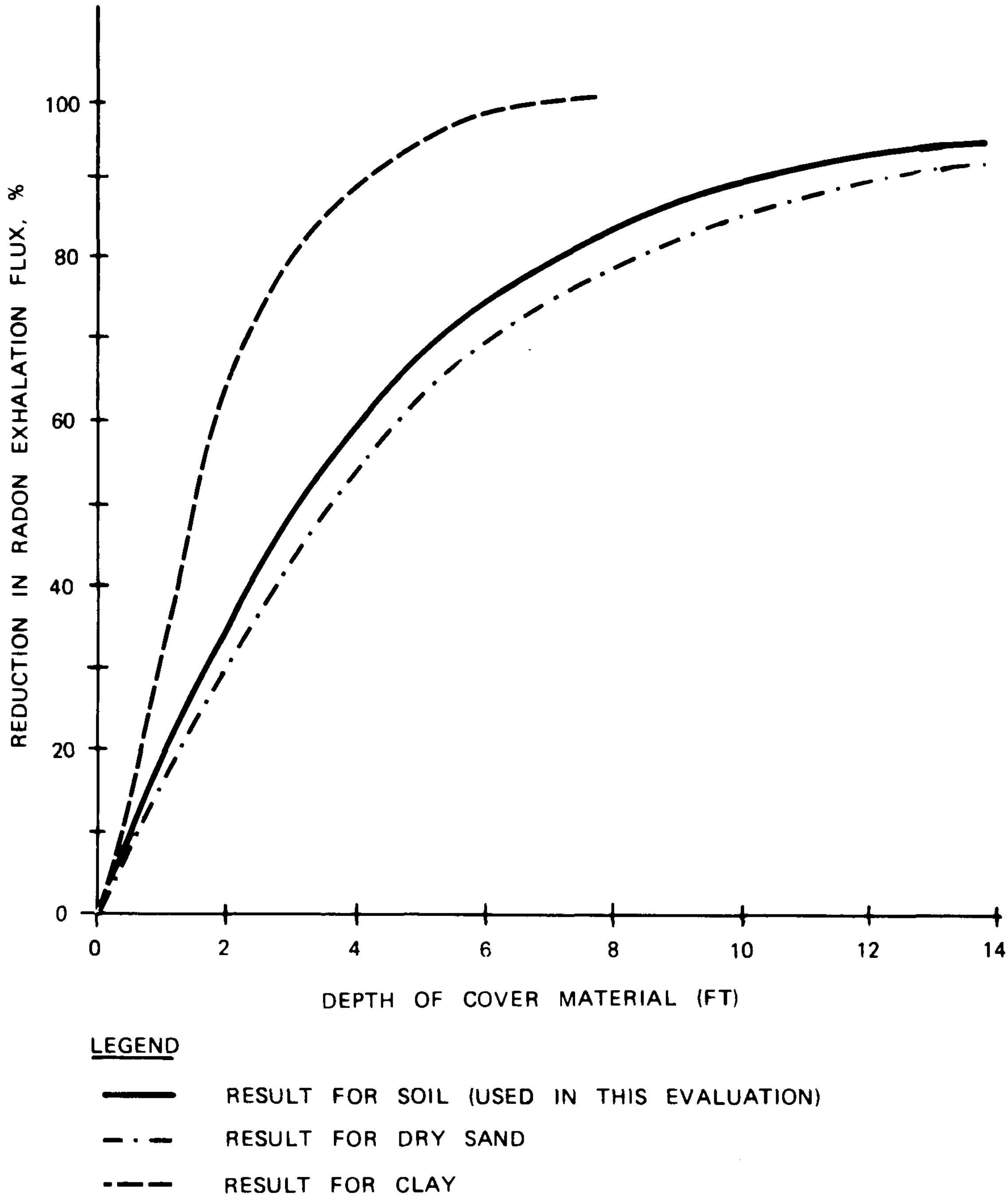

FIGURE 6-2. REDUCTION OF RADON EXHALATION FLUX WITH DEPTH OF COVER

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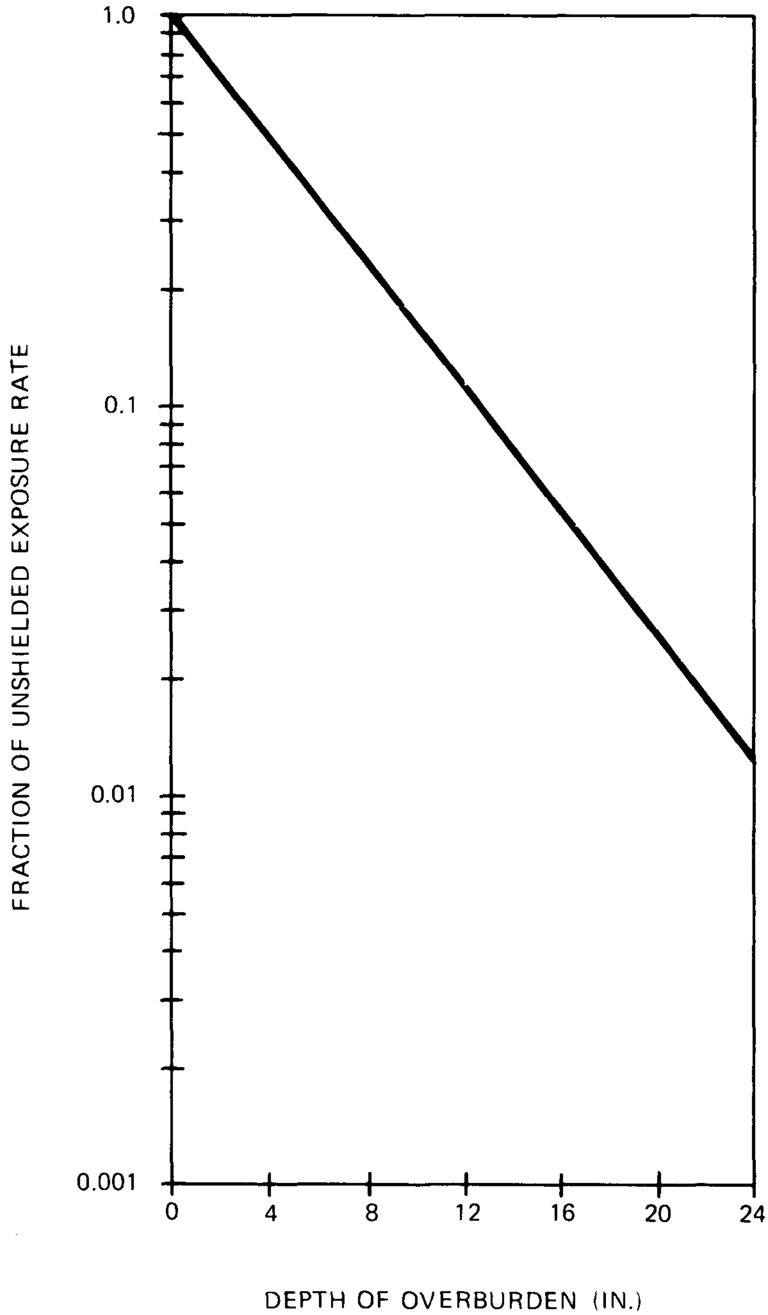

FIGURE 6-3. REDUCTION OF GAMMA EXPOSURE RATE RESULTING FROM PACKED EARTH SHIELDING

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CHAPTER 7

OFF-SITE REMEDIAL ACTION

CHAPTER 7

OFF-SITE REMEDIAL ACTION

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

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

7.1 DATA SOURCES

A mobile scanning unit, operated by the AEC under an interagency agreement with the EPA, performed a gamma radiation survey of the Green River, Utah, area prior to 1973. Of the 342 structures scanned, 23 anomalies were discovered where the radiation was significantly above background. A joint team from the EPA Office of Radiation Programs, Las Vegas, Nevada, and from the Utah State Division of Health performed individual gamma surveys of the 23 locations to determine the source of the anomalies and, if tailings, how they had been used. High and low inside and outside gamma readings were recorded. A gamma map was drawn of areas inside the structures where gamma readings exceeded 20 μR/hr.(1)

The gamma survey 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

A follow-up survey of the 23 anomalies(1) indicated that there was only one tailings-use location. At this location, tailings were discovered within 10 ft of the structure, but the owner refused to allow a detailed survey of the property. For the purpose of this report, this structure is assumed to require remedial action and is classed as a "tailings-under and away" structure.

Of the remaining 22 anomalies identified by the scanning survey, 14 were caused by the presence of radioactive material in instruments or ore, one resulted from natural radioactive materials, and seven resulted from unknown sources.

The cost for remedial action at the off-site location has been estimated at $74,000, 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 5-pCi/g line in Figure 3-13. Decontamination of those areas containing windblown tailings would involve removing the off-site contaminated soil and replacing it with clean fill. The result of this action is assumed to satisfy remedial action criteria as mentioned 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.

Cleanup and restoration costs for the approximately 14 acres of land outside the designated site boundaries that are contaminated by windblown tailings in the vicinity of the tailings site are estimated to be about $174,000, exclusive of engineering and contingency allowances. This cost includes radiological monitoring and health physics services.

All windblown areas would be decontaminated by removing an average of 6 in. of soil, gravel from roads, vegetation, etc., to the perimeter of the tailings pile and mill area. After decontamination, the affected area would be restored with the addition of clean material and appropriate establishment of vegetation. Cleanup of the windblown contamination and off-site properties will be accomplished as part of any remedial action option.

CHAPTER 7 REFERENCES

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CHAPTER 8

DISPOSAL SITE SELECTION

CHAPTER 8

DISPOSAL SITE SELECTION

The conclusion of the 1977 engineering assessment report was that the existing Green River site can meet the criteria specified for stabilization of tailings, and no other disposal sites were identified therein. However, due to the location of the tailings adjacent to Browns Wash, which has eroded the tailings during flood conditions in the past, it may be advisable to move the tailings from their present site and dispose of them at a hydrologically superior site. If the tailings are to remain in their present location, significant upgrading of the existing diking around the site will be required to meet stabilization criteria.

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

8.1 CRITERIA FOR DISPOSAL

Table 8-1 lists the name of each of the four possible disposal sites and its road distance from the present Green River tailings site; Figure 8-1 shows the relative locations of the four sites. A reconnaissance survey was made of the sites, and cost estimate studies based on their feasibilities are included as Options II through V in Chapter 9.

Each of the four sites was evaluated to a limited extent on the bases of hydrology, meteorology, literature surveys, and on-site inspections. Economic considerations included distance from the Green River site, preliminary estimates of support facilities such as highways and railroads, and the extent of site preparation and long-term maintenance required at the site.

8.2 DESCRIPTIONS OF DISPOSAL SITES CONSIDERED AS OPTIONS

Sites near Woodside, Utah, and Sager's Flat, east of Thompson, Utah, each about 30 mi from Green River, were suggested as possible locations for a central heap leach facility.[1] These two sites also could serve as disposal sites for the Green River tailings and are identified as sites 3 and 4 in Table 8-1. However, if such a facility is not developed, as now appears to be the case, these locations have the significant disadvantage of greater distance from the tailings site when compared with sites 1 and 2. As demonstrated in Chapter 5, the uranium content of the Green River tailings is too low to be reprocessed at a profit and the reprocessing would apparently produce no income to offset the greater transportation costs.

The area surrounding the Green River tailings site has many potential disposal sites that could be used at substantial cost savings over disposal at site 3 or 4. The Northeast Green River, Utah site (site 1) and the Southeast Green River, Utah site (site 2) are two such sites. A more thorough investigation of the area would undoubtedly reveal other similar and perhaps superior sites for tailings disposal.

All four of these sites are located on the Mancos Formation of southeastern Utah. At each site, vegetation is less than a 30% cover, and rainfall averages 6 in./yr. Soil development on the Mancos Formation in these areas is often quite shallow. While the abundant pediment deposits in the area possibly could be used for cover material, they might not contain enough fine material to act as an effective radon barrier. Finer-grained material would need to be located to be used as the initial 3 to 4 ft of cover and possibly to mix with the pediment materials for the bulk of the 3-m cover. Any decomposed shale excavated from the site could be used for this purpose. Additional areas for fine-grained cover would have to be obtained from the Mancos Formation with deeper soils, identified by intensive local reconnaissance.

Generally, the Mancos Formation beneath the sites is characterized by low permeabilities and serves as an aquiclude, isolating lower aquifers. Placement of the tailings on a shale sequence of this formation would probably result in excellent hydrologic isolation. The pediments, on the other hand, are undoubtedly quite permeable and, if the disposal pit were located in the pediment, lining the pit with finer-grained soils might be desirable. However, since the pediments probably do not serve as an aquifer in the area and since they are resting on the Mancos Formation, this may not be necessary.

8.2.1 Northeast Green River, Utah, Site 1 (Option II)[7]

The Northeast Green River site is located 4.5 road miles northeast of the Green River tailings site on a gentle slope formed on the Mancos Formation leading away from the Book Cliffs. The site is in the southeast quarter of Section 6, Township 21 South, Range 17 East, and can be reached via a gravel road heading northeast from Interstate 70 about 0.5 mi east of where Interstate 70 crosses the Green River. The haul would proceed over this road, which would require some upgrading to handle the heavy loads, for about 3.3 mi to the disposal site. Vegetation covers about 10% of the site surface area. The site offers the advantages of a sparsely populated area, good evaporative conditions, and a short haul distance from the tailings site.

Riprap and low-permeability cover materials probably could be obtained from sources located about 4 to 6 mi from the site.

The main advantages of the site are its isolation from populated areas and its proximity to the tailings site. Major disadvantages include the difficulty of excavating to a depth of 3 m for disposal and a potential scarcity of cover material.

8.2.2 Southeast Green River, Utah, Site 2 (Option III)[8]

The Southeast Green River site is located 7 road miles southeast of the Green River tailings site at the head of a natural, U-shaped hollow on the Mancos Formation. The site lies in Section 30 of Township 21 South, Range 17 East, and can be reached via a paved road leading south from Interstate 70 about 4 mi east of where Interstate 70 crosses the Green River. The haul would proceed over this road for about 1.6 mi and then head southeast over a haul road for 0.5 mi to the site. Vegetation covers about 15% of the surface area at the site. The site offers the advantages of a sparsely populated area, good evaporative conditions, and a short haul distance from the tailings site.

Riprap and fine-grained cover materials could probably be obtained from sources located about 4 to 6 mi from the site.

The main advantages of the site are its isolation from populated areas and its proximity to the tailings site. Major disadvantages include the difficulty of excavating to a depth of 3 m for disposal and a scarcity of cover material.

8.2.3 Location 2 Miles North of Woodside, Utah, Site 3 (Option IV)

The Woodside, Utah, site is located 30 road miles northwest of the Green River tailings site on an eroded pediment at the base of the Book Cliffs.[2] Vegetation in the area is limited to a 30% cover. The site offers the advantages of a sparsely populated area, good evaporative conditions, and proximity to a highway. Present access to the site area is about 3 mi on either of two dirt roads off Highway 6.

Some commercial grade shales and clays have been identified along the Castle Dale-Woodside road about 6 to 10 mi southwest of Woodside.[3] These could provide a source of fine-grained material to improve the permeability of local cover material. Gravel cap material could be obtained from the pediment in the site area or from terrace gravels within 5 mi of the site.[2,4]

The main advantages of this disposal location are its isolation from populated areas and its proximity to a highway. Major disadvantages of this site are the long distance from the tailings site, the difficulty of excavating to a depth of

3 m for disposal, a potential scarcity of cover material, and the necessity of hauling the tailings through the city of Green River.

8.2.4 Sager's Flat, 6 Miles East of Thompson, Utah, Site 2 (Option V)[5]

The Sager's Flat site is located 30 road miles east of the Green River tailings site in a gentle slope formed on the Mancos Formation leading away from the Book Cliffs.[6] Vegetation covers about 10% of the surface in the area. Potential sites could be located on either side of Interstate 70.

Some commercial grade clays have been identified about 10 mi south of Crescent Junction and about 20 mi from the disposal area.[3] These materials might also be a source for fine-grained cover, possibly to mix with Mancos soils if they prove to be too silty to provide the most effective radon barrier. Riprap probably could be obtained from sources about 2 to 6 mi from the site.[4,5]

The main advantages of this disposal location are its isolation from populated areas and its proximity to highway and rail transportation facilities. Major disadvantages include the long distance from the tailings site, the difficulty of excavating to a depth of 3 m for disposal, and a potential scarcity of cover material.

8.2.5 Moab, Utah, Site 5

The operating mill of Atlas Corporation at Moab, Utah, has a large tailings pile that eventually must be stabilized. The center of this tailings pile contains an area of soft slimes that will require the addition of sandy material before it will support a 3-m cover. It is possible that an arrangement could be made with Atlas to consolidate the Green River material with their existing pile. While transportation costs would be higher than to the other sites evaluated, the elimination of disposal site costs could conceivably make this an attractive alternative. The distance to Moab is about 50 mi. The company has not been approached concerning this alternative.

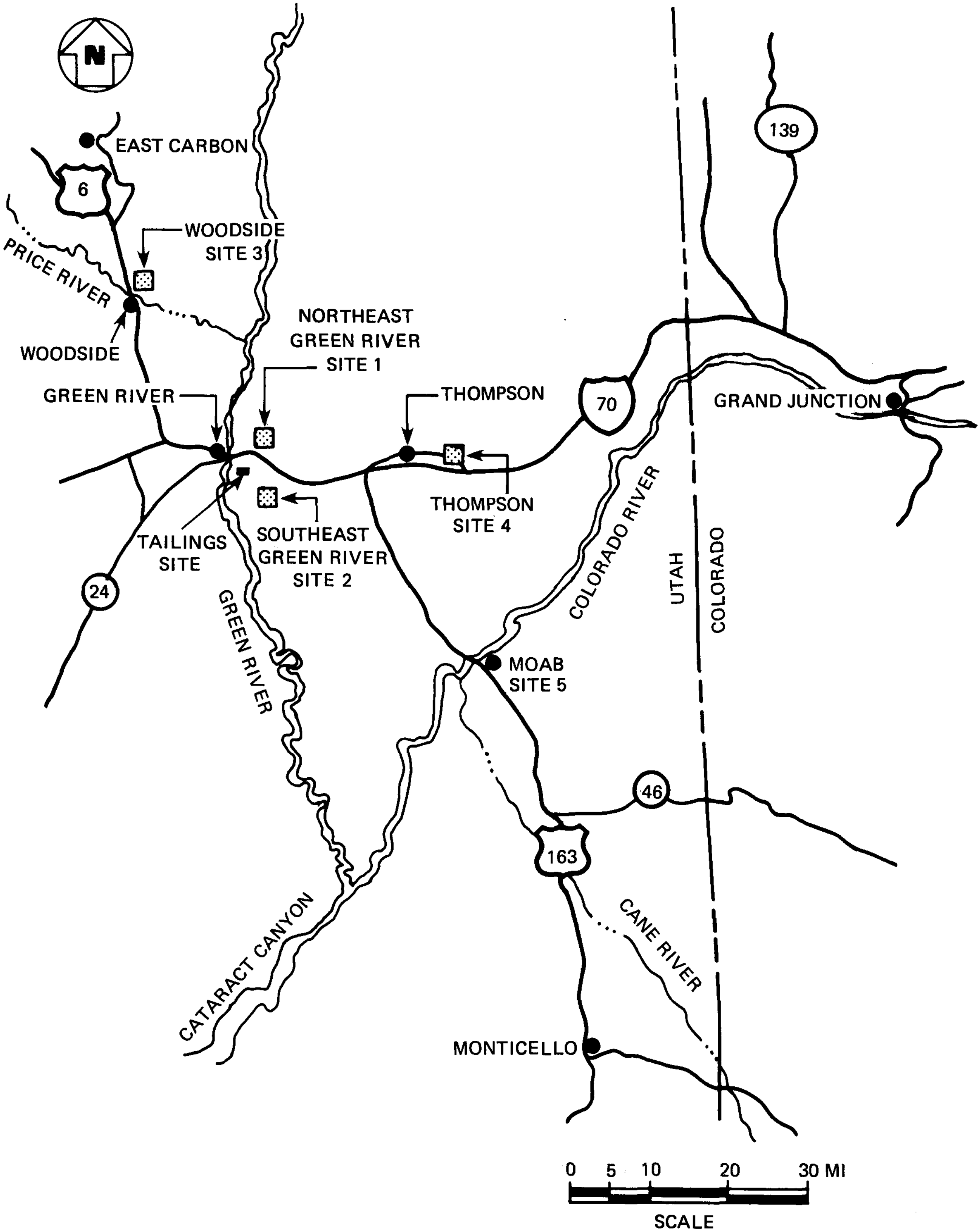

FIGURE 8-1. DISPOSAL SITE LOCATIONS

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TABLE 8-1

SITES EVALUATED FOR DISPOSAL OF THE GREEN RIVER TAILINGS

Site No.	Option No.	Road Miles From Pile	Site Name
1	II	4.5	Northeast Green River, Utah
2	III	7	Southeast Green River, Utah
3	IV	30	North of Woodside, Utah
4	V	30	Sager's Flat; East of Thompson, Utah
5	--	50	Moab, Utah

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CHAPTER 9

REMEDIAL ACTIONS AND COST-BENEFIT ANALYSES

CHAPTER 9

REMEDIAL ACTIONS AND COST-BENEFIT ANALYSES

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

The procedures for decontaminating inactive mill tailings sites have not been well established. Although remedial action criteria have been tentatively established, 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. Furthermore, 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.

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

The process of obtaining the necessary permits and the associated costs are considered to be included in the various agency budgets and are not included in this report. Similarly, the tailings sites, the proposed disposal sites, and related gravel or clay material borrow pits have been treated as public lands and no acquisition costs are included.

Costs for future maintenance and radiological monitoring at the disposal sites are not included in any option. Funding for such future costs is assumed to come from separate contracts administered by the Federal Government.

On-site stabilization of the tailings, described in Option I, requires that the windblown areas, ore storage areas, and mill area be cleaned up and the contaminated materials be consolidated on the tailings pile before placement of the 3-m depth of stabilizing cover material.

Options for disposal at the alternative sites (Options II through V) provide for the relocation of all tailings and contaminated material from the ore storage area, windblown areas, and off-site locations. These areas would be decontaminated of any tailings or contaminated materials to such levels as required by remedial action standards.

The off-site remedial actions described in Chapter 7 are included in all options. In Option I, the off-site material is to be deposited on the Green River pile before it is stabilized. In Options II through V, the off-site contaminated material is relocated directly to the disposal site. The area to be decontaminated can be seen in Figure 9-1.

A discussion of the concepts involved in tailings stabilization and their applicability to the Green River site has been included in Chapter 6. For both on-site and off-site disposal options, a riprap cap of 0.3-m thickness on top of a 3-m depth of cover material is assumed to suffice for erosion control.

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

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

9.1.1 Conceptual Design

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

Because of the potential for flooding of Browns Wash and possible resulting erosion of tailings, stabilization in place would require extensive diking and possibly stream diversion to minimize the possibility that the integrity of the stabilized pile would be violated. Allowances have been made in cost estimates for accomplishing such protective actions.

The windblown tailings, millsite, and ore storage area would be cleaned up and the resulting contaminated materials placed on top of the existing tailings. The leaching building, offices, crushing building, and one other building would be decontaminated. The other buildings and sheds at the millsite would be demolished and placed on the pile. An average of 3 ft of material would be removed from the ground at the millsite and 1 ft from the area east of the millsite and south of the tailings pile. An average of 6 in. of soil would be scraped off of windblown areas and placed on the pile. These areas are shown in Figure 9-1. All areas would be backfilled to natural grade and landscaped to be similar to original conditions.

The tailings site would be contoured, graded, and stabilized with 3 m of cover material. This cover is assumed to be well-engineered and placed so that it would reduce radon flux to the required 2 pCi/m^2-s. Low-permeability soil for cover material can be obtained 5 to 10 mi from the site. The final shape of the tailings pile surface would be generally the same as the present convex surface. The stabilization cover would be contour-graded to prevent erosion and covered with 0.3 m of riprap.

If the Green River tailings were to be stabilized in place, the site would continue to have limited use. The presence of the resulting 17-ft-high stabilized pile could be objectionable, but property and land values in the area might not be substantially affected.

9.1.2 Costs

As shown in Table 9-1, the cost for stabilization at the Green River site is estimated to be $4,300,000. Costs include cleaning up of windblown, millsite, and ore storage areas; covering of all contaminated materials with a 3-m depth of cover; contouring of the surface; establishing of vegetation or covering with riprap; reclaiming of all areas; realignment and riprapping of Browns Wash; diking of the north and east edges of the tailings pile; and health physics and radiological monitoring services during the cleanup work.

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

Options II through V would provide for the complete transfer of all tailings, contaminated soil, existing stabilization cover, contaminated materials, and rubble from the Green River tailings site to a disposal site. The mill buildings would be decontaminated with the exception of the sheds, which would be demolished. Removal to averages of 3 ft of subsoil beneath the tailings pile, 3 ft of soil from the former millsite, 1 ft of topsoil from the area of high radium content, and 6 in. from the windblown contaminated areas was assumed to reduce residual radium concentration to less than the required 5 pCi/g above background levels. Finally, the site would be backfilled to natural grade, appropriately restored, 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 tailings, and discussions with earthmoving contractors in the area, it appears that there would be no difficulty in removing the tailings from the tailings site. The contractor performing this work could use any number of conventional loading methods (e.g., front-end tractor loaders or conveyor belt feed to overhead loading). Since the base of the tailings pile is 20 ft above the elevation of and 0.5 mi away from the Green River, a system for dewatering the contaminated subsoil beneath the tailings during excavation is not expected to be required. There is ample room on site for fast loading and easy truck ingress and egress.

To eliminate any possible dispersion of tailings 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 onto the site, would be used as backfill. No special treatment of the final surface other than establishing native grass or providing a riprap cover at the decontaminated tailings site is considered in this assessment.

9.2.2 Transportation of the Materials

Various methods of transporting the tailings to the disposal sites were evaluated. Rail transportation was evaluated for Option V, and its estimated cost for the 30-mi distance was compared to the cost of a 30-mi haul by truck in Option IV. Because of the relatively small amount of tailings to be hauled, it appears that truck transportation would be the most economical means of transporting the tailings.

Slurry pipeline technology was also evaluated but was judged not to be feasible because of the high costs involved, the scarcity of water in the vicinity, and the need to dewater at the disposal site.

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

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

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

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

However, there are many complications involved in the use of conveyors, many of which are difficult to quantify. Public acceptance, acquisition of rights-of-way and permits within a reasonable time frame, and environmental impacts are factors which would have to be evaluated. With all of these factors considered, it appears that truck transportation of tailings and contaminated materials is preferable to the use of conveyors. At such time as a specific site is chosen, a detailed evaluation would disclose whether this generalization holds true for the selected site and routes.

Therefore, at the present time, truck transportation is judged to be the most economical means of hauling materials to the disposal sites. 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 3 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 would not be exceeded and that the state gasoline taxes would provide the needed revenues for such repair and maintenance.

The necessity of building railroad sidings and facilities at the loading and unloading sites cause Option V to be more costly than Option IV, even though the haul distances are the same and unit haul costs are less by rail.

9.2.3 Disposal at Alternative Sites

A discussion of proposed disposal sites is included in Chapter 8. Each disposal site has distinct 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 any of the disposal sites considered in this report will be selected. Nevertheless, an effort was made to quantify these differences based on the limited data available for each site and to show the costs that would result if the contaminated materials were actually disposed of at one of the four sites, as discussed in Chapter 8.

Vegetative cover presently does not exceed 30% of the surface area at any of the disposal sites, and average rainfall at all the sites is approximately 6 in./yr. All areas are accessible by using a combination of paved, gravel, and dirt roads. Where existing dirt roads must be upgraded for hauling the tailings by truck, the cost estimates include the construction of a gravel-based surface sufficient to handle the heavy loads.

The disposal sites selected can be isolated from drainage basins naturally or by dikes and drainage ditches. The procedure for depositing the tailings would involve removing as much cover material as possible from the site in a strip-mining operation, placing the tailings, and covering the tailings with previously removed and supplementary cover materials to a depth of at least 3 m. The stabilized disposal site would be gently sloped and contoured to minimize the potential for water erosion, and a riprap cap 0.3 m thick placed over the cover material to protect against wind erosion. Figure 9-2 is a schematic representation of how these disposal sites would be developed.

The costs of all options are shown in Table 9-1. The disposal sites associated with the various options are those presented in Chapter 8.

Moab, Utah, is the site of a large tailings pile that requires the addition of sandy material for stabilization. While costs have not been estimated for the possibility of transporting the Green River tailings to Moab, it is probable that the increased haul cost would be offset by the elimination of disposal site costs.

The estimated costs for disposal options range from about $6,800,000 for Option II to about $9,600,000 for Option V. In Options II through V, the estimated costs include cleanup of windblown tailings, decontamination of the millsite and the ore storage area at the Green River site, backfilling the decontaminated area at and around the Green River site, establishing a vegetative or riprap cover at and around the Green River site, emplacing the tailings at the disposal site, covering all tailings and contaminated materials at the disposal site with a 3-m depth of cover material, contouring the stabilized disposal site, placing a 0.3-m cap of riprap for erosion control, and health physics and radiological monitoring services at the disposal and present tailings sites during cleanup and disposal operations.

The costs for Options IV and V are considerably higher than the costs associated with Options II and III because the haul distances are much shorter for the latter two options and the haul costs (strongly dependent on distance) are important components of the total costs. The difference in cost between Option IV and Option V is mainly due to the difference in the mode of transporting the tailings to the disposal sites; the cost of Option IV is based on hauling the tailings by truck while the cost of Option V is based on the use of rail transportation. In this case, truck transportation appears to be the more economical method because the amount of tailings to be moved is relatively small and the capital costs of constructing railroad sidings and loading and unloading facilities must be amortized over the short project life. Also, the necessity of loading and unloading the tailings more than once is a factor that makes rail transportation appear less attractive.

There are also cost differences between disposal sites that can be attributed to varying requirements for upgrading access routes to the sites, preparing the sites, and protecting the emplaced tailings from erosion.

9.3 ANALYSES OF COSTS AND BENEFITS

9.3.1 Health Benefits

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

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

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

As an alternative to the presentation in Table 9-2, the number of potential cancer cases avoided per million dollars expended was calculated and plotted in Figure 9-3. Option I yields the maximum health benefit per unit cost, whereas Option V yields the minimum benefit per unit cost.

9.3.2 Land Value Benefits

Most of the land surrounding the Green River site is presently used for military purposes, and there are no foreseeable pressures to use the land for other purposes in the immediate future.

The presence of the tailings pile affects land usage and values only slightly. If the remedial actions of Option I (stabilization of the tailings in their present location) were taken, the tailings area would have limited future use but there would be little or no effect on the value of the balance of the site or on its surrounding areas.

If the remedial actions of Options II through V (disposal of the tailings at an alternative disposal site) were taken, the entire site could be released for unlimited use. However, this action also would apparently have little effect on the value of the site or on its surrounding areas.

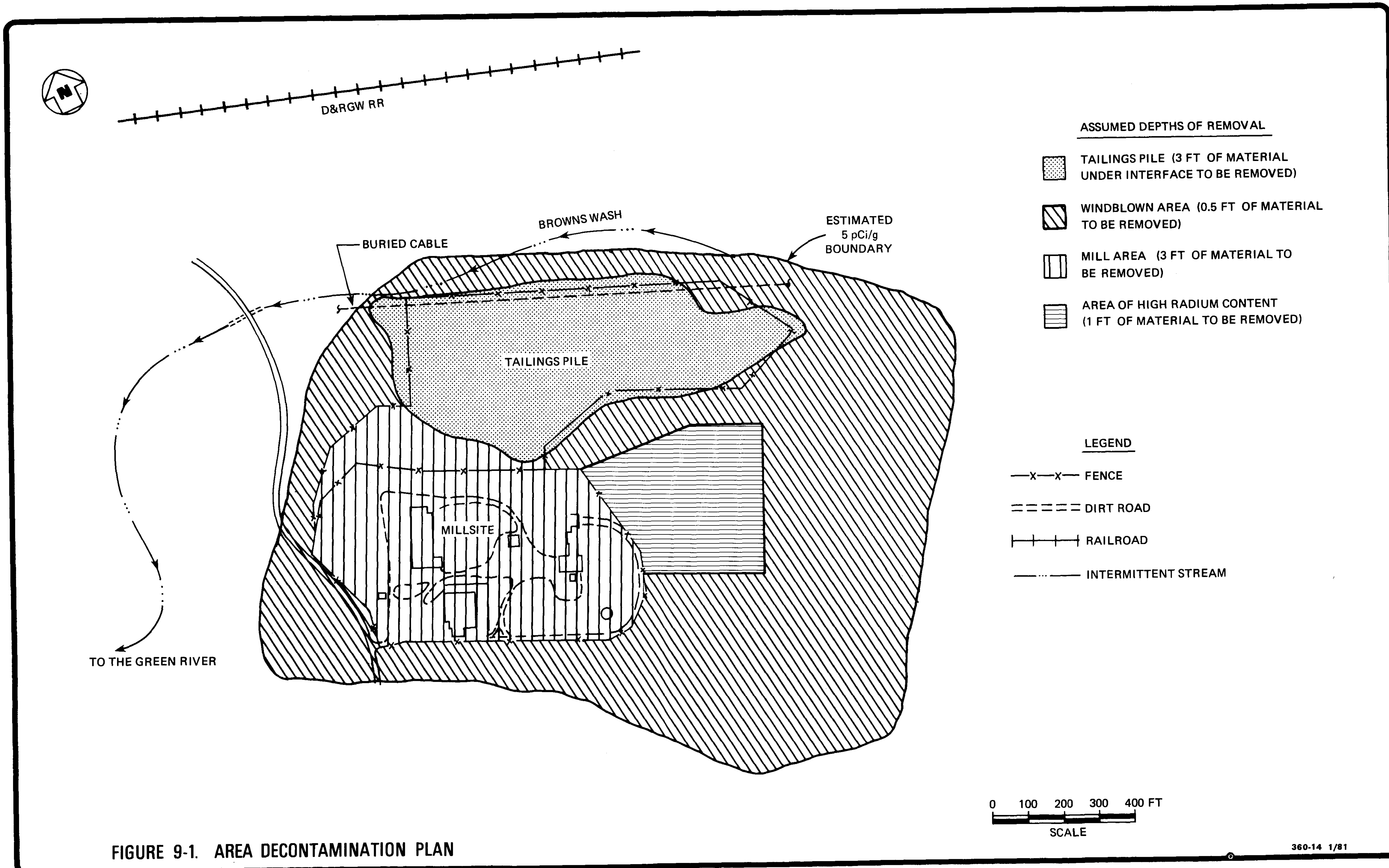

FIGURE 9-1. AREA DECONTAMINATION PLAN

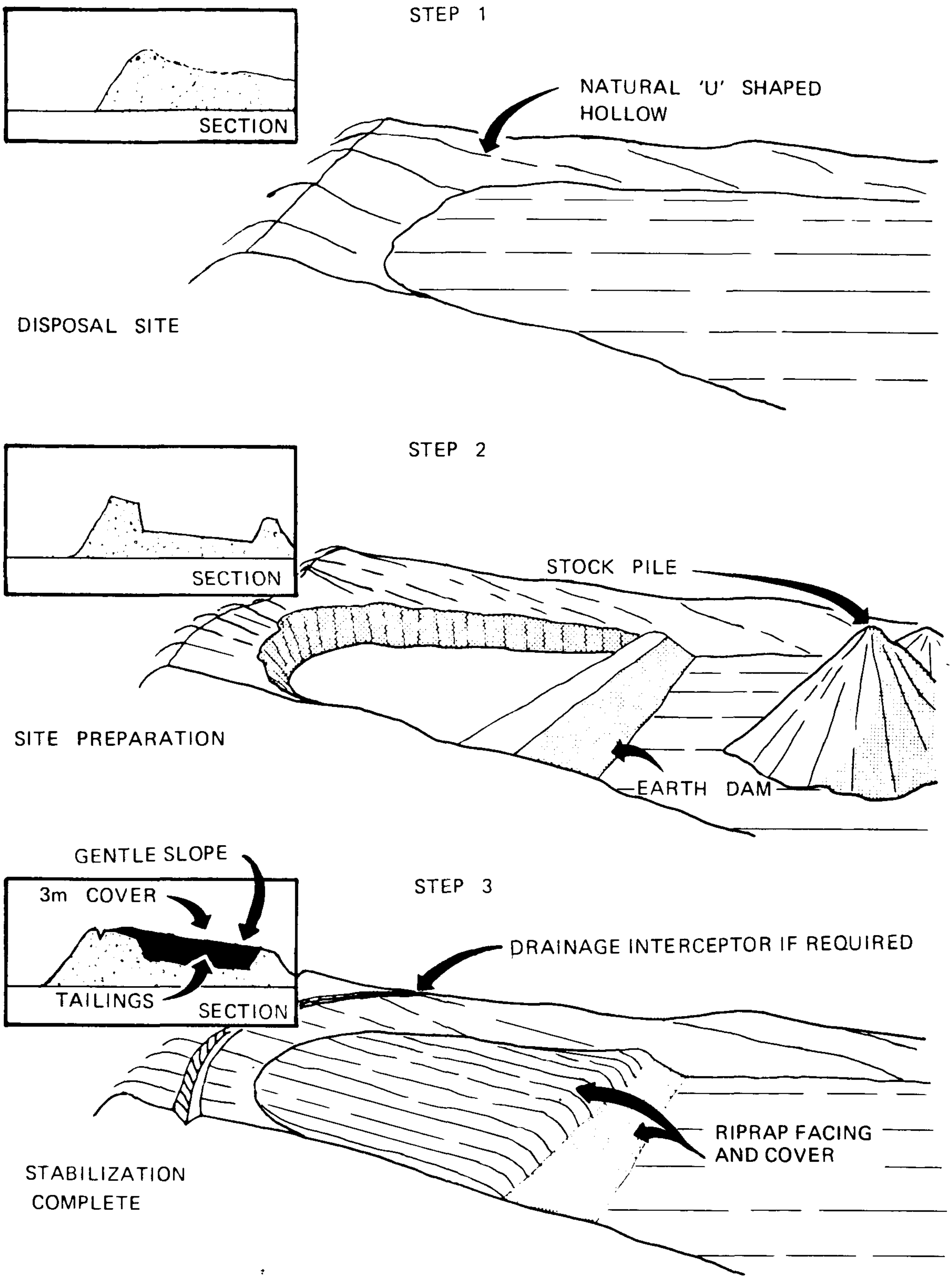

FIGURE 9-2. SCHEMATIC OF TYPICAL TAILINGS DISPOSAL SITE

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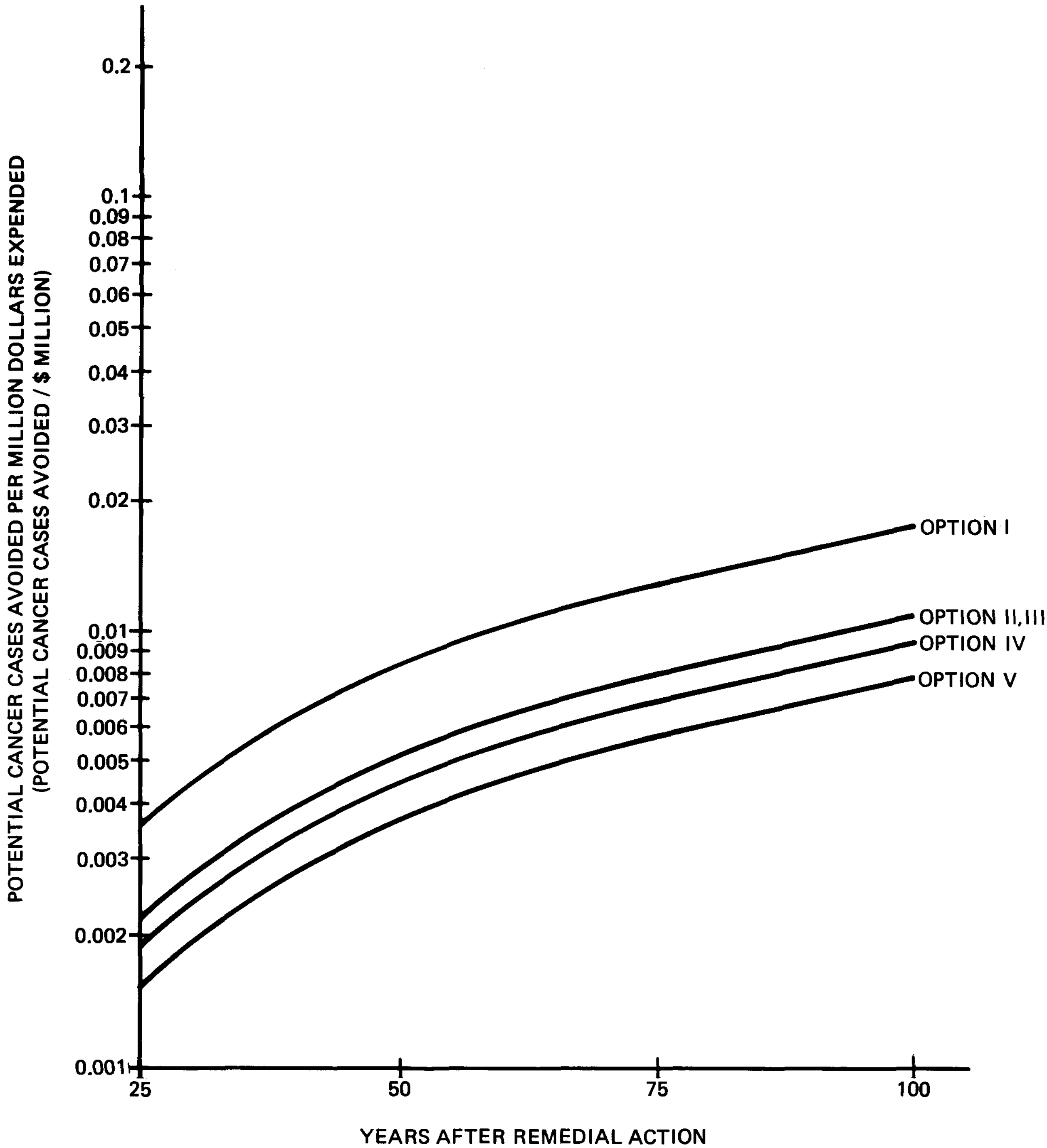

FIGURE 9-3. POTENTIAL CANCER CASES AVOIDED PER MILLION DOLLARS EXPENDED

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TABLE 9-1

SUMMARY OF STABILIZATION AND DISPOSAL COSTS[a]

		Options				
		I	II	III	IV	V
1.	Tailings Site Costs	2.3	1.7	1.7	1.7	2.0
2.	Off-Site Other than Windblown	0.1	0.1	0.1	0.1	0.1
3.	Off-Site Windblown	0.2	0.2	0.2	0.2	0.2
4.	Transportation					
	a. Capital Costs	--	0.8	0.8	0.1	1.0
	b. Haul Costs	--	0.8	0.9	1.8	1.5
5.	Disposal Site Costs	--	1.3	1.3	1.3	1.3
6.	Total Cleanup[b] (sum of lines 1 through 5)	2.5	4.2	4.3	5.2	6.0
7.	Engineering Design and Construction Management (30% of the difference between lines 6 and 4b)	0.8	1.0	1.0	1.0	1.3
8.	Total[b] (sum of lines 6 and 7)	3.3	5.2	5.3	6.2	7.3
9.	Contingency (30% of line 8)	1.0	1.6	1.6	1.9	2.2
10.	GRAND TOTAL[b] (sum of lines 8 and 9)	4.3	6.8	6.9	8.1	9.6

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

[b]Totals may differ from the sum of the cost components because of round-off.

TABLE 9-2

POTENTIAL CANCER CASES AVOIDED AND COST PER POTENTIAL CASE AVOIDED

A. Number of Potential Cancer Cases Avoided

Options:	I	II	III	IV	V
Option Cost (million $)	4.3	6.8	6.9	8.1	9.6
Years After Remedial Action					
25	<0.015	0.015	0.015	0.015	0.015
50	<0.036	0.036	0.036	0.036	0.036
75	<0.056	0.056	0.056	0.056	0.056
100	<0.077	0.077	0.077	0.077	0.077

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

Options:	I	II	III	IV	V
Option Cost (million $)	4.3	6.8	6.9	8.1	9.6
Years After Remedial Action					
25	>287	453	460	540	640
50	>194	189	192	225	267
75	> 77	121	123	145	171
100	> 56	88	90	105	125

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

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

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

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

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

riprap
: An irregular protective layer of broken rock.

roentgen (R)
: A unit of exposure to ionizing radiation. It is that amount of gamma or X-rays required to produce ions carrying 1 electrostatic unit of electrical charge, either positive or negative, in 1 cubic centimeter of dry air under standard conditions, numerically equal to 2.58×10^{-4} coulombs/kg of air.

sands
: Relatively coarse-grained materials produced along with the slimes as waste products of ore processing in uranium mills (see tailings). These sands normally contain a lower concentration of radioactive material than the slimes.

scintillometer
: A gamma-ray detection instrument normally utilizing a NaI crystal.

slimes
: Extremely fine-grained materials mixed with small amounts of water, produced along with the sands as waste products of ore processing in uranium mills (see tailings). The highest concentration of radioactive material remaining in tailings is found in the slimes.

tailings
: The remaining portion of a metal-bearing ore after the desired metal, such as uranium, has been extracted. Tailings also may contain other minerals or metals not extracted in the process (e.g., radium).

UMTRA
: Uranium Mill Tailings Remedial Action

working level (WL)
: A unit of radon daughter exposure, equal to any combination of short-lived radon daughters in 1 liter of air that will result in the ultimate

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

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