ENGINEERING ASSESSMENT OF INACTIVE URANIUM MILL TAILINGS

EDGEMONT SITE
EDGEMONT, SOUTH DAKOTA

MAY 1978

PREPARED FOR

U.S. NUCLEAR REGULATORY COMMISSION
WASHINGTON D.C. 20555

BY

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SINCE 1894

LEGAL NOTICE

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375 Chipeta Way
Salt Lake City, Utah 84108

FB&DU 211F

ABSTRACT

Ford, Bacon & Davis Utah Inc. has performed an engineering assessment of the problems resulting from the existence of radioactive uranium mill tailings at Edgemont, South Dakota. The assessment included core drillings and radiometric measurements sufficient to determine areas and volumes of tailings and other radioactively contaminated materials, the evaluation of resulting radiation dose commitments to individuals and nearby populations, the investigation of site hydrology and meteorology and the evaluation and costing of alternative remedial actions.

Residents of Cottonwood Community receive dose commitments from the Edgemont site by inhalation of radon gas and radioactive particulates and from external gamma radiation. Residents of Edgemont receive dose commitments primarily through inhalation of radon diffusing from the tailings site.

The six alternative remedial actions presented range from stabilization of the tailings at the present site and decontamination or demolition of the mill buildings (Alternatives I and II) to removal of the tailings and all contaminated materials to an alternate disposal site, leaving the present site available for unrestricted use (Alternatives III through VI). Four alternative sites were selected as possible disposal sites for the tailings. Estimated costs for the first two alternatives are $6,110,000 and $7,270,000, and costs for moving the tailings to alternative disposal sites range from $10,790,000 to $18,970,000. Costs of remedial actions at off-site structures were estimated at $200,000.

Reprocessing of the tailings for uranium does not appear to be economically attractive at present.

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GLOSSARY

Abbreviations/Terms	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 material. 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 radiation (α, β, γ), hence is not dangerous unless alpha-emitting substances have entered the body.
amenability	The relative ease with which a mineral(s) can be removed from an cre 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 a large gamma-ray detector exceed the determined background for that area by 50 or more c/s.
aquifer	A water-bearing formation below the surface of the earth; the source of wells. A confined aquifer is overlain by relatively impermeable rock. An unconfined aquifer is one associated with the water table.
atmospheric pressure	Pressure exerted on the earth by the mass of the atmosphere surrounding the earth; expressed in inches of mercury (at sea level and 0°C, standard pressure is 29.921 in. Hg).
background radiation	Naturally occurring low-level radiation to which all life is exposed. Background radiation levels vary from place to place on the earth.
beta particle (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.
Ci	Curie (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).
EGR	External gamma radiation (gamma radiation emitted from a source(s) external to the body, as opposed to internal gamma radiation emitted from ingested or inhaled sources).
EPA (USEPA)	Environmental Protection Agency.
ERDA (USERDA)	Energy Research and Development Administration.
ERDA-GJO	Energy Research and Development Administration-Grand Junction Office.
erg	The basic unit of work or energy in the centimeter-gram-second.

	system (1 erg is equal to 7.4 x 10^{-8} ft-lb).
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.
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	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 Drinking Water Standards (EPA)	Title No. 40 of the Code of Federal Regulations, Chapter 1, Part 141, dated Dec 24, 1975; scheduled to become effective Jun 24, 1977.
iso-exposure line	A line drawn on a map to connect all points having the same exposure rate.
isotope	One of two or more 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.
μR/hr	Microroentgen per hour.
mR/hr	Milliroentgen per hour.
MeV	Million electron volts.
MPC	Maximum permissible concentration (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.

PHS (USPHS) — Public Health Service.

QF — Quality factor (an assigned factor which denotes the modification of the effectiveness of a given absorbed dose by the linear energy transfer).

R — Roentgen (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).

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 gamma background.
radon	A radioactive, chemically inert gas, having a half-life of 3.8 days (^{222}Rn); formed as a daughter product of radium (^{226}Ra).
radon background	Low levels of radon gas found in an area, due to the presence of 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).
RDC	Radon daughter concentration (the concentration in air of short-lived radon daughters, expressed usually in pCi/l; also measured 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/cm^2-sec).
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	(Acronym of roentgen equivalent man). The unit of dose 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 wall of broken rock, placed as a retaining wall, as a protection for dikes, etc.
risk estimator	Absolute - the number of excess (radiation related) cases of cancer per unit of time in an exposed population of a given size per unit of dose, using the linear dose-incidence model. Relative - the ratio between the cancer incidence risk in the exposed population and the cancer incidence risk if no radiation exposures occurred, per unit of dose. This assumes the radiation risk increases in direct proportion to the natural risk.
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 less radioactive materials 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). Most of the radioactive material

remaining in tailings is found in the slimes.

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

WL — Working level. 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 1.3×10^5 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.

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

CHAPTER 1

SUMMARY

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1.1 INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC), through an interagency agreement with the U.S. Department of Energy (DOE), has contracted with Ford, Bacon & Davis Utah Inc. (FB&DU) of Salt Lake City, Utah, to provide architect-engineering services in the assessment of the problems resulting from the existence of large quantities of radioactive uranium mill tailings at the Edgemont, South Dakota uranium millsite. This assessment effort has been similar to the Phase II - Title I studies of 22 inactive uranium mill tailings sites in 8 western states recently conducted by FB&DU for the U.S. Energy Research and Development Administration (ERDA), now part of the DOE. However, since the NRC is planning to use this assessment as part of the technical basis for a future licensing decision regarding this site, the present assessment of the Edgemont site has been based on an expanded scope of work in areas such as hydrology studies and in radiological pathway analyses.

The problems relating to the presence of uranium tailings at he Edgemont site are similar to those at many of the 22 above-entioned inactive uranium millsites. To determine the extent f those problems, a preliminary survey of inactive uranium mill tailings sites in the Western United States (Phase I) was carried out by AEC in cooperation with the EPA and the affected states. That survey was completed in October 1974. In the Summary Report[1] on the findings of the survey, 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) to the list for a total of 22 sites. Most of the mills at these sites produced by far the greatest part of their outputs of uranium under contracts with the U.S. Atomic Energy Commission (AEC) during 1947 through 1970. After operations ceased, some companies made no attempt to stabilize the tailings, while others did but with varying degrees of success.

Before the Phase II - Title I program, studies of radiation levels on and in the vicinities of the 22 sites had been limited in scope. The data available were insufficient to permit assessment of risk to people with any degree of confidence in the conclusions reached. In addition, information on practicable measures to reduce radiation exposures and estimates on the projected

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[1] See end of chapter for references.

costs of the measures were limited. Also, concern was increasing 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. Thus the purpose of the Phase II - Title I study was to develop the necessary information that would provide a basis for decision-making for appropriate remedial actions for each of the 22 sites.

Although the Edgemont uranium mill was inactive the source material license SUA-816 and responsibilities associated with it were transferred to the Tennessee Valley Authority (TVA) after purchase of the site by the TVA in August 1974. The TVA applied for timely renewal of SUA-816 in January 1976. Personnel at the site have performed measurements of radiological effluent releases and have reported these data to the NRC semiannually (in accordance with Code of Federal Regulations, Title 10, Section 40.65).

In assessing the significance of the conditions existing at the Edgemont site, evaluations of the following factors were included:

(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 metals from the tailings

Investigation of these and other factors led to the detailed evaluation of several alternatives. These may be placed within two main categories:

(a) Stabilization of the recontoured tailings designed for long-term storage at the present site

(b) Removal of the tailings to alternative disposal sites suitable for long-term storage and stabilization

The estimated costs of carrying out the remedial work to implement each alternative depend on such parameters as the degree of decontamination to be achieved, disposition of the mill buildings, stabilization materials availability, and haul distances. The goal of the remedial actions is to meet as many of the NRC performance objectives for tailings management as possible. These objectives as given in Reference 2 are as follows:

(a) Siting and Design

(1) Locate the tailings isolation area remote from people such that population exposures would be reduced to the maximum extent reasonably achievable.

(2) Locate the tailings isolation area such that disruption and dispersion by natural forces is eliminated or reduced to the maximum extent reasonably achievable.

(3) Design the isolation area such that seepage of toxic materials into the ground water system would be eliminated or reduced to the maximum extent reasonably achievable.

(b) During Operations

(4) Eliminate the blowing of tailings to unrestricted areas during normal operating conditions.

(c) Post Reclamation

(5) Reduce direct gamma radiation from the impoundment area to essentially background.

(6) Reduce the radon emanation rate from the impoundment area to about twice the emanation rate in the surrounding environs.

(7) Eliminate the need for an ongoing monitoring and maintenance program following successful reclamation.

(8) Provide surety arrangements to assure that sufficient funds are available to complete the full reclamation plan.

It should be noted that all of these objectives must be satisfied for tailings management programs for new milling operations. However, during the course of license renewal reviews, the locations of existing tailings areas are reviewed considering objectives 1 through 3 to determine if sufficient cause exists to require an alternate disposal location for tailings generated by future milling operations and the relocation of existing tailings at the time of mill decommissioning. The NRC decided that in the Edgemont assessment, therefore, objectives 5, 6, and 7 were mandatory goals and that consideration would be given to objectives 1 through 3 in determining whether to move or reclaim the Edgemont tailings in place.

1.1.1 Scope of the Edgemont Engineering Assessment

As indicated previously, this assessment is similar in scope to the Phase II - Title I assessment performed by FB&DU for ERDA, but also has included additional work in specific areas. In general, the scope requirements of the Phase II - Title I assessment as given in the contract included the following items:

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

(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 clean-up or decontamination.

(f) Determination of the adequacy and the environmental suitability of sites to which mill tailings containing radium can be moved for long-term (>50 yr) storage; and once such sites are identified, perform evaluation 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. Availability of suitable stabilization cover material was also determined.

(i) 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

(j) Investigation of site hydrology and meteorology.

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

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

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

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

Not all of the above items were included in the scope of the Phase II - Title I work at each site. In the Edgemont assessment, however, each of these items was addressed in varying detail, and the following additional items were included:

(o) Original work was performed on the hydrology of the Edgemont site.

(p) Dose commitments were calculated for the population and for the maximum individual in the Edgemont vicinity for each of the pathways of radionuclides to man. (Note that under Phase II - Title I, health effects resulting from the tailings piles via inhalation of radon daughters were estimated from epidemiological data on lung cancer in miners. This Edgemont site assessment includes a similar approach to estimation of health effects for a comparison with the Phase II - Title I assessment results.)

(q) Costs for mill structure decontamination and for destruction and burial were estimated.

(r) Alternative tailings reclamation plans were developed which would meet current NRC criteria (tailings management performance objectives). When the alternative plan involved an alternate storage site the siting and design performance objectives were given full consideration.

1.2 SITE DESCRIPTION

1.2.1 Location and Topography

The Edgemont millsite and tailings area are located in southwest South Dakota immediately east of the City of Edgemont, in Fall River County, some 85 mi southwest of Rapid City, South Dakota. Figure 2-1, Chapter 2, is a photograph showing the relationship of the site to the surrounding area. Cottonwood Community, along Cottonwood Creek, is adjacent to the west side of pond 7 and south of the mill building.

The site is in the Cheyenne River Valley at an elevation of 3,450 ft above sea level, at the point where Cottonwood Creek empties into the Cheyenne River. It is in a broad area of gently rolling terrain about 3 mi southwest of the foothills of the Black Hills mountains.

Vegetation in the area is primarily grasses and sagebrush with native pines in scattered locations on the higher hills and cottonwood trees along the natural waterways.

1.2.2 Ownership and History of Milling Operations and Processing

The mill was constructed in 1956 and was operated by Mines Development, Inc., a subsidiary of Susquehanna-Western, Inc., of Chicago, Illinois. The initial capacity of 250 tons of ore per day, was expanded within a year to 500 tons/day.

The original process for uranium extraction from ore involved acid leaching, resin-in-pulp ion exchange, and neutralization of the pregnant solution with magnesium oxide to precipitate the yellow cake. A solvent extraction circuit was added in 1958 to use the Eluex process and later, ammonia was used for precipitation. Facilities for separating and recovering a molybdenum byproduct were added to the circuit as sufficient amounts of molybdenum became present in the lignite ash that also was processed for uranium. In 1960, a vanadium circuit was added and additional vanadium was recovered from reclaimed resin-in-pulp (RIP) slime tailings by acid leaching and solvent extraction.

Uranium recovery initially averaged 95% but towards the end of operations averaged about 90%. Vanadium recovery from the ore was 75 to 80%. The U_3O_8 content of the ore averaged 0.20%

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1.2.1 Location and Topography

The Edgemont millsite and tailings area are located in southwest South Dakota immediately east of the City of Edgemont, in Fall River County, some 85 mi southwest of Rapid City, South Dakota. Figure 2-1, Chapter 2, is a photograph showing the relationship of the site to the surrounding area. Cottonwood Community, along Cottonwood Creek, is adjacent to the west side of pond 7 and south of the mill building.

The site is in the Cheyenne River Valley at an elevation of 3,450 ft above sea level, at the point where Cottonwood Creek empties into the Cheyenne River. It is in a broad area of gently rolling terrain about 3 mi southwest of the foothills of the Black Hills mountains.

Vegetation in the area is primarily grasses and sagebrush with native pines in scattered locations on the higher hills and cottonwood trees along the natural waterways.

1.2.2 Ownership and History of Milling Operations and Processing

The mill was constructed in 1956 and was operated by Mines Development, Inc., a subsidiary of Susquehanna-Western, Inc., of Chicago, Illinois. The initial capacity of 250 tons of ore per day, was expanded within a year to 500 tons/day.

The original process for uranium extraction from ore involved acid leaching, resin-in-pulp ion exchange, and neutralization of the pregnant solution with magnesium oxide to precipitate the yellow cake. A solvent extraction circuit was added in 1958 to use the Eluex process and later, ammonia was used for precipitation. Facilities for separating and recovering a molybdenum byproduct were added to the circuit as sufficient amounts of molybdenum became present in the lignite ash that also was processed for uranium. In 1960, a vanadium circuit was added and additional vanadium was recovered from reclaimed resin-in-pulp (RIP) slime tailings by acid leaching and solvent extraction.

Uranium recovery initially averaged 95% but towards the end of operations averaged about 90%. Vanadium recovery from the ore was 75 to 80%. The U_3O_8 content of the ore averaged 0.20%

with a relatively low vanadium content of about 0.25% V_2O_5. The bulk of the uranium output was produced under contract with the AEC.

At one time nearly 10% of the ore feed to the Edgemont mill was uraniferous ash derived from the burning of lignite coal near Belfield, North Dakota. The lignites were burned at the mine site to an ash which then was shipped to the mill at Edgemont for extraction of the uranium. When properly burned, the ash contained an average of 0.35% U_3O_8 and 0.35 to 0.25% Mo. The ash also contained considerable amounts of clay, iron, residual organics, and various acid-consuming minerals which complicated the process and increased the cost of subsequent treatment.

Most of the ore processed at Edgemont was mined by the company on a lease basis. Mines were located mostly in the Black Hills area of southwestern South Dakota and northeastern Wyoming, but a considerable amount of ore was shipped from near Douglas, Wyoming, and some of the early shipments were from Washington State.

Uranium processing ended in 1972 and vanadium processing was shut down in August 1974, when the plant was purchased by the TVA.

1.2.3 Present Condition of the Site

The approximately 213-acre site currently is being used only as an operational base by the TVA for uranium exploration in the Edgemont area. No processing has occurred since 1974.

There are 13 buildings on the site with a total area of about 53,000 ft^2. Most of these buildings are in usable condition. However, the mill buildings would require considerable refurbishment to be usable. The water distribution system from an on-site well and storage tank is operable, also the sewage system which is serviced by the City of Edgemont. The site is fenced, and currently a new 6-ft-high chainlink fence is being installed around the site.

The mill produced approximately 2.3 million tons of solid uranium mill tailings, 80% of which were sand tailings and the balance slime tailings. These materials were deposited into 11 areas covering approximately 123 acres. These tailings piles or pond areas are in various sizes and shapes and are located south and east of the mill buildings. All but three tailings ponds are east of Cottonwood Creek. The numbered tailings locations are referred to as ponds although several of these areas are now stabilized with soil cover and vegetation. In 1972, a stabilization program was undertaken on two of the piles. The stabilization consisted of a 4-in.-thick crushed limestone cover topped with vegetation. Later, a 2-ft-thick total cover was added to the two piles and a cover of grasses, clover, and rye was planted. Attempts to stabilize the piles with vegetation, applied directly to the tailings, have proven ineffective, primarily because of

harsh weather conditions (insufficient summer moisture) and steepness of the banks, where severe erosion has washed away the plants and perhaps pH of the tailings.

About half of the tailings areas (or ponds) have been stabilized with 2 to 3 ft of earth cover obtained from the site. No imported material has been used. Tailings area B has only a thin cover of soil and is used as an ore storage area.

Dikes used to contain the tailings were constructed from on-site material. Some of the banks of these dikes are steep, and most show signs of increasing water erosion attributable to the lack of riprap aggregates (rocks) which would help prevent erosion. This condition is also true of stabilization material that has been applied on the piles; the stabilization has worked well on the level or gently sloping surfaces, but has suffered erosion on the steeper slopes.

Wind action has carried tailings off site, especially to the east of the eastern property line.

There are no formal surface drainage patterns which divert precipitation from rain or snow around the tailings and off the site. Consequently, there is erosion of the tailings onto roads and other areas and into surface ponds which are formed after a storm.

1.2.4 Geology

The millsite lies within the Missouri River plateau and the southwestern edge of the Black Hills uplift as shown in Figure 2-7, Chapter 2.

Alluvial deposits, including mud and siltstones, of the Cheyenne River, Cottonwood Creek, and other creeks exist along and within the lower river flood plain and creek beds as shown in Figure 2-8, Chapter 2. It is the combination of these sediments which underlie and separate most of the mill tailings deposits from the shale bedrock and unconfined water table aquifer of the site.

Stratigraphically, only sedimentary rocks exist in the area. These sedimentary layers range in age from early to late Cretaceous overlain by Quaternary and some Tertiary age sediments.[3] Older pre-Cambrian rocks underlie the site at a depth in excess of 3,000 ft; younger Jurassic, Triassic, and Permian formations underlie the Cretaceous about 5 mi to the northeast of the site as shown on the cross-sections in Figure 2-7, Chapter 2.

Most of the formations exist in a conformable position at the site with only the New Castle sandstone believed to be missing. Some disagreement exists in the literature as to the exact stratigraphy of the site. Wells drilled near the site in 1945 and 1954 identified the upper shale layer as Skull Creek and Mowry shale, respectively. Other references[3,5] defined the upper shale as the Belle Fourche shale. (See Figure 2-7, Chapter 2.) Observations by FB&DU personnel during site investigations and drilling operations favored the descriptions of the Belle Fourche and/or

Mowry shale with the dark-grey siltstones and limestone concentrations. A detailed distinction between the formations was not made since it was not believed to be critical to the scope of the study.

Occasionally, weathered or fractured shale provides pathways for waterborne contamination to aquifers even though the formation is considered to be impermeable. Nevertheless, the shale sequence existing beneath the site was found to be very consolidated and highly impervious. The upper shale apparently acts as an aquiclude and prevents or minimizes downward migration of ground water. Likewise, the shale combination could inhibit upward migration of deeper confined waters.

1.2.5 Surface Water Hydrology

The Cheyenne River, which passes immediately north of the mill tailings site, drains an area of approximately 7,140 mi^2 upstream from the site and 9,100 mi^2 above the reservoir encompassing parts of South Dakota, Wyoming, and Nebraska.[3] All streams in this recharge basin are tributary to the river. Data from USGS WATSTORE indicate that the river had year-round flow only during 7 yr from 1947 through 1976. The river is impounded at the Angostura Reservoir, located some 15 mi east of the site.

Cottonwood Creek, which passes directly through the site, does not have a historic flow record. However, measurements taken during November 1977 from two rectangular and one 90°-V notch weirs showed an average flow rate near 280 gal/min.

Additional sources of surface flow to the site are from: the sewage outfall line (intermittently when the system breaks down), city well and mill fire safety tank which form a combined discharge at the pumphouse just north of the ore stockpile areas; overflow from the Edgemont City Park well and pond entering the site immediately south of sand tailings area A; potential seepage from ponded waters in tailings ponds on the site, and from both direct and ponded precipitation runoff. Figure 2-11, Chapter 2, shows the surface drainage and ponded areas of the site.

Potential means whereby surface waters near the site could be contaminated by mill tailings are:

(a) Physical transport by runoff or dike failure

(b) Seepage of ponded waters through the dikes or pond basins into surface water courses

(c) Erosion of tailings dikes or sand tailings piles adjacent to the Cheyenne River or Cottonwood Creek

(d) Discharge of process/sewage/wash-well waters

Physical transport of tailings off site is evident and is a potential threat at almost every pile and pond. Eroded tailings

can easily reach Cottonwood Creek from sand tailings area A and the East sand tailings pile, and possibly from sand tailings area B, although a dike has been constructed to prevent drainage into Cottonwood Creek.

Ponded waters are common on site, especially after a rainfall. Although annual evaporation exceeds precipitation, water trapped in broad surface areas in tailings ponds collects in the smaller lower areas and does not entirely evaporate in a year's time. The hydraulic head varies considerably in these ponds, and at pond 7 results in a seep to the west of the pond at times of high pond levels.

Physical transport of tailings due to flooding of the Cheyenne River or Cottonwood Creek is possible. Surface runoff is a relatively low percentage of yearly precipitation, less than 20%.(3) The meandering Cheyenne River channel is braided and its flood plain is broad; but the flood stages can reach the base of the tailings in ponds 1 and 2. The riverbed in the reach containing the tailings is at elevations of 3,412 to 3,416 ft above sea level, whereas the base of the tailings is near 3,425 ft; therefore, the potential of flooding from either an intermediate flood (25-yr) or a more severe probable maximum flood is moderate. A maximum flow of 13,800 ft^3/sec was recorded at Edgemont in 1971. Such a high flow could erode and undercut sections of the alluvial bank on which the northeastern corner of pond 2 is situated and could also undercut the bank underlying the northwestern corner of pond 1. A high continuing flow would be required to erode through the dikes and reach the tailings.

Since Cottonwood Creek drains approximately 150 sq mi, in the reach containing the mill tailings deposits, the stream has cut through the Cheyenne River alluvium and upper bedrock to reach levels ranging between 3,414 to 3,430 ft, leaving 10- to 30-ft-high banks at the site. During mill operations, the channel was straightened and covered in the vicinity of sand tailings area A and the East sandpile. The Cheyenne River and perhaps Cottonwood Creek are gaining streams during most of the year, meaning that they are partly recharged by unconfined ground waters along their paths. If there were seepage from the tailings ponds and piles into these waters, an impact on the creek and river waters could occur. However, this impact would be minimized by evapotranspiration and attenuation of the fine-grained soils and bedrock, and by the effects of sedimentation.

1.2.6 Ground Water Hydrology

Ground water exists throughout the Edgemont area and millsite, primarily in unconfined alluvial water table aquifers along the main drainage channels and in confined artesian aquifers located at depth in the more permeable formations. The primary unconfined aquifer in the area is the Quaternary alluvial deposit. Confined ground water in the vicinity is found in four principal aquifers: The Fall River, Lakota, Sundance, and Pahasapa formations, with the Fall River being the most common. Several deep artesian and

near surface wells exist throughout the area. Within and near the millsite two deep wells (greater than 2,300 ft) penetrate through the upper formations into the confined ground water; and even though thermal, the artesian waters are used by the City of Edgemont, Burlington-Northern Railroad, and the mill facility. A total of 26 monitor wells have been installed on the site into the unconfined alluvial aquifer and overlying sediments. The monitor wells are used to measure water level fluctuations and to obtain permeability and water quality data. None of the monitor wells are sources for domestic use.

Attempts to utilize the upper Cretaceous shales as producing aquifers in nearby off-site areas have resulted in low yields and poor quality waters.(3) Most of the wells in the area are located in the alluvial deposits (unconfined aquifers) along the larger streams and comprise the most important existing and future water supply zone. This is primarily attributable to accessibility of the water, adequate amount and quality of the water, and lowest cost outlay due to the shallower drilling depths. This is significant since the existing and future flood plain alluvial wells within the Cheyenne River flood plain downstream from the millsite have a potential of being contaminated from the recharging downgradient migrating surface and ground waters.

As noted, the Fall River sandstone aquifer is the largest producing aquifer in the Edgemont quadrangle and Fall River County. The significance of understanding the general characteristics of the Fall River formation is that the aquifer represents the uppermost confined ground water zone with a potential for contamination from migrating contaminated seepage. The aquifer extends beneath the entire millsite at a depth near 260 ft. The potential for contamination is very low because of the overlying 260 ft of highly impervious shales.

Ground water characteristics specific to the site were determined by evaluation of existing data from: referenced reports; on-site information from TVA; mill rec rds; and FB&DU field observations, permeability testing, data evaluations, and model calculations. A piezometric surface (water level) and flow direction of the unconfined aquifer was established across the site. An average flow gradient of about 1.5% in a north-northwesterly direction was determined. Water levels in the monitor wells were measured using an electronic M-scope-type meter.

Evaluation of the data indicates that the horizontal permeability coefficient ranges between a high of 6.0×10^{-2} cm/s in test well M-13 to a low value of 1.83×10^{-5} cm/s in test well PH-1. Model calculations were used to determine diffusion characteristics of the unconfined ground water. A flow velocity of 1.7 m/yr (5.6 ft/yr) was calculated as the horizontal flow velocity between pond 7 and Cottonwood Community. The INTERA hydrological code was used to calculate specific velocity values throughout the site.

In conclusion, based on the test data and model calculations, the unconfined ground water characteristics of the site can be

defined as an anistropic, semi-heterogenous medium exhibiting a variable but overall low permeability range. Also, the vertical and horizontal flow velocities are considered very low when compared with the higher rate of flow in areas where coarse-grained, well-sorted, more isotropic aquifer conditions exist.

1.2.7 Meteorology

The climate at Edgemont is described as semiarid and temperate. Average annual precipitation at Edgemont is approximately 14 in.[4] with extreme variations in the area from less than 6 in. to more than 23 in. per year. The driest season is November-January, and the wettest season is May-August when between one-half and two-thirds of the precipitation falls as gentle rains or as high-intensity thunderstorms. Potential average annual evaporation is reported at approximately 37 in./yr.[5] However, in certain months, precipitation exceeds evaporation.

Long-term weather records are not available for Edgemont. Limited weather data are available from the Hot Springs Airport 23 mi east of Edgemont, for the period from 1956 through 1960. Weather data also were recorded at the Black Hills Army Ordnance Depot, 8 mi south-southwest of Edgemont from mid-1962 to mid-1967. Limited weather data are being collected at a station set up on pond 2 by TVA in 1977.

Regional winds tend to be northerly to northwesterly winds. A wind rose for Edgemont was constructed from the weather data recorded at the Black Hills Army Ordnance Depot.

1.3 RADIOACTIVITY AND POLLUTANT IMPACTS ON THE ENVIRONMENT

About 85% of the total radioactivity originally in uranium ore remains in the processing wastes after removal of the uranium because the radium and thorium, principal contributors to radioactive emissions, were not normally removed from the uranium ores during milling. 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 waste materials. Other isotopes of uranium and thorium and their daughter products also may be present depending upon the type of ore present. 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.

1.3.1 Radiation Exposure Pathways, Contamination Mechanisms, and Background Levels

The major potential evnrionmental routes of exposure to man are:

(a) Inhalation of ^{222}Rn and its daughter products resulting from the continuous radioactive decay of ^{222}Ra in the radioactive materials. Radon is a

gas which diffuses from the site. The principal exposure results from inhalation of the ^{222}Rn and Rn daughters. This exposure affects the lungs. For this assessment, no criteria have been established for an upper limit for radon concentrations in air. Generally, the pathway for radon and radon daughters accounts for the major portion of the exposure to the population from uranium tailings sites.

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

(c) Inhalation and ingestion of windblown materials. 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 water 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.

1.3.1.1 Radon Gas Diffusion and Transport

Radon gas concentration measurements at two background locations averaged 1.4 pCi/l. The ^{222}Rn measurements were made with continuous radon monitors for 7 days each. A week-long radon measurement in Cottonwood Community averaged 3.3 pCi/l. Radon concentrations reached background values about 0.7 mi to the west of the site.

Radon flux measurements performed with charcoal canisters at three locations off the site averaged 2.8 pCi/m^2-s. On site, the flux measurements ranged from 3 to 970 pCi/m^2-s.

In the mill office building, average ^{222}Rn concentration was 3.4 pCi/l during the 24-hr measurement period.

1.3.1.2 Direct Gamma Radiation

The external gamma radiation (EGR) measured at 11 background locations with a pressurized ion chamber counter averaged 13 μR/hr.

The highest gamma radiation rate measured on the site was 3,780 μR/hr on pond 1. Gamma rates greater than 1,000 μR/hr were measured on ponds 1, 2, 3, and 7. Measurements made on stabilized areas of the ponds indicated gamma rate reductions greater than an order of magnitude compared with unstabilized areas of the ponds.

Gamma rates reached background levels about 0.1 mi west and south of the site. In Cottonwood Community the gamma rate averaged

15 μR/hr above background. The gamma rates were still twice the average background rates, one-third of a mile southeast of the site where wind has carried tailings from the site. In the mill area, the gamma rates ranged from 26 to 190 μR/hr.

1.3.1.3 Radiation Measurements Inside Mill Structures

A preliminary radiological survey of the buildings on the Edgemont site was performed to determine the magnitude of the contamination of the structures and processing machinery. Measurements were taken of direct surface activity, gross smearable surface activity, and beta-gamma dose rates at 3 ft above the surface.

The measurements indicate alpha contamination levels ranging from 175 to 5×10^5 dpm/100 cm^2 with average contamination levels greater than 10^3 dpm/100 cm^2. This exceeds the NRC criteria for unrestricted use of such facilities for surface activity and fixed contamination. Generally, the areas of high smearable contamination were on or near highly contaminated processing equipment. Uncorrected surface dose rate measurements on the floor adjacent to the yellow-cake dryer indicated beta-gamma dose rates of 150 mR/hr at the surface. At 3 ft the dose rate in the dryer area reached 10 mR/hr. Surveys of the eroded concrete floors indicated alpha levels of 10^3 to 10^4 dpm/100 cm^2.

Surveys of the FeV building, the oil storage area, the garage, and other mill buildings indicated alpha levels ranging from 350 to 1,000 dpm/100 cm^2.

The alpha survey of the office building showed activities of 350 to 525 dpm/100 cm^2 on the floors, but little or no contamination was found on the vertical surfaces surveyed.

In general, contamination levels in buildings on the site exceeded the alpha activity permitted for release of the buildings for unrestricted use. Thus, the buildings would have to be decontaminated or demolished and buried.

1.3.1.4 Windblown Contaminants

The approximate extent of windblown contamination is outlined in Figure 3-9, Chapter 3. The location of the line was determined primarily from measurements made with a scintillation detector 1 ft above the ground surface with and without a 0.5-in.-thick lead shield between the detector and the ground. The difference between the two readings (Δ) is a measure of the extent of surface contamination.[6] Some difference in readings exists even at background locations as a result of natural radioactivity in the soil.

Soil samples were taken from the surface and 6 in. deep at 200-yd intervals along the gamma measurement traverses away from

the site. The extent of soil contamination is generally in agreement with the determination made with the scintillation counter and lead shield.

Model calculations, with model parameters adjusted to fit data taken by TVA, were used to determine air particulate concentrations in Edgemont and Cottonwood Community for the purpose of determining population dose by inhalation of radioactive particulates.

1.3.1.5 Surface and Ground Water Contamination

Water samples were collected from surface waters (Figure 2-11) and many wells on and off the site for radionuclide and chemical analyses. Location and depth of wells are shown in Figures 2-12, 13, 15, and 16. A radium balance in Cottonwood Creek indicated that the largest source of radium in the water is from the overflow of the pond in the city park in Edgemont. This water is from a city water well and flows into Cottonwood Creek upstream from the sand tailings area A. Similar balances were performed for ^{230}Th, Fe, V, Ba, Mo, sulfates, and total dissolved solids and they support the radium balance. Samples taken from the mouth of Cottonwood Creek, where it enters the Cheyenne River, in July, August, and November contained 1.55, 3.1, and $<$1.4 pCi/l, respectively.

Other than water from tailings ponds and drill holes, the highest concentrations of ^{226}Ra are found in water from the Edgemont water supply well (4.1 pCi/l), the well flowing into the pond in city park (4.3 pCi/l), and the Burlington-Northern well (3.6 pCi/l). The radium concentration in all the domestic wells sampled was below 1 pCi/l.

The average ^{226}Ra concentration in 4 samples from the Cheyenne River upstream from the site was 0.28 pCi/l, while the average concentration in 2 samples downstream from the site was 0.42 pCi/l. Cottonwood Creek inflow accounts for the major portion of this increase, but the increased ^{226}Ra in Cottonwood Creek is primarily from the overflow of the pond in the Edgemont city park.

1.3.1.6 Soil Contamination Beneath the Tailings

Soil samples obtained from auger holes and logs obtained from a gamma probe with a slotted lead collimator were used to determine the extent of leaching of ^{226}Ra into the soil beneath the tailings.

In general, ^{226}Ra contamination was found to an average depth of approximately 5 ft below the tailings-subsoil interface; however, the depth of contamination ranged from 2 to 13 ft in the holes tested.

1.3.1.7 Radium Concentration in Vegetation

Samples of pasture grasses were collected at several loca-

tions around the site and at a background location. Samples taken east of the site where windblown tailings are present ranged from 1.6 to 9.2 pCi of ^{226}Ra/g of dry grass. The other samples contained ^{226}Ra concentrations from 0.11 to 0.72 pCi/g of dry material. A tomato plant from Cottonwood Community and a grass sample from east of the site also retained relatively high concentrations of radioactive dust (0.71 and 0.3 pCi/g of dry weight). The area to the east of the site is cattle grazing land and windblown tailings enter the food chain through beef cattle that eat the grasses during the portion of the year that grazing occurs.

1.3.2 Potential Health Impact

1.3.2.1 Radiological Impacts from Background

Dose commitments to the population results from several background sources such as cosmic radiation, cosmogenic radioactivity, and terrestrial radioactivity. Background gamma radiation rates produce a dose rate of 114 mrem/yr and a population dose commitment of 230 man-rem annually in the 2,000 residents of Edgemont. Population dose commitments to residents of Edgemont from natural background pathways total about 250 man-rem to the whole body and lungs and 450 man-rem to the bone. Bronchial epithelium dose is about 2,400 man-rem, primarily from inhalation of radon.

Dose commitments to the population due to the Edgemont millsite are 8 to 16% of the natural background dose commitments for the whole body, bone, and bronchial epithelium. For the lungs, the population dose commitment due to the site is about 50% of the natural background dose.

Using a different approach to determining the health impact of the Edgemont tailings, the potential lung cancer risk in the population can be calculated from data on lung cancer incidence in miners versus exposure to radon and radon daughters. The number of potential lung cancer cases in the population of Edgemont from inhalation of radon daughters from the millsite is on the order of 0.01 cases per year. This is about 10% of the incidence resulting from inhalation of background concentrations of radon daughters.

Health impacts are discussed in detail in paragraph 3.5 and additional information on the calculation of dose commitments is presented in Appendix A.

1.3.3 Remedial Action Criteria

Radiological criteria established for this engineering assessment for possible remedial action at the site are divided into four categories: NRC guidelines for decontamination of facilities for unrestricted use, NRC performance objectives for post-operational reclamation of uranium tailings,[2] EPA guide-

lines for decontamination of open land areas adjacent to the tailings ponds,(7) and the Surgeon General's criteria applicable to structures with tailings underneath them or within 10 ft.

NRC guidelines for decontamination of facilities and equipment prior to release for unrestricted use are included in Appendix B of this report. The NRC performance objectives for uranium mill tailings management to reduce exposure of the public are listed in paragraph 1.1. The EPA guidelines for decontamination of open lands are provisional and were developed for purposes of the Phase II assessments. In this assessment they have been similarly applied to the cleanup of windblown tailings and are described in paragraph 3.6, Chapter 3. If the gamma levels are less than 10 μR/hr above background, the land may be released for unrestricted use.

The Surgeon General's criteria for cleanup of structures where tailings were used has been applied in the Grand Junction, Colorado remedial action program. These criteria are also included in Appendix B.

1.4 POPULATION AND LAND USE

Populated areas are located immediately west of the railroad that forms the western boundary of the Edgemont site. Cottonwood Community, with about 75 residents, is located adjacent to tailings pond 7 and south of the mill building.

From population studies in 1975, it is estimated that approximately 2,000 people live within 1 mi of the Edgemont site, mostly west of the site. A map indicating the population distribution around the site is shown in Figure 2-5, Chapter 2.

The millsite is off the main highway (U.S. 18) and located east of town where no commercial growth has taken place. A railroad switchyard is adjacent to the site on the west, and northward expansion of Cottonwood Community is blocked by the site. To the east of the site is the City of Edgemont sewage pond which would also limit residential growth in that direction. Further to the east and south of the site are grazing and pasture land.

Both residential and commercial areas are growing primarily to the west of Edgemont. If the site were decontaminated and released for unrestricted use, it would probably be best suited for industrial use.

Bare land close to town is valued at approximately $2,000/acre. It is possible that the millsite. if released for unrestricted use, could rise to nearly this value. The proximity of the railroad switchyard and the sewage pond probably would prevent the land value from equalling that of residential lots in Edgemont.

1.5 RECOVERY OF RESIDUAL VALUES

Since there are 11 tailings locations at Edgemont with varying concentrations of uranium and vanadium, even within one pond, an estimate of the cost of recovering uranium and vanadium was made for only pond 7, which appears to have the highest concentration of uranium remaining in the tailings. Data from analyses by Hazen Research Laboratory and the TVA, and samples collected by FB&DU were considered in choosing the value of 0.013% U_3O_8 and 0.165% V_2O_5 in the dry tailings.

The approach used to determine the cost of extracting uranium from the tailings is that used in the Phase II - Title I reports.

There are five factors employed to evaluate whether reprocessing the Edgemont tailings to extract residual uranium and other mineral values would be practicable:

(a) The amount of tailings present

(b) Concentration of residual values

(c) Projected recovery

(d) Current market price of recovered values

(e) Proximity to processing mills

Based on the aforementioned criteria, reprocessing of the pond material with the highest concentration of uranium does not appear to be economically viable. The lowest cost for recovery of uranium was calculated to be $79/lb which would be reduced to $68/lb if vanadium recovery were used to offset part of the reprocessing costs.

1.6 MILL TAILINGS RECLAMATION

Goals for the tailings reclamation program include eliminating or minimizing seepage from the tailings, reduction of gamma radiation rates to background values, reduction of radon exhalation flux to twice the background value in the vicinity, and elimination of the need for a long-term monitoring and maintenance program.

Physical stabilization with clay, soil, and riprap can meet several of the performance objectives, such as gamma radiation and radon reduction through proper use of cover materials. Although chemical stabilizers have been tested, physical stabilization with clay and soil appears to be the most successful method for meeting the performance objectives. Stabilization at the present location will require reconfiguration of some of the piles and improvements in several of the pond dikes to reduce

seepage and protect against water erosion.

If the tailings are moved to a new site for storage or disposal, other objectives such as elimination of seepage from the ponds and location in areas remote from population can be met also.

1.7 OFF-SITE REMEDIAL ACTION

A mobil scanning unit, operated by the AEC under an interagency agreement with EPA, conducted a scanning survey in the Edgemont area in 1971. In 1972, field survey teams, consisting of personnel from the EPA and the State of South Dakota, performed gamma-screening surveys of locations suspected of contamination reported in the 1971 survey. Of the 56 structures scanned, uranium tailings or possible use of tailings were found at 25 locations within 10 ft of a structure in Edgemont and at one location in Provo. At 18 other locations, tailings were found more than 10 ft from structures or on vacant land; however, these locations are not covered under the Grand Junction Remedial Action Criteria specified for this assessment. The 1972 surveys were completed prior to aquisition of the site by the TVA in 1974.

Based upon remedial action costs at Grand Junction, Colorado, a cost of $200,000 was estimated to conduct the off-site remedial actions in Edgemont and Provo, South Dakota.

The extent of remedial action for open lands was determined by soil analyses and by survey techniques using a scintillation counter. The cost for cleanup to no more than twice background radium soil concentration in the vicinity is estimated at $50,000 without engineering costs and contingency.

The costs for remedial action for open lands and for structures are not included in the total costs for on-site remedial action alternatives.

1.8 ALTERNATE DISPOSAL LOCATIONS

Four of the remedial action alternatives include moving the Edgemont tailings to an alternate disposal site. The sites were selected after consultation with local and federal agencies, concerned individuals, and personnel in industry. Each site was evaluated on the basis of hydrology, meteorology, geology, ecology, economics, and proximity to transportation routes, the existance of a mill, possible future mills, and population centers. The 4 sites used in the alternatives were selected from a total of 15 sites initially considered.

The sites referred to in Table 1-1 under Alternatives III through VI are shown in a map in Figure 8-1, Chapter 8. The goal at each of these locations would be to meet the NRC performance

objectives for tailings management to prevent re-entry of radioactive and chemical contaminants into the environment. In all alternatives, a limited monitoring and maintenance program would be required until such time that the successful completion of the reclamation program could be assured. Land occupied by reclaimed tailings might have to be deeded to the state or to a federal agency for long-term land use control.

1.9 REMEDIAL ACTIONS AND COST-BENEFIT ANALYSES

1.9.1 Remedial Action Options

The many alternative remedial actions evaluated for solution to the problems associated with the radioactive tailings and other contaminated materials may be condensed into two major categories:

(a) Stabilization of the piles in place at the Edgemont site, with demolition and/or decontamination of the buildings and decontamination of the millsite.

(b) Removal of the tailings and other contaminated materials from the Edgemont site to an off-site disposal area, with demolition and/or decontamination of the buildings and decontamination of the millsite. The goal of these alternatives would be to leave the Edgemont site available for unrestricted use.

Of the many potential approaches to remedial actions for the Edgemont site, six alternatives were considered to be viable: Alternatives I and II are considered to be in category (a), and Alternatives III through VI are in category (b) above.

The evaluation of all available data on costs of processing projections for the uranium industry leads to the conclusion that reprocessing of the Edgemont tailings is not economically viable at this time. Consequently, none of the six practicable alternatives presented in this assessment report consider the estimated costs of reprocessing of the tailings.

Several of the remedial measures are common to all the alternative approaches costed; these measures were considered but not included in the total cost of each alternative because they were relatively low in relation to the total cost of the remedial action and are roughly equivalent for each alternative. For example, in all of the alternatives, monitoring and maintenance will be required until such time as successful completion of the site reclamation program can be demonstrated.

No acquisition costs for the alternative disposal sites are included in the cost estimates. The costs of off-site remedial actions for cleanup of windblown tailings are not included, although they would be roughly the same for all alternatives.

Several of the performance objectives formulated by the NRC for the siting and stabilization of uranium mill tailings can be met by long-term storage of radioactive materials on the Edgemont site, if proper stabilization is implemented. It should be possible to meet all applicable objectives if the tailings are relocated. In every alternative, the performance objectives have been considered in formulating the remedial actions.

1.9.2 Cost-Benefit Analyses

As summarized in Table 1-1, the total costs to implement the remedial actions vary from a low of $6,110,000 for Alternative I to a high cost of $18,970,000 for Alternative V. Each of the six alternatives would yield a distinct health benefit and monetary benefit (in terms of reclaimed land available for unrestricted use). The calculated number of cancer cases avoided per million dollars expended is given in Figure 9-2, Chapter 9. Alternatives I through VI are described briefly in Table 1-1. The curves projected in Figure 9-2 indicate an increase in the health benefit/cost ratio with time as a result of the number of cancer cases avoided. The potential number of cancer cases avoided for each option and the cost per potential cancer case avoided are given in Table 9-2, Chapter 9. Alternatives I and II yield the highest health benefits per unit cost. In contrast, Alternative V yields the lowest benefit per unit cost.

TABLE 1-1

SUMMARY OF ALTERNATIVES

Alternative No.	Description	Alternative Cost
I	Tailings remain on Edgemont site, mill structure demolition and burial, decontamination of millsite grounds, stabilization of pond/piles in place, erosion protection	6,110,000
II	Same as I, except tailings pond/piles consolidated prior to stabilization	7,270,000
III*	Complete site decontamination, removal of all tailings and other contaminated materials to site 2, 2.5 mi SE	10,790,000
IV*	Same as III, except tailings removed to site 6, 5.3 mi NW	15,525,000
V*	Same as III, except tailings removed to site 7, 10.6 mi NW	18,970,000
VI*	Same as III, except tailings removed to site 8, 12.4 mi NW	16,230,000

Notes: 1. All costs are in 1978 dollars.

2. The costs of the alternatives do not include the estimated costs for off-site remedial actions. These costs are the same for all alternatives and are $200,000 for off-site structures and $50,000 for off-site open lands.

*Involves removal of all contaminated materials from the Edgemont site to an alternate disposal site and includes the demolition of structures which remain, except the office building and mobile equipment shop.

CHAPTER 1 REFERENCES

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

2. NRC Branch Position on Uranium Mill Tailings Management; May 13, 1977.

3. R. C. Culler; Hydrology of the Upper Cheyenne River Basin; U.S. Geological Survey Water-Supply Paper 1531; 1961.

4. "Climatic Summary of the United States for 1951 through 1960 - South Dakota"; U.S. Department of Commerce; 1965.

5. J. R. Keene; "Groundwater Resources of the Western Half of Fall River County, South Dakota"; Report of Investigations No. 109; Science Center, University of South Dakota; 1973.

6. "Gamma Radiation Surveys at Inactive Uranium Millsites"; Technical Note ORP/LV-75-5; EPA; Las Vegas, Nevada; Aug 1975.

7. "Radiological Criteria for Decontamination of Inactive Uranium Millsites"; Attachment to letter from EPA; Dec 1974.

CHAPTER 2

SITE DESCRIPTION

CHAPTER 2

SITE DESCRIPTION

The purpose of this chapter is to describe the site at Edgemont, South Dakota, its ownership, history of operations, geology, hydrology, and meteorology, characteristics of the tailings areas at the site, and population distribution.

2.1 LOCATION

The Edgemont millsite and tailings area is located in Edgemont, Fall River County in Southwest South Dakota. It is 13 mi east of the Wyoming-South Dakota border, 27 mi southwest of Hot Springs, the county seat of Fall River County, and 85 mi southwest of Rapid City, South Dakota. It is immediately south of the junction point of Cottonwood Creek with the Cheyenne River. Portions of the site are within the eastern extremities of the Edgemont City corporate limits. Figure 2-1 is a photograph of the site and its relationship to Edgemont and other local geographic features.

The site is located in the southeast 1/4 of Section 36, Township 8 South, Range 2 East; the southwest 1/4 of Section 31, Township 8 South, Range 3 East; the east 1/2 of Section 1, Township 9 South, Range 2 East; and the west 1/2 of Section 6, Township 9 South, Range 3 East; all referenced to the Black Hills Meridian. More precisely, the northern portion of the mill area is located at 103 deg 49 min 10 sec west longitude and 43 deg 18 min 8 sec north latitude.

2.2 TOPOGRAPHY

The Edgemont millsite is located just south of the confluence of Cottonwood Creek and the Cheyenne River at an elevation of 3,450 ft above sea level. The immediate vicinity of the millsite consists of bottom lands and alluvial terraces which exhibit low relief. There is about an 80-ft grade difference between the low point and the highest elevation on the site. Across the Cheyenne River to the north is a broad area of gently rolling hills. Beyond this, the land breaks into rugged northwest-southeast trending ridges. About 3 mi to the northeast are the beginnings of the foothills of the Black Hills mountains. South of the mill, the land consists of northwest-southeast trending ridges traversed by Cottonwood Creek.

Vegetation in the site area is primarily native rangeland grasses made up of western wheat grass, buffalo grass, blue grama grass and sagebrush. On the ridges of higher slopes there are native pines in scattered concentrations. Cottonwood trees grow in abundance along natural waterways.

The total site area encompasses some 212.7 acres of which 121.4 acres are tailings areas. Figure 2-2 is a topographic map of the site that details site elevations and locations of the tailings ponds, Cottonwood Creek, and the Cheyenne River.

2.3 OWNERSHIP

The mill was constructed and operated by Mines Development, Inc. a subsidiary of Susquehanna-Western, Inc. of Chicago, Illinois.

The startup of their operational control was in July 1956. In August 1974, the Tennessee Valley Authority (TVA) purchased the mill, tailings area, and associated uranium properties; they are the current owners.

2.4 HISTORY OF MILLING OPERATIONS AND PROCESSING[1]

The discovery of uranium ore in South Dakota in 1951, and the location of an AEC ore buying station at Edgemont, South Dakota, eventually led to the construction of a mill at Edgemont. This mill went on stream in July 1956 with an initial capacity of 250 tons of ore per day. The mill was expanded to a capacity in excess of 500 tons per day within a year and facilities for the recovery of vanadium were installed in 1960. Uraniferous lignite ash from North Dakota was treated in the Edgemont mill from 1963 to 1967 in amounts up to 10% of the total mill feed. Facilities for processing vanadium-bearing materials containing little or no uranium were installed in 1970.

The original process for uranium extraction involved acid leaching, resin-in-pulp ion exchange, and neutralization of the pregnant solution with MgO to precipitate the yellow cake. A solvent extraction circuit was added in 1958 to use the Eluex process and ammonia was then used for precipitation. Facilities for separating and recovering a molybdenum by-product were added to the circuit when this was justified by sufficient amounts of molybdenum in the lignite ash. Vanadium was recovered from reclaimed and RIP slime tailings by acid leaching and solvent extraction. During the 1970's, vanadiferous iron slags were roasted, the calcine was water leached, and the solution was then combined with the other vanadium pregnant solutions in the mill.

Uranium recovery initially averaged 95%, but towards the end of operations averaged about 90%. Vanadium recovery from the ore was 75 to 80%.

Most of the ore processed at Edgemont was company mined on a lease basis. Mines were previously located in the foothill area of the Black Hills of southwestern South Dakota and in northeast-

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[1] See end of chapter for references.

ern Wyoming, but a considerable amount of ore was shipped from near Douglas, Wyoming, and some of the early shipments were from Washington State. The bulk of the uranium production at the Edgemont Mill was under contract with the AEC.

Ore from the Black Hills area is generally characterized as very amenable to the milling process employed. Host rock is medium- to fine-grained sandstone, not too well cemented, and moderately low in lime and in clay constituents. Most of the uranium is in the oxidized form and the principal ore mineral is carnotite with some tyuyamunite noted. The U_3O_8 content of the ore has averaged 0.20% with a relatively low vanadium content of about 0.25% V_2O_5.

At one time nearly 10% of the ore feed to the Edgemont mill was uraniferous ash derived from the burning of lignite coal near Belfield, North Dakota. The lignites were burned at the mine site to an ash which was shipped to the mill at Edgemont for extraction of the uranium. When properly burned, the ash contained an average f 0.35% U_3O_8 and 0.35 to 0.50% Mo. The ash also contained considerable amounts of clay, iron, residual organics, and various acid-consuming minerals which complicated and increased the cost of subsequent treatment.

2.5 PRESENT CONDITION OF THE SITE(2)

2.5.1 Facilities and Layout

The plant has not been in operation since August of 1974. A descriptive map of the site is shown in Figure 2-3. The facility is being utilized by the owner as an operational base for uranium exploration in the Edgemont area.

All of the structures remain on site with most of the processing and operational equipment still in place. The locations of the buildings are shown in Figure 2-4. The buildings are:

(a) The main mill building, a seven-section, steel-framed, galvanized metal exterior structure, containing almost 40,000 ft^2. This structure was utilized on a 24-hr-per-day basis for 18 yr, and the equipment has been sitting idle for at least 3.5 yr. As a result, the structure is in poor condition. The acid leach process caused erosion of most of the concrete flooring. The floor has many cracks and is in a dangerous condition as a work surface. It would require extensive repairs, or even a new floor for almost any use. The metal wall surfaces are rusted extensively in many locations, and the roof leaks in a few places. The structural-steel frame appears to be in a safe condition in spite of some rusting near the column foundations. The electrical system servicing all the mill equipment is in poor condition, and the panels and distribution

boxes are rusted. Most of the electric motors have been removed. The lights are still in working condition, but provide poor lighting. Most of the mezzanine floors and stairs are made of metal grating and are rusted, but otherwise appear to be sound. The fixed equipment, such as hoppers, belts, conveyors, lifts, etc., is in sound condition. Whether or not this equipment can be used again in the future would have to be determined on a need/condition analysis on an individual basis. Most of the wooden tanks are broken or have deteriorated and are completely useless at the present time.

(b) The "FeV" building, a 480-ft^2 metal-framed and galvanized metal exterior structure.

(c) The electric shop, a wood framed-sheet metal exterior building containing 576 ft^2.

(d) The office building, a single story masonry building containing 2,890 ft^2. This brick structure is in good condition since it has been in constant usage and kept in good repair. The building has several private offices with a central work area and a reception or central entry location and rest rooms. A rear entry provides access to the mill building and to a laboratory also located in the building.

(e) The crusher and sampling building, a metal, two-section building of 1,824 ft^2.

(f) A wood frame, metal exterior storage shed in the mobile equipment compound containing 432 ft^2.

(g) A railroad car shaker building which is steel-framed with metal siding containing 2,040 ft^2.

(h) The fly ash pump house, a wood-framed building with metal siding containing 204 ft^2.

(i) The reagent warehouse, an all-metal building containing 1,120 ft^2.

(j) The mobile equipment shop building, an all-metal building of 1,840 ft^2.

(k) The scale house, a metal building of 740 ft^2.

(l) The lime plant, a metal building of 440 ft^2.

(m) The carpenter shop, a metal building of 720 ft^2.

The total area of all these buildings is 52,790 ft^2 and approximately 13 acres are utilized for these structures. The structures are mostly in fair condition with some having concrete and others dirt floors. The buildings were designed and built for specific milling operation purposes, but are now full of stored equipment or materials. Except for the mill building and the office, the other floor space would be difficult to adapt for use.

Water for the mill is still being supplied from an on-site artesian well. Storage of water is accommodated by an elevated metal storage tank located just north of the main mill building. The 130-ft-tall tower provides the water supply and pressure for the fire protection system in the mill building and to hydrants on the site.

Sanitary sewage is disposed of through the City of Edgemont sewage treatment facilities. The city's 22-acre sewage effluent pond is located immediately east of pile 3. There are two city sewage effluent lines which pass through the site in a west-to-east direction that supply the pond. One line is north of the East sandpile and north of pond 3, the other is south of the East sandpile and runs beneath the tailings located in the area between piles 4 and 7. One of these lines is serviced by a pumphouse which is located on TVA millsite property. The pumphouse on the north line is located in a gully about 200 ft southeast of the southeast corner of pile 2. The pumphouse on the south line is located about 75 ft west of the northwest edge of pile 7 on private property.

Electricity for the mill is supplied by the local utility company. A high voltage, electric transmission line on wooden poles crosses the site in an east-west direction approximately 400 ft parallel to the north property line. The line crosses the south side of pile 1 and through the middle of pile 2. Only two of the poles appeared to be in or near any tailings.

The site is completely fenced with locked gates. Existing fencing is comprised of a variety of types: three- and four-strand barbed wire fence, 6-ft chainlink fence with barbed wire on top, and 6 x 8 in. mesh hog fence. Some sections are posted with radiation warning signs and others are not. Pedestrian access to the site would not be difficult either from the area which is adjacent to the Burlington Northern railroad switching and mainline facilities which are just west of the site, or on the west or south edges of the tailings area. Unauthorized vehicle access is unlikely because of fencing and/or remoteness of entry points. At the time of this report, TVA was installing new fencing around the site using 6-ft chainlink fencing with three strands of barbed wire on top.

2.5.2 Tailings Storage Areas

The mill produced approximately 2-1/3 million tons of solid

uranium mill tailings (see Table 2-1), approximately 80% of which were sand tailings and the balance was slime tailings with some vanadium tailings. During the operational period these materials were deposited in 11 ponds or piles. The area dedicated to ponds or tailings storage comprises approximately 180 acres, which includes areas covered by piles, ponds, dikes, access roads, and unused areas.

The numbering and/or naming of the piles was and is unusual. A July 1969 print of the site area prepared by Mines Development Inc. indicates that what has been called the "AEC" pile has also been called "sand tailings area A" and is so designated in this report. A tailings area of approximately 4.5 acres located east of the mill area and west of Cottonwood Creek was designated as "sand tailings area B". This pile does not appear on subsequent drawings which were made available to FB&DU. It was discovered while drilling holes in the ore storage area which were to be used in determining the depth of soil contamination in the area. The tailings sand fraction in Area B apparently had been recontoured for the purpose of increasing the ore storage area. The 1969 print also labels the pile now known as the "East" pile as "sand tailings area C".

The other ponds or piles have been numbered from 1 through 10 except that there are no tailings piles on site using the designations 5 or 6. They are missing from any references.

At the onset of operations the sand tailings were first stored in sand tailings area A and then in the "East" sand tailings pile and later in pile (pond) 2. Dikes for the ponds were formed from soil on site, usually from future bottom areas of the ponds. No dike material was imported. These original storage areas are no longer active. A small portion of pond 7 was the last area to be used for disposal of uranium tailings material. When the U_3O_8 milling operations were discontinued in 1972, ponds 2 and 7 were utilized as disposal areas for solid waste generated during vanadium processing.

Several stages of tailings disposal area expansion occurred during the history of the site. All pond and dike designs were prepared by engineering firms and approved by the AEC. None were lined with any special treatment such as imported clay, and all dikes were wide enough at the top for vehicles to travel on. From 1962 through 1970, disposal areas 3, 4, 7, 8, and 9 were constructed. Ponds 4 and 9 were built solely to provide for solar evaporation of liquids for concentration of the metallic constituents. In 1971, the solar evaporation capacity was expanded by the construction of pond 10. The soil beneath this pond was found to be a sand, silt, and clay mixture suitable as dike and pond liner material.

Since 1956, slime tailings were impounded and disposed of in ponds 1, 2, 3, 7, and 8. During the first 4 yr of uranium operations, all slimes were treated with lime for neutralization.

The original limed slimes in ponds 1, 2, and 3 have been reprocessed for the vanadium content. The reprocessed slime residues were then disposed of in pond 7. Pond 2 was subsequently utilized for a sand tailings disposal area. Approximately one-half of the uranium slimes in pond 7 was treated for vanadium recovery, and the waste material was disposed of in pond 1.

Sand tailings area B has been leveled and recently covered with a thin layer of assorted materials, including crushed rock used as base meterial for roads. The area drains generally toward Cottonwood Creek although the specific area of this former pile has been graded so that it collects drainage from contaminated areas into a holding basin. The area is now a storage area for mill and yard materials and equipment. Also, there are at least three piles of original source ore stored in this general area.

At present, ponds 3, 4, 7, 8, and 10 contain V_2O_5-bearing liquors of varying assay. In the past, the uranium slime ponds were used for collection of V_2O_5-bearing liquors and solutions. All of the slime ponds were intermittently filled and drained in an attempt to leach out the contained solids of economic values. Solar evaporation was used to concentrate the metallic elements in solution.

Table 2-1 is a summary of the type and amount of tailings in each pond or pile on the site. Additional data on the uranium, vanadium, radium, and thorium content of the ponds and piles are included in Chapters 3 and 5.

2.5.3 Tailings Stabilization

The initial tailings stabilization work at Edgemont was started in June 1972 in two 100-by 100-ft test plots established in the tailings pond 2 area and in the area designated as sand tailings area A. Both sand plots were bladed smooth, then received a 4-in. bed of crushed limestone that was disced under to a depth of 6 in. A mixture containing 40% yellow clover and 60% crested wheat grass with 50 lb of ammonium nitrate per plot was drilled into the prepared beds. Approximately 2 tons of fresh manure was added to each test area. A water sprinkling system was installed on the pond 2 plot and daily watering was commenced. The other plot was left for natural rainfall.

2.5.3.1 Vegetative Cover

By mid-July 1972, the pond 2 plot had a 50% growth cover established, whereas sand tailings area A had approximately 15%. Hot, dry winds during July and August stunted the growth in both areas and by early September, only 20% cover remained on test plot 2 and the other plot deteriorated. Windborne sand caused the greatest damage by cutting into the root systems and covering the remaining plants. Both plots were abandoned in favor of other stabilization techniques.

The addition of 1.5 to 2 ft of topsoil on pond 2 was commenced in May and completed in late June 1973. The area was seeded (60-lb seed/acre) and fertilized with the following mixtures:

25% yellow clover

25% rye

50% crested wheat grass

50-lb ammonium nitrate (34-0-0)/acre

12 tons fresh manure/acre

Topsoil addition of 1.5 to 2 ft to sand tailings area A was commenced in early July and completed in late August 1973. The same seed and fertilizer mixture as for pond 2 was added. Neither plot received artificial watering; however, soil moisture was sufficient to start a medium to medium-heavy growth. The areas received only 1.75 in. of rainfall during the growing season, but both plots contained 80% ground cover by the end of the growing season.

Natural growth reestablished itself in both plots during the spring of 1974 and by early summer, ground cover was estimated at 90%. Severe drought conditions prevailed through September of 1974, causing retarded growth.

At present, sand tailings area A is well covered with vegetation (about 90%). The top surface and the west slopes and edges of the pile have withstood erosion and are holding up well. The steep east slope of the pile, however, is eroding rapidly and there are many locations where the contour or terrace grading of the stabilization cover has been eroded by surface water. In these locations the entire cover has eroded and is, along with the tailings, being carried by surface water into Cottonwood Creek. The north edge of the pile, south of the mill building, and the south edge are likewise being eroded by water.

Pile 2 is covered with about an 80% vegetative cover. Its entire surface and edges appear to be holding up well, as no surface signs of wind or water erosion are evident. The south and east side slopes of this pile are quite gentle, but between the pile and the river there are places where erosion is starting to develop.

On pile 9, an approximately 90% cover of native weeds has been established.

Leveling, contouring, benching, and topsoil addition to the high, east sand tailings area were commenced during the early winter and spring of 1973-74. Sand material was removed from the

top of the pile during leveling. This material was moved to the south and north, extending the tailings area in length but reducing its profile height. The top area was fertilized and seeded with the above specified mixture and a growth of approximately 50% was established by June 1974. This area did not survive the dry summer and only 20% growth remained by early fall 1974. During the winter of 1974-75, subsequent to TVA's purchase of the facility, benching, leveling, and contouring of the east tailings area was continued and topsoil on the benched areas was increased in thickness.

At present, the surface and benches of the east pile has only a sparse growth of weeds. Fertilizer in the form of cow manure has been dumped at intervals on the terraced side slopes of the pile, but little growth exists on these steep banks, some of which are 45°, or steeper. Because of the steepness of the slopes, there is severe water-caused erosion on the pile.

Attempts were made in recent years by the Bureau of Mines to establish shrub growth on the steep sand slopes by planting shrubs in short length 3-in. diameter tubes. This, however, has failed because of the steep unstabilized banks that have eroded at such a rate that the root system could not be established. This is very evident on the southeast corner of the pile where sand tailings are eroding across the dirt road at the toe of the slope and into Cottonwood Creek. Lack of moisture is also a factor which has adversely affected plant growth.

2.5.3.2 Physical Stabilization

Pond 1 is unstabilized and contains some surface water. The dikes were formed from soil obtained from the bench of the Cheyenne River upon which the pile rests. The dike along the river (north side) has about a 45° slope, is vegetated, and has been resisting erosion very well. There are signs of rodents burrowing into this dike. Recently, TVA has installed a 6-ft chainlink fence along the toe of the north dike. In doing so, a bench was cut in the toe which also destroyed a protective berm between the toe of the dike and the Cheyenne River. This disruption in the well-established dike could bring about serious erosion problems unless some method of protection of the newly graded areas is installed. Because of the location of the fence, remedial action appears to be difficult. The eastern dike is also steep and at its southern end is beginning to erode as a result of surface water runoff. This pile is being considered as a dump site for mill debris which has been placed on the west and south sides of the pile, as well as elsewhere on the site.

Pond 3 is unstabilized and contains some surface water. Its main dikes are on its north, south, and east ends. These dikes support very little vegetation and water erosion is removing dike material into the undrained swale which lies between the pile and the city sewage effluent basin.

Pond 4, a small pond located at the toe of the south edge of the East sand tailings pile, is now stabilized and contains no solid tailings. The area between ponds 4 and 7 has been stabilized with an average of 3 ft of earth cover obtained from the extreme south end of the site, beyond pond 10. The distance between this newly applied stabilization and the toe of the East sand pile is so narrow (averaging ±20 ft) that pond 4 has virtually been eliminated.

At present, about 50% of pond 7 (the eastern one-half) has been stabilized with earth obtained from the area south of pond 10. This cover is about 3 ft thick. The balance of the pile is unstabilized with liquid present on the western portion of the pile. The main dike surrounding the pile is on the east and north sides. It has resisted water and wind erosion quite well and has a good cover of weed growth. East of the pile at its tow and across the property line of the site there is evidence of leaching on the ground surface.

Pond 8 is unstabilized with some water in it. Its steepest dike is on the north edge and is eroding quite rapidly as a result of surface water runoff.

Pond 9 has been stabilized with an average cover of 3 ft of soil obtained from the southeast corner of the inside of pond 10. There is about a 90% cover of native weeds that has grown on the pile's cover material. Along the north edge of the pile, at the junction of the dike with the stabilization, the surface cover and the dike are rapidly being eroded by surface water runoff.

Pond 10 contains some water, no tailings, and consequently no stabilization. The containment dike is steep, and mostly weed covered, but on the northwest corner it is beginning to be eroded quite rapidly as a result of surface water runoff.

Since the containment dikes on site were constructed with material from the site, and are quite steep, most are showing signs of increasing water erosion, mainly because of lack of aggregates (rocks) of various sizes which would act as riprap, thus preventing such erosion. This is also true of the weathered shale stabilization material that has been applied on the piles; it works well when on a level surface, or gentle slope, but erodes rapidly on steeper slopes. Weed or other vegetative cover is helpful in preventing such erosion, but in major storms and over a long period of time, these surfaces without riprap will not last.

The potential for tailings transport into streams from water erosion is high along the lower portion of Cottonwood Creek adjacent to pond 2 and adjacent to ponds 1 and 2 along the Cheyenne River. However, direct impact on the nearby populace is remote since the populace is situated upstream from these locales. The most immediate potential threat from water erosion would be to

Cottonwood Community from erosion of the dikes of ponds 7 and 10. Even though these dikes are constructed of natural soil materials, they do contain windblown contaminants.

Because of the predominant wind coming from the northwest, there is considerable visual evidence that tailings have been carried by wind off site as much as 1,500 ft south and east of pond 7. This material has been blown well into the gullies and draws of the low mountain southeast of the tailings area.

2.6 POPULATION DISTRIBUTION

The population of Edgemont was estimated at 1,775. The total population within 1 mi of the millsite is about 2,000. For purposes of health effects calculations, the population in 16 sections within 1/4, 1/2, and 1 mi of the site was estimated from a count of residences within each sector. The results of this estimate are shown in Figure 2-5. Cottonwood Community is located between Cottonwood Creek and pond 7, and thus includes the residents with the occupied residences indicated.

2.7 GEOLOGY, HYDROLOGY AND METEOROLOGY

2.7.1 Geology

The millsite lies within the Missouri River plateau and the southwestern edge of the Black Hills uplift as shown in Figure 2-7. The site is located near the center of the Edgemont geologic quadrangle and is in the southwestern corner of Fall River County. The Cheyenne River passes immediately adjacent to the site and is the major drainage feature of the quadrangle along with several intermittent tributary streams, including Cottonwood Creek which passes through the millsite. The topography is described as rolling hills and plains with a maximum relief of less than 1,000 ft throughout the quadrangle. Maximum relief at the site is approximately 130 ft.

Alluvial deposits of the Cheyenne River, Cottonwood Creek, and other creeks exist along and within the lower river flood plain and creek beds as shown in Figure 2-8. Unconsolidated, fine-grained deposits (mud and siltstones) also exist, as does the alluvium in varying thicknesses along the drainage channels. It is the combination of these sediments which underlie and separate most of the mill tailings deposits from the shale bedrock of the site. The unconfined water table aquifer was found to exist within the alluvium and/or on top of the shale bedrock. Discontinuity in the water levels was found along the Cheyenne River where the fine-grained alluvial sediment intertongued with the river flood plain sediment. The soil sediments are primarily fine-grained sands, silt and clay combinations in Cottonwood Creek and grading from fine-to-coarse sands and gravels with

some silts and clays in the Cheyenne River. Also, some eolian (windblown) sands and silts occur just north of Edgemont across the river.

Stratigraphically, only sedimentary rocks exist in the area which range in age from early to late Cretaceous overlain by Quaternary and some Tertiary age sediments.[3,4,5] Older pre-Cambrian rocks underlie the site at a depth in excess of 3,000 ft and younger Jurassic, Triassic, and Permian formations underlie the Cretaceous about 5 mi to the northeast of the site as shown on the cross-sections in Figures 2-7 and 2-9.

The general trend (strike) of the strata is to the northwest with the dip southwest at right angles between 1 and 5 degrees. Although the bedrock dips towards the south, the erosional surface slopes to the north at the site.

Most of the formations exist in a conformable position at the site with only the New Castle sandstone believed to be missing. Some disagreement exists in the literature as to the exact stratigraphy of the site. Wells drilled near the site in 1945 and 1954 identified the upper shale layer as Skull Creek and Mowry shales, respectively. Other references[3,4] (Figure 2-7) define the upper shale as the Belle Fourche shale. Observations by FB&DU during site investigations and drilling operations favored the descriptions of the Belle Fourche and/or Mowry shale with the dark-grey siltstones and limestone concentrations. A detailed examination of the distinction between the formations was not made since it was not believed to be critical to the scope of the study.

Nevertheless, boring log data and field observations indicated the shale sequence existing beneath the site was very consolidated and highly impervious. Information on Figure 2-9 also indicates that the shales are not a flow zone and have low permeability. The upper shale apparently acts as an aquiclude and prevents or minimizes downward migration of ground water. Likewise, the shale combination could inhibit upward migration of deeper confined waters. Extensive studies would have to be conducted to evaluate fully both the downward and upward movement of ground waters through the shale zones.

Major structural features of the Edgemont Quadrangle are the gently, south plunging anticlinal folds radiating southward from the Black Hills uplift. The most prominent is the Chilson anticline, about 4 mi to the east of the site and the Cottonwood Creek anticline trending northeast-southwest immediately west of the site as shown in Figure 2-10.[5] Few faults are located in the quadrangle and none are identified on the site. Likewise, joint fractures are uncommon and reported only in the deep underlying Fall River sandstones. Some sandstone dikes exist in the area cutting the near horizontal formations along near vertical planes but none are identified within or adjacent to the millsite.

2.7.2 Surface Water Hydrology

The Cheyenne River which passes immediately north of and borders the mill tailings site drains an area covering parts of South Dakota, Wyoming, and Nebraska of approximately 9,100 mi^2 into the Angostura Reservoir.[3] The drainage area to the site encompasses approximately 7,140 mi^2. All streams in this recharge basin are tributary to the river. The Cheyenne River is recorded as having an average annual flow of 65,179 acre-ft as measured at the Edgemont station (Highway 18 bridge north of town), as shown in Figure 2-11. For the 20 yr of record (1949-1968) studied, a peak annual flow of 314,400 acre-ft was reported in 1962 with a minimum flow of 9,340 acre-ft in 1961. The river data also show that the river in only 7 yr during the period of record (1947-1977) has experienced continual yearly flow.[4] The river is the tributary to the Angostura Reservoir located some 15 mi east of the site.

A point of additional interest involving the future runoff of the river is the existence of an increasing number of small reservoirs (9,320 in 1965) within the recharge basin. The impact of steadily potential decreasing flow rate on the dilution ratio along the river could result in future increase of the overall contaminant ratio in the river. The reservoirs are used for stock watering and/or irrigation. Two such reservoirs are located above the site on Cottonwood Creek and Coal Creek[3] but none are known to exist down-river between the site and the Angostura Reservoir.

Cottonwood Creek which passes directly through the site does not have a historic flow record. However, measurements taken during November 1977 from two rectangular and one 90°-V notch weirs showed an average flow rate near 280 gpm. The weirs are located as shown in Figure 2-11 and the data are reported in Table 2-2.

Additional sources of surface flow to the site are from: the sewage outfall line (intermittent, depending on system breakdown), city well, and mill fire safety tank which form a combined discharge at the pumphouse just north of the ore stockpile areas (designated as D-1 in Figure 2-11); the overflow from the Edgemont City Park well and pond entering the site immediately south of the sand tailings area A; potential seepage from ponded waters in tailings ponds on the site; and from both direct and ponded precipitation runoff. Figure 2-11 shows the surface drainage and ponded areas on and off the site.

Nine major points were selected as surface water sampling stations on and near the site and are also shown in Figure 2-11. The stations were selected on the basis of location with respect to existing ponds, drainages, historic data accumulations, background (off-site upstream) and potential flow impact areas. Water quality data complete with radiometric and mathematical model evaluations are reported in paragraphs 3.4.5 and 3.5.1. Addi-

tional data from a water quality monitoring program conducted by the TVA are included in Table 3-6.

Potential means whereby surface waters near the site could be contaminated by mill tailings are:

(a) Physical transport by runoff or dike failure

(b) Seepage of ponded waters through the dikes or pond basins into surface water courses

(c) Erosion of tailings dikes or sand tailings piles adjacent to the Cheyenne River or Cottonwood Creek

Physical transport of tailings off-site is already evident at some and is a potential at almost every pile or pond. The northern bank of pond 1 is designed to limit erosion to the Cheyenne River; however, there is evidence of erosion along the eastern side of the dike which can enter the Cheyenne River via the roadway or adjacent gully. Erosion is also evident along the northern and eastern border of pond 2 and could reach the nearby Cheyenne River and Cottonwood Creek. Also, wind erosion has drifted tailings into ponded surface waters along pond 3 and along the northern border of pond 4 where there also is evidence of water erosion. The eastern side of pond 8 has withstood erosion and pond 9 has been stabilized. However, some of the cover material along the eastern side and along the southern border of pond 9 has eroded. On pond 10, off-site erosion can take place at the southwestern corner and along steeper sections of the western dike. A vegetated berm protects most runoff from pond 7 from running off site except at the northwestern corner where ponded water exists. At the East sand tailings, eroded materials could easily reach Cottonwood Creek from severely eroded sections of the southwestern, western, northwestern sides. Also, the dirt road bordering the East sandpile might have been a protective measure to prevent runoff; however, it has been breached in several places providing direct runoff paths to the creek. Another source of eroded material to Cottonwood Creek includes sections of the eastern and southern sides of the sand tailings area A and from sand tailings area B near the millsite.

Off-site and on-site runoff collection in the tailings ponds or behind dikes has occurred along the southern margin of pond 9, the eastern side of pond 7, at the intersection with ponds 9 and 7, and further south at pond 10. At some of these interceptions, water is seeping through the dikes into the tailings ponds or beneath the dikes via buried drainage channels. As an example, a series of catchment areas exist toward the southeastern border of pond 10. (See Figure 2-11.) Note that immediately north of and within the dike a pond has formed which is being recharged by the infiltrating runoff waters.

Ponded waters within inactive tailings ponds consist of the residual process waters further recharged by precipitation that

is trapped in the broad surface areas of the ponds and collected in the smaller lower areas. Although annual evaporation exceeds annual precipitation, the precipitation is not entirely evaporated in a year's time. Therefore, the hydraulic head in these ponds varies considerably and likewise the associated piezometric ground-water surface. It is speculated that collected waters from pond 7 percolate through the tailings dike and appear as seeps along the western margin of the pond at times of high pond levels. Available data indicate that when the head in the tailings pond is high, the associated phreatic line (water table) is encountered quite high at drill holes in the western dike. Likewise, when the head is low, the water table configuration in the dikes is below the base or nonexistant. The potential seep (shown in Figure 2-11) in the western dike of pond 7 is masked by surface runoff collection at the same location. Runoff has migrated off site to the west of pond 10 also.

Physical transport of tailings due to flooding of the Cheyenne River or Cottonwood Creek is possible. The meandering Cheyenne River channel is braided and its flood plain is broad, but the flood stages can reach the base of the tailings in ponds 1 and 2. The peak flood of record at the Edgemont USGS Station (No. 3950) at the Highway 18 bridge was in 1922 when a flow of nearly 14,000 cfs reached a measured elevation of 3,428.63 ft. The riverbed in the reach containing the tailings is at elevations between 3,412 and 3,416 ft, whereas the base of the tailings is near 3,425 ft; therefore, the potential of flood transport of tailings from an intermediate flood (25 yr) or a more severe flood (100 yr) is moderate. A maximum flow of 13,800 cfs (25-yr flood equivalent) was recorded at Edgemont in 1971. Such a high flow could erode and undercut sections of the alluvial bank on which the northeastern corner of pond 2 is situated and could also undercut the bank underlying the northwestern corner of pond 1. A continuing high flow would be required to erode through the dikes and reach the tailings. The projected elevation of a probable maximum flood (33,000 cfs)[6,7] is difficult to estimate due to flood plain irregularities at the site, but a conservative estimate is 3,435 ft.

Since Cottonwood Creek drains approximately 150 mi^2 within the reach containing the mill tailings deposits, the stream has cut through the Cheyenne River alluvium and upper bedrock to reach levels of 3,414 to 3,430 ft leaving 10-to 30-ft-high banks at the site. An estimated 25-yr and 100-yr flood level was calculated for Cottonwood Creek utilizing a theoretical USGS technique[6]. A value of approximately 3,600 cfs was estimated as a 25-yr flow whereas a value of about 7,850 cfs was estimated for a 100-yr flow. Respective water levels predicted at the site should not exceed 3,440 ft. Flooding of the creek would not reach the community living level. During mill operations, the channel was straightened and covered in the vicinity of sand tailings area A and the East sandpile. Both the Cheyenne River and Cottonwood Creek are gaining streams during most of the year, meaning that they are, in part, recharged by unconfined ground waters along their paths, such as those at the Edgemont

site. Wells located within the flood plain are likewise recharged by entering ground water and/or by flood plain surface water flows. Should these waters be affected by seepage from the tailings ponds/sandpiles, an impact on the wells, creek and river waters could occur.

2.7.3 Ground Water Hydrology

Ground water exists throughout the Edgemont guadrangle and millsite, primarily in unconfined alluvial water table aquifers along the main drainage channels and in confined artesian aquifers located at depth in the more permeable formations. The primary unconfined aquifer in the area is the Quaternary alluvial deposits. Confined ground water in the vicinity is found in four principal aquifers: the Fall River, Lakota, Sundance, and Pahasapa formations, with the Fall River being the most common. Several deep artesian and shallow near-surface wells exist throughout the area. Within and near the millsite two deep wells (greater than 2,300 ft) penetrate through the upper formations into the confined ground water. Even though the artesian waters are thermal, they are used by the City of Edgemont, Burlington-Northern Railroad, and the mill facility. A total of 26 monitor wells have been installed on the site into the unconfined alluvial aquifer and overlying sediments. The monitor wells are used to measure water level fluctuations and to obtain permeability and water quality data. None of the monitor wells are employed for domestic use.

Attempts to utilize the upper Cretaceous shales as producing aquifers in nearby off-site areas have resulted in low yields and poor quality waters.(4) Most of the wells in the area are located in the alluvial deposits along the larger streams and comprise the most important existing and future water supply zone primarily due to accessibility, adequate amount and quality of water, and lowest cost outlay due to the shallower drilling depths. The significance of this observation is that existing and future alluvial wells along the Cheyenne River downstream from the millsite have a potential of contamination from downgradient migrating surface and ground waters. The average depth of the wells is about 23 ft with a water level near 13 ft. Most are hand-dug or drilled 36-in. wide utilizing concrete or steel casings. Production is low, generally less than 3 gpm. Obviously, from the shallow depths and water levels reported the river is the dominant recharge source to the wells via seepage through the alluvial gravels.

As mentioned previously, the Fall River sandstone aquifer is the largest producing aquifer in the Edgemont guandrangle and Fall River County. Significance of understanding the general characteristics of the Fall River formation is that the aquifer represents the uppermost confined ground water zone with a potential for contamination from migrating contaminated seepage. The aquifer extends beneath the entire millsite and exists at a depth near 260 ft. Figure 2-10 shows the direction and slope of the

structure-controlled area gradient beneath the site. However, the potential is very low to nonexistant for contamination of the aquifer, due to the presence of the overlying 260 ft of highly impervious shales. Recharge to the aquifer in the area is through infiltration of precipitation where the formations crop out at or near the surface. Additional recharge occurs where surface drainages cross exposed aquifer formations.

Ground water characteristics specific to the site were determined by evaluation of existing data from the referenced reports; on-site information from the TVA and mill records[8]; and from FB&DU field observations, permeability testing, data evaluations, and model calculations. A piezometric surface (water level) and flow gradient of the unconfined aquifer was established across the site as shown in Figure 2-12. A gradient of 1.4% was determined in a north-northwesterly direction. Water levels in the monitor wells were measured using an electronic M-scope-type meter.

Permeability values of the unconfined aquifer were determined using the "slug injection" technique[9] and the "falling head" technique.[10] Tests were conducted in the field on selected existing monitor wells installed in 1975 by the TVA and also on wells installed in November 1977 by FB&DU. Records showed that the TVA wells were drilled into the shale zone below the aquifer, perforated, gravel-packed at the aquifer, and developed by bailing, jetting and pumping. Wells installed by FB&DU also were drilled into the shale and installed with an injection casing bottoming within the aquifer. The casing-to-hole annulus was gravel-packed and grout-sealed before injection testing. Locations of all wells tested are shown in Figure 2-13. Figure 2-13 also shows the horizontal permeability in relation to site contours. Table 2-3 shows the respective coefficients of permeability of each test well and designates horizontal or vertical values.

Evaluation of the data indicates that the horizontal permeability coefficient ranges between a high of 6.07×10^{-2} cm/s in test well M-13 to a low value of 1.83×10^{-5} cm/s in test well PH-1. An average horizontal permeability of 1.3×10^{-2} cm/s was assumed for the site.

Utilizing Darcey's Law:[11]

$$V = K \frac{(h_1 - h_2)}{\ell}$$

where:

V = flow velocity
K = permeability
$h_1 - h_2$ = difference in hydrostatic head
ℓ = distance between $h_1 - h_2$

A flow velocity of 0.35 m/yr (1.1 ft/yr) was calculated using a permeability of 1×10^{-4} as the horizontal velocity between pond 7 and Cottonwood Creek. However, in modeling the contaminant transport to the nearest resident in Cottonwood Community, a flow velocity of 1.7 m/yr was calculated based on an average permeability value of 5×10^{-4}. An average integranular velocity of 6.8 m/yr was obtained by dividing the flow velocity by the porosity (0.25). Site specific aquifer characteristics, e.g. permeability, porosity, and saturated thicknesses, etc., were input to the Intera[12] mathematical flow model to obtain specific flow velocity values throughout the site. These are shown in relation to flow potentials and pond locations in Figure 2-14.

Note that Figure 2-14 represents a flow net based on velocity rather than head potentials. Velocity rate and migration patterns are considered critical at the site. The flow net illustrates the overall general pattern, but is lacking detail in the southwest and northwest quadrants due to lack of data. Trends shown in these areas are therefore computer averaged. Vertical flow velocities were estimated using permeability coefficient tests conducted in a partially saturated medium. Therefore, a true permeability could not be achieved due to the effects of attenuating factors, such as soil/bedrock sorption, evapotranspiration, and sedimentation. A diffusion/dispersion concentration rate for radium was, therefore, developed using a measured horizontal permeability and an estimated vertical permeability based on the unsaturated medium test data and hydrostatic heads from annual precipitation data. Figures 2-15 and 2-16 illustrate by cross-section the respective boring depths, location and permeability coefficients by stratigraphic soil profile, and relation to nearby ponds.

Note that the figures also show the interbedded relationship between the Cheyenne River alluvial flood plain soil sediments and those of the Cottonwood Creek drainage which exists beneath most of the ponds/piles of the site. The intensive nature of the intertonguing sediments is believed to be responsible for the discontinuity in the static unconfined water table across the site. Likewise, the variable but typically fine-grained nature of the soils beneath the ponds is believed to minimize and cause variability in both vertical and horizontal migration of pond/pile contaminants towards and into the creek and river. Some drill holes were found to be dry to bedrock which leads to the partially saturated media conclusion, gives additional evidence of perched water tables and low permeability values, and helps to explain the extremely low recharge rates encountered during attempts to pump the fully developed TVA wells on the site. Limited data prevent a full analysis of all seepage characteristics of the site and a calculated estimate of total pond seepage into the ground.

In conclusion, based on the test data and model calculations,

the unconfined ground water characteristics of the site can be defined as an anisotropic, semiheterogeneous medium exhibiting a variable but overall low permeability range. Also, both the vertical and horizontal flow velocities are considered very low as compared to high in areas where coarse-grained, well-sorted, more isotropic aquifer conditions exist.

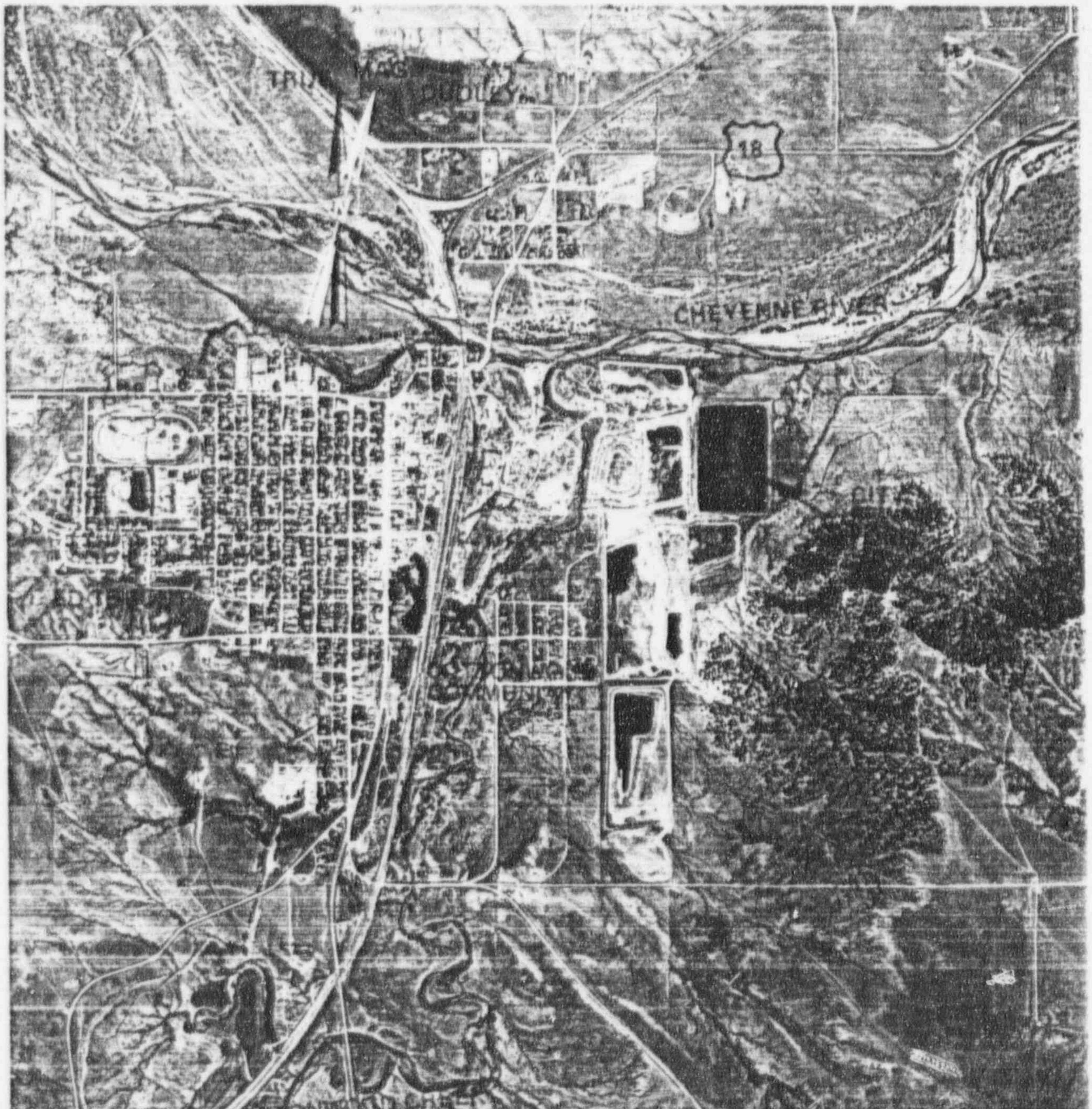
Of additional concern when evaluating the potential of seepage from tailings ponds and piles entering the surface of ground waters of the site is the aspect of flow migration from seepage through the tailings pond dikes. Since most of the precipitation that falls on the site is accumulated in ponds and depressions and either evaporates or seeps into the ground water, the effects of the variable hydrostatic heads in the ponds and their potential seepage must be realized. The major source of recharge to the unconfined aquifer is from seepage of surface precipitation. Even though the effects of the seepage through dikes is difficult to measure and may be going unnoticed beneath the outward toe of the dike bases, seepage does occur as evidenced by the variable phreatic (water level) zone observed in several borings along the dikes of ponds 7 and 10. Also, a potential for dike failure exists when the phreatic line rises due to seasonal runoff collection in a pond above the established safety factor of the embankment. Overtopping also has a high potential during seasonal highs with resultant dike erosion.

2.7.4 Meteorology

The climate at Edgemont has been described previously as semi-arid and temperate. Average annual precipitation at Edgemont is reported as 14 in.[14] with extreme variations in the area from less than 6 in. one year to more than 23 in. another year. The driest season is November-January, and the wettest season is May-August when between one-half and two-thirds of the precipitation falls as gentle rains or as high-intensity thunderstorms. Potential free evaporation is estimated to be approximately 37 in./yr[4] using an evaporation pan coefficient correction factor of 0.7 and a yearly evaporation rate of 53 in. However, in certain months, precipitation exceeds evaporation.

Long-term weather records are not available for Edgemont. Limited weather data are available from the Hot Springs Airport, 23 mi east of Edgemont, for the period from 1956 through 1960. Weather data also were recorded at the Black Hills Army Ordnance Depot, 8 mi south-southwest of Edgemont from mid-1962 to mid-1967. These data were assembled by the TVA for the Edgemont environmental report and were used in the FB&DU model calculations. Weather data have been recorded by the TVA at the Edgemont site for about 1 yr.

Regional winds tend to be northerly to northwesterly. A wind rose for Edgemont, shown in Figure 2-17, was constructed from the weather data recorded at the Black Hills Army Ordnance Deport.[2]


18
CHEYENNE RIVER

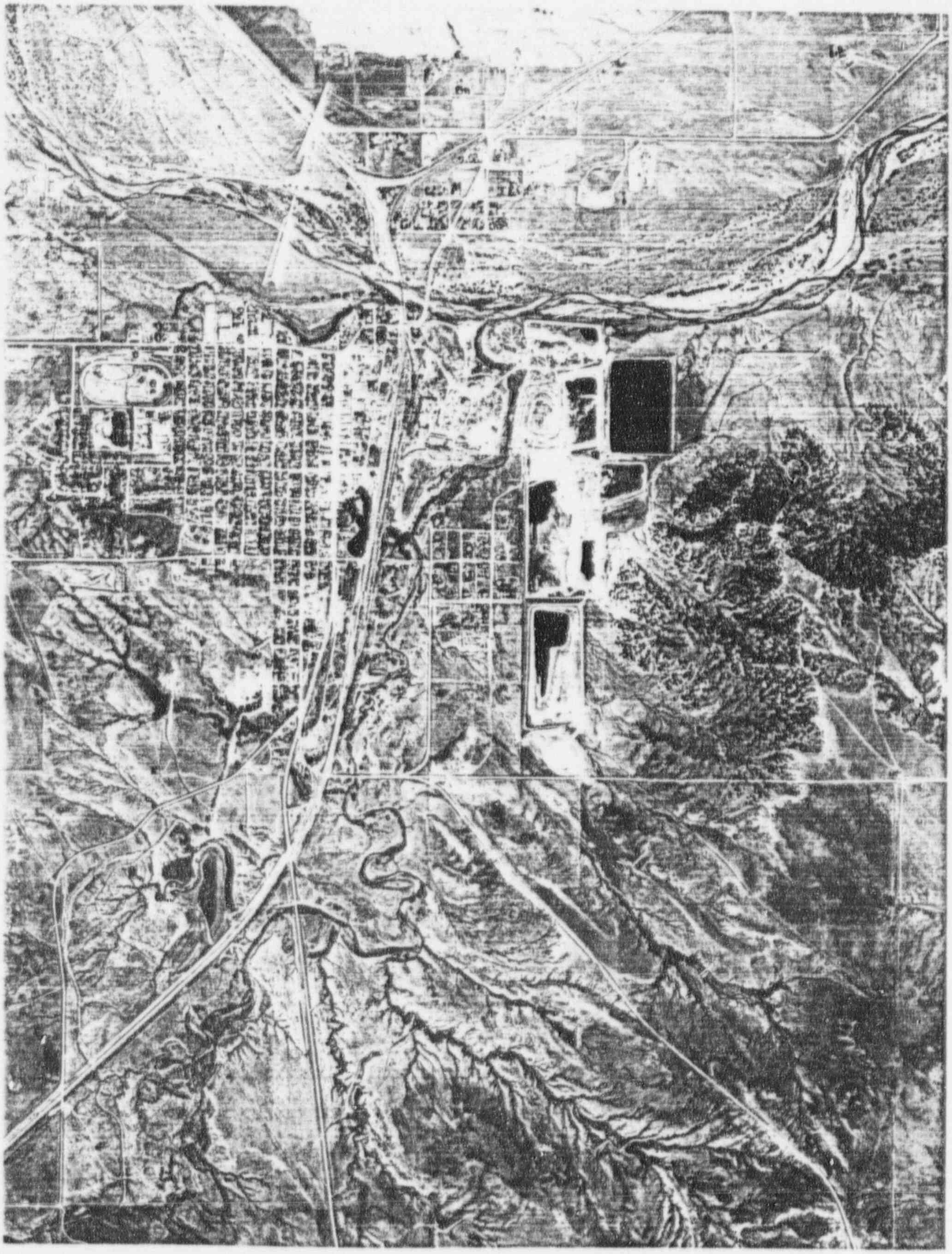
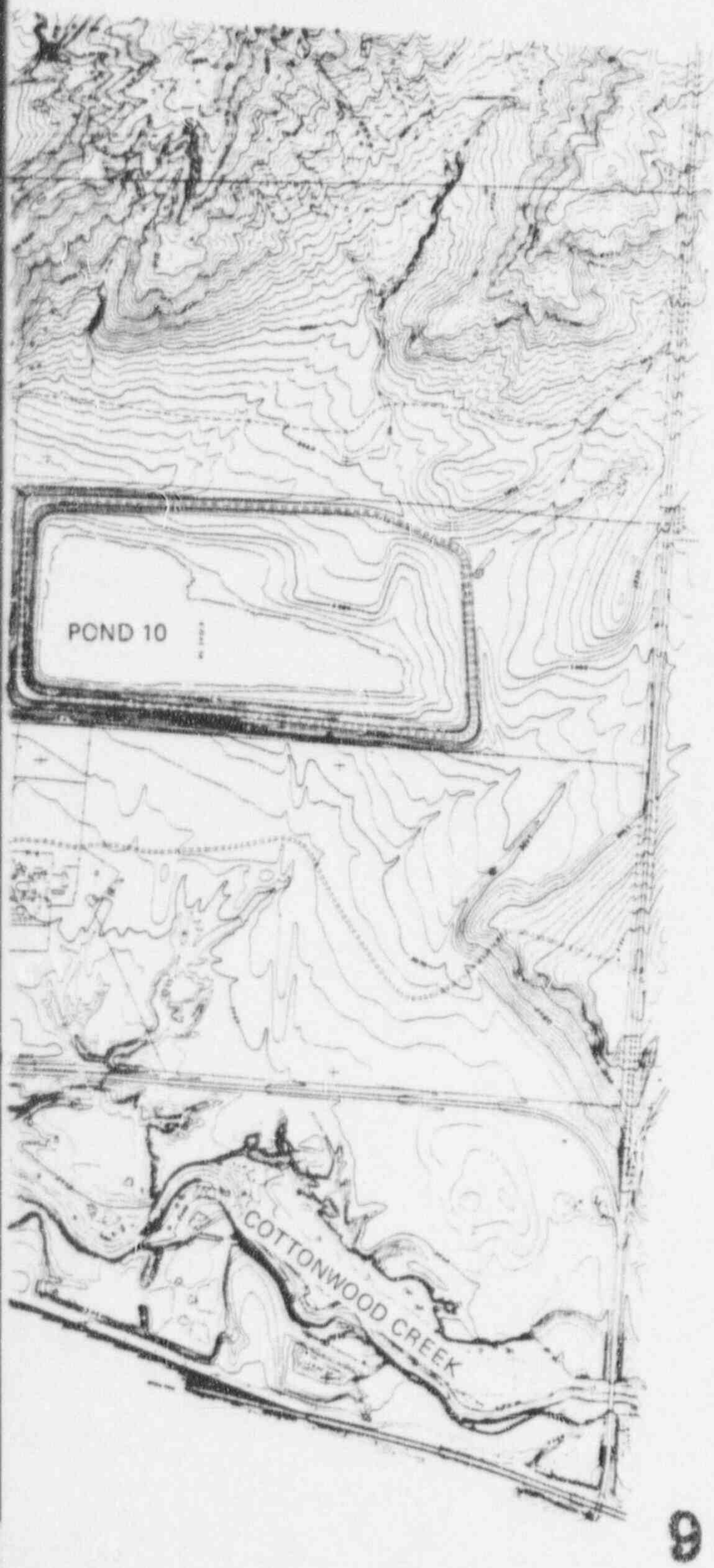


FIGURE 2-2. TOPOGRAPHIC MAP



NOTE:

MAP DRAWN FROM TVA–SUPPLIED INFORMATION–
CONTOURS VALID AS OF JUNE, 1977

0 500 1000 FT

CONTOUR INTERVAL 2 FT

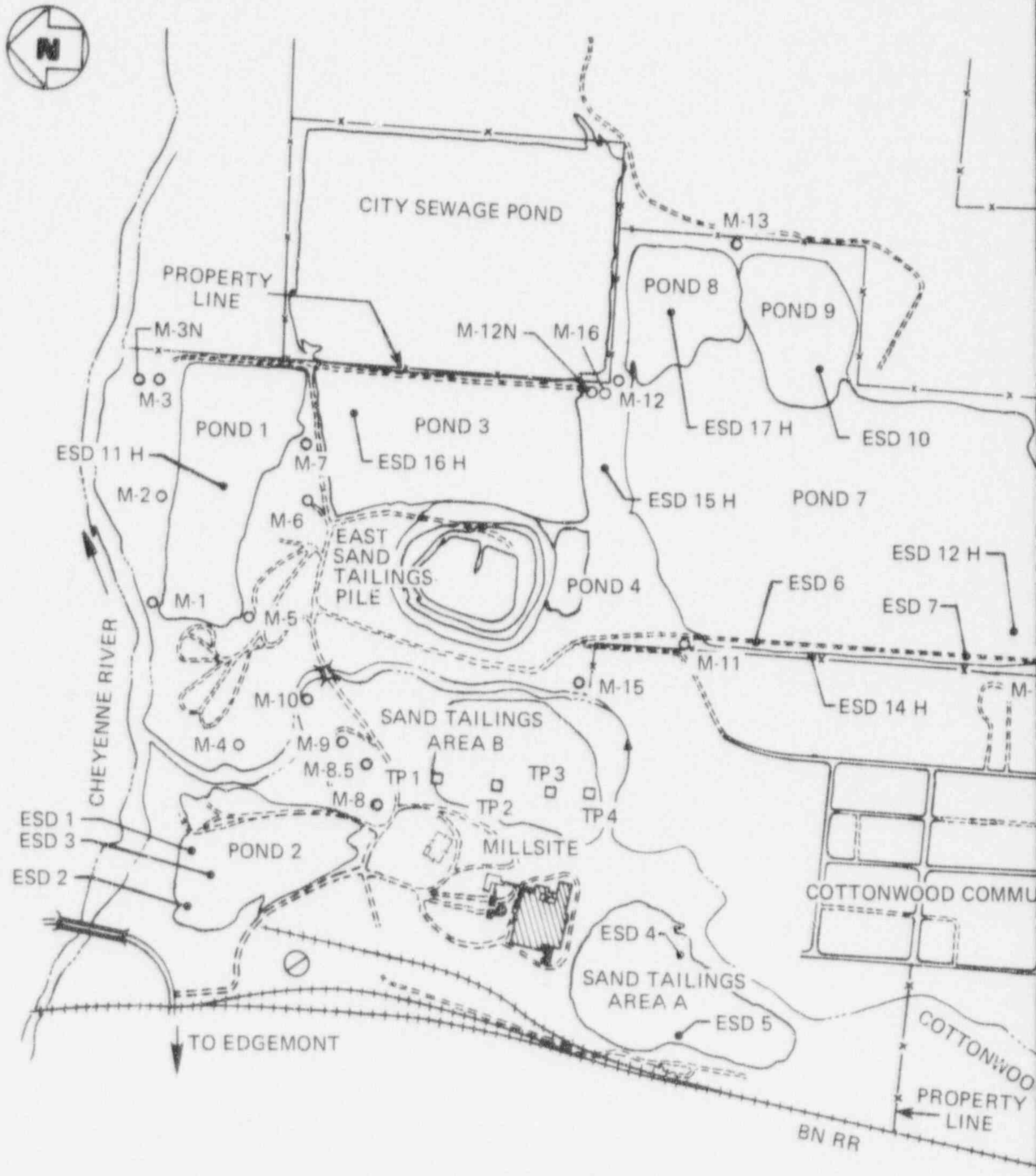
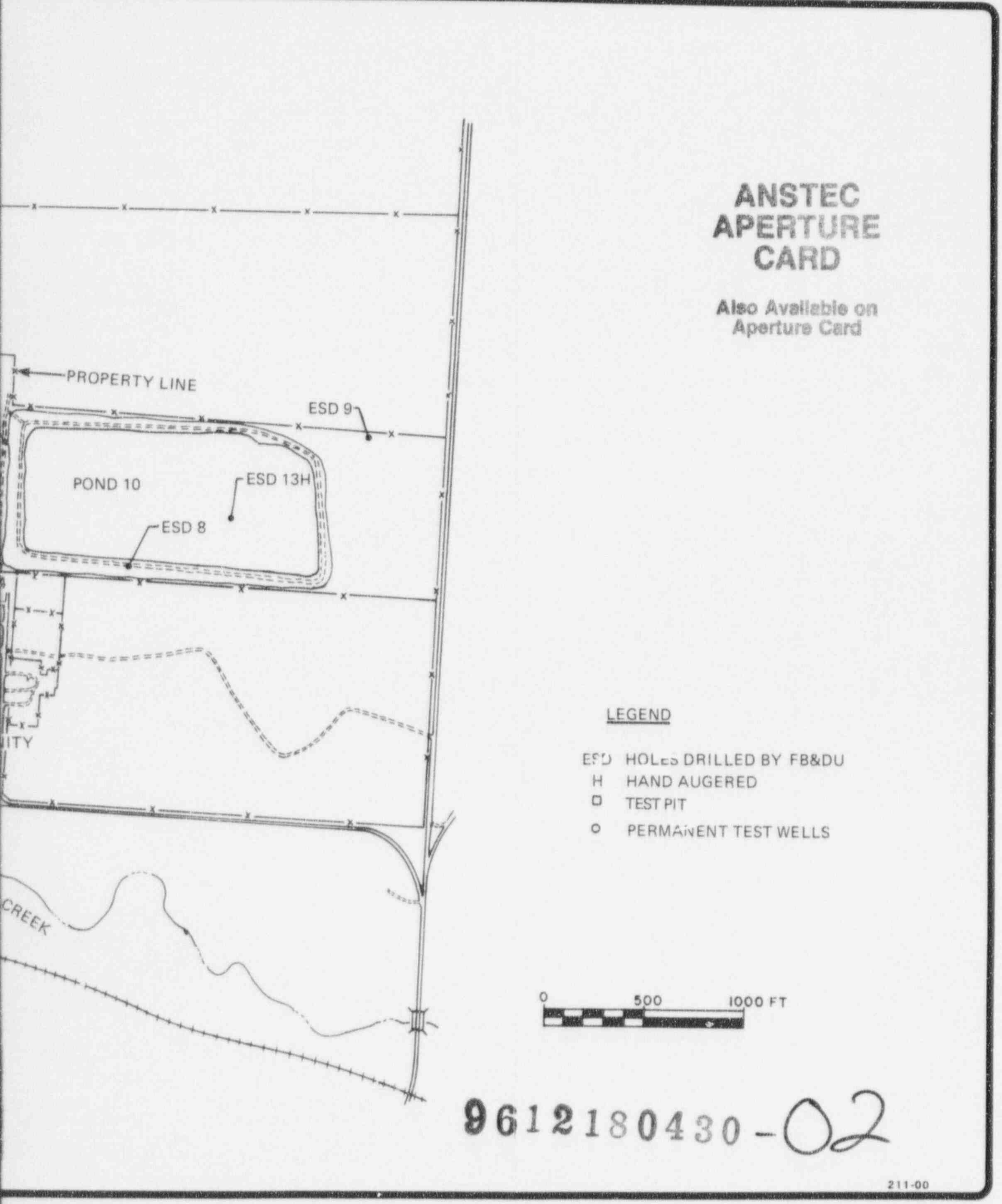


FIGURE 2-3. DESCRIPTIVE MAP


PROPERTY LINE
ESD 9
POND 10
ESD 13H
ESD 8
ITY
CREEK
LEGEND
ESD HOLES DRILLED BY FB&DU
H HAND AUGERED
TEST PIT
PERMANENT TEST WELLS
0
500
1000 FT
211-00

LEGEND

A = MAIN MILL BUILDING
B = "FeV" BUILDING
C = ELECTRIC SHOP
D = OFFICE
E = CRUSHER & SAMPLING BUILDING
F = STORAGE SHED
G = RAILROAD CAR SHAKER
H = FLY ASH PUMP HOUSE
I = REAGENT WAREHOUSE
J = MOBILE EQUIPMENT SHOP BUILDING
K = SCALE HOUSE
L = LIME PLANT
M = CARPENTER SHOP

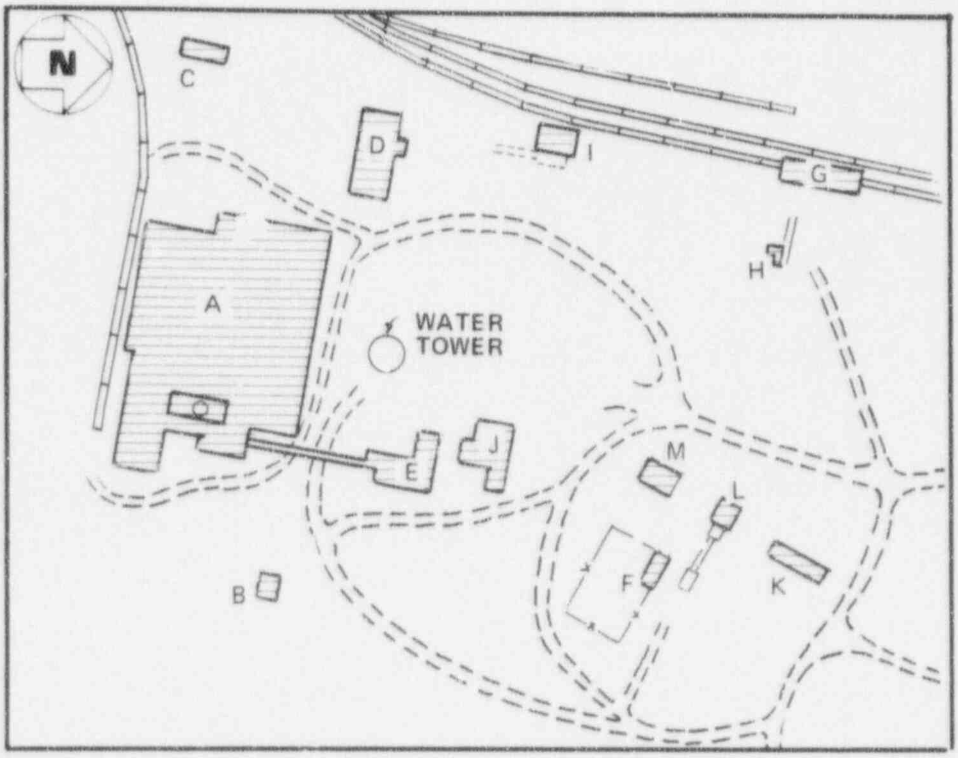


FIGURE 2-4. MILLSITE BUILDING LOCATIONS

211-00

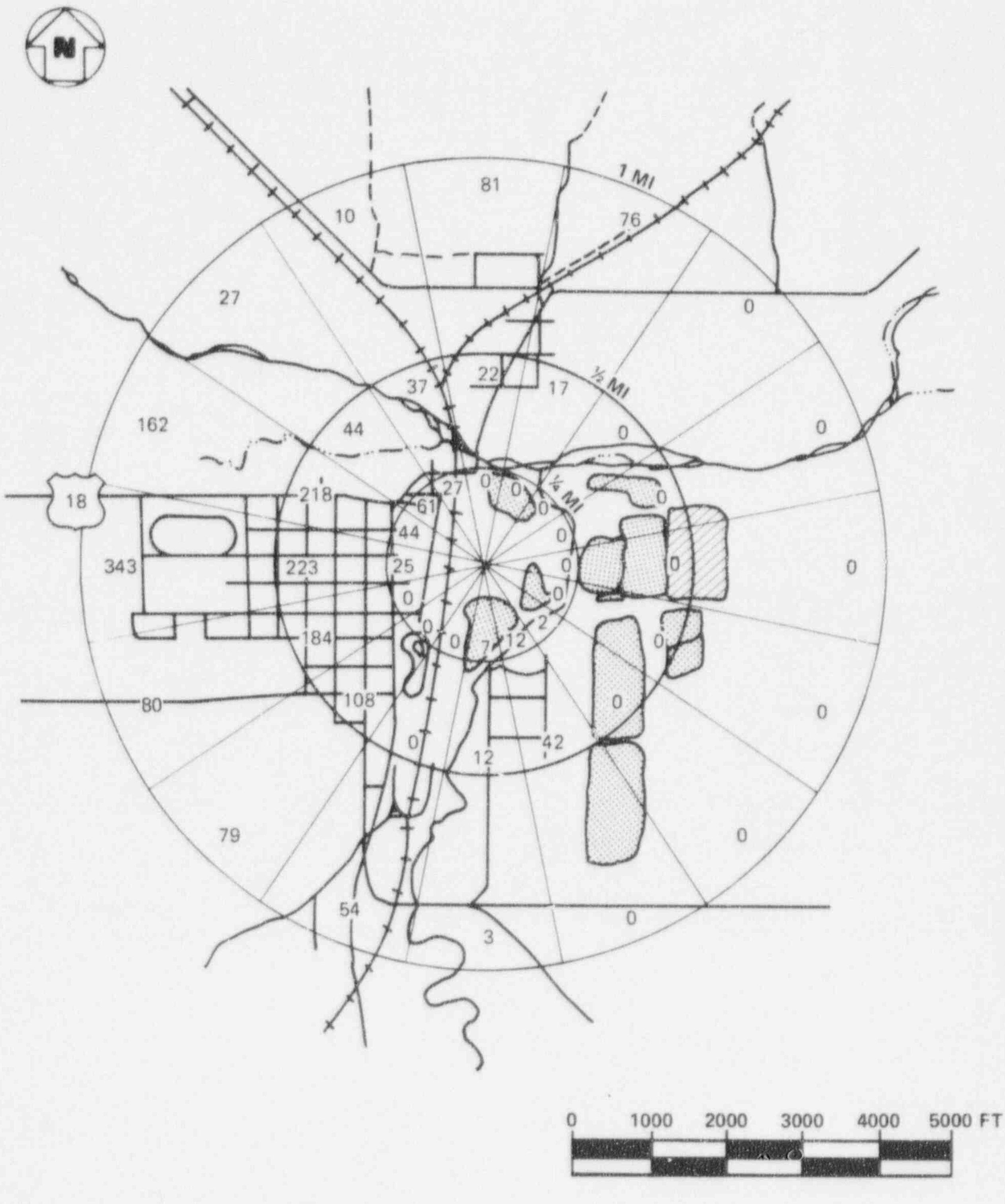


FIGURE 2-5. POPULATION DISTRIBUTION AROUND MILLSITE

211-00

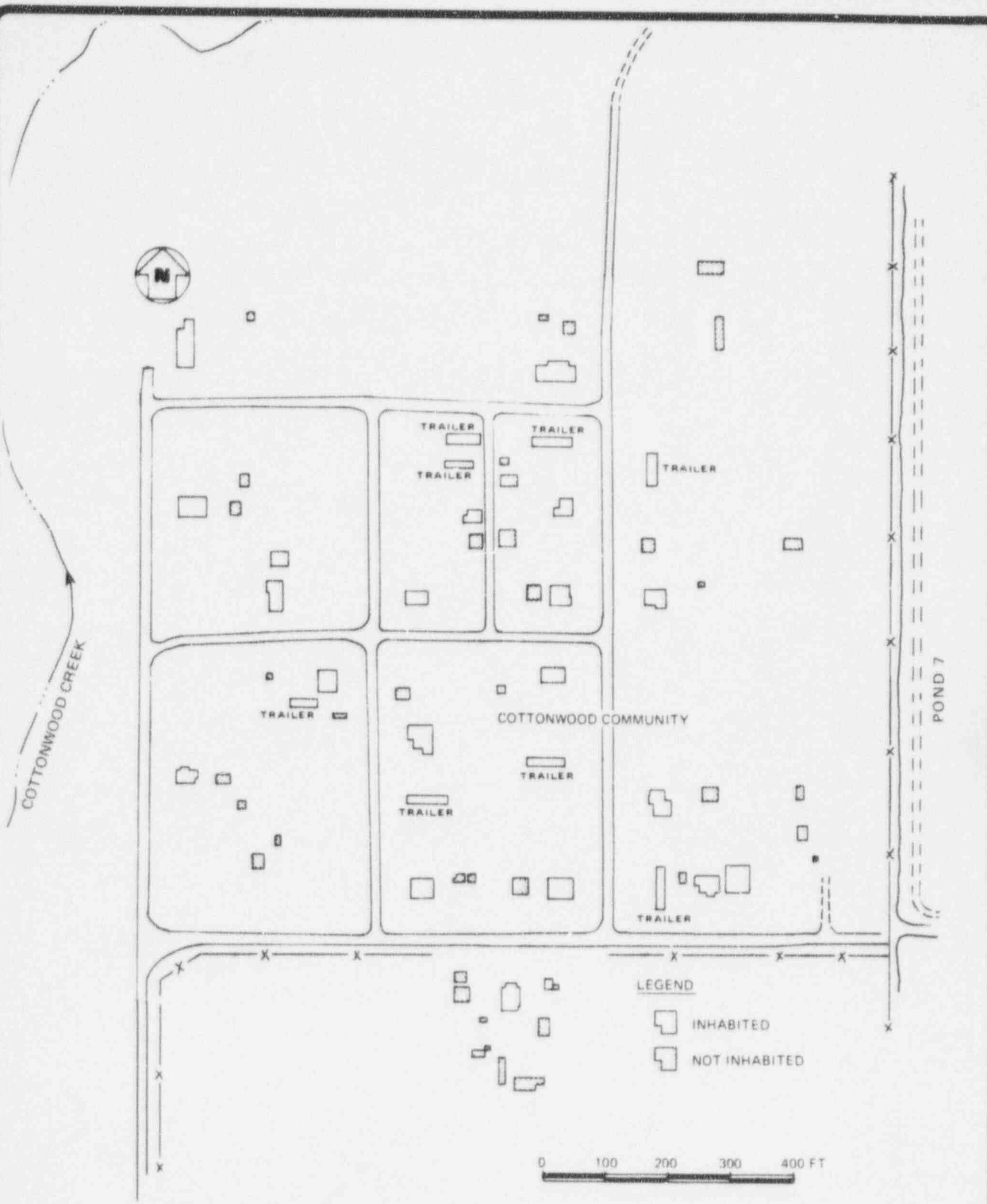
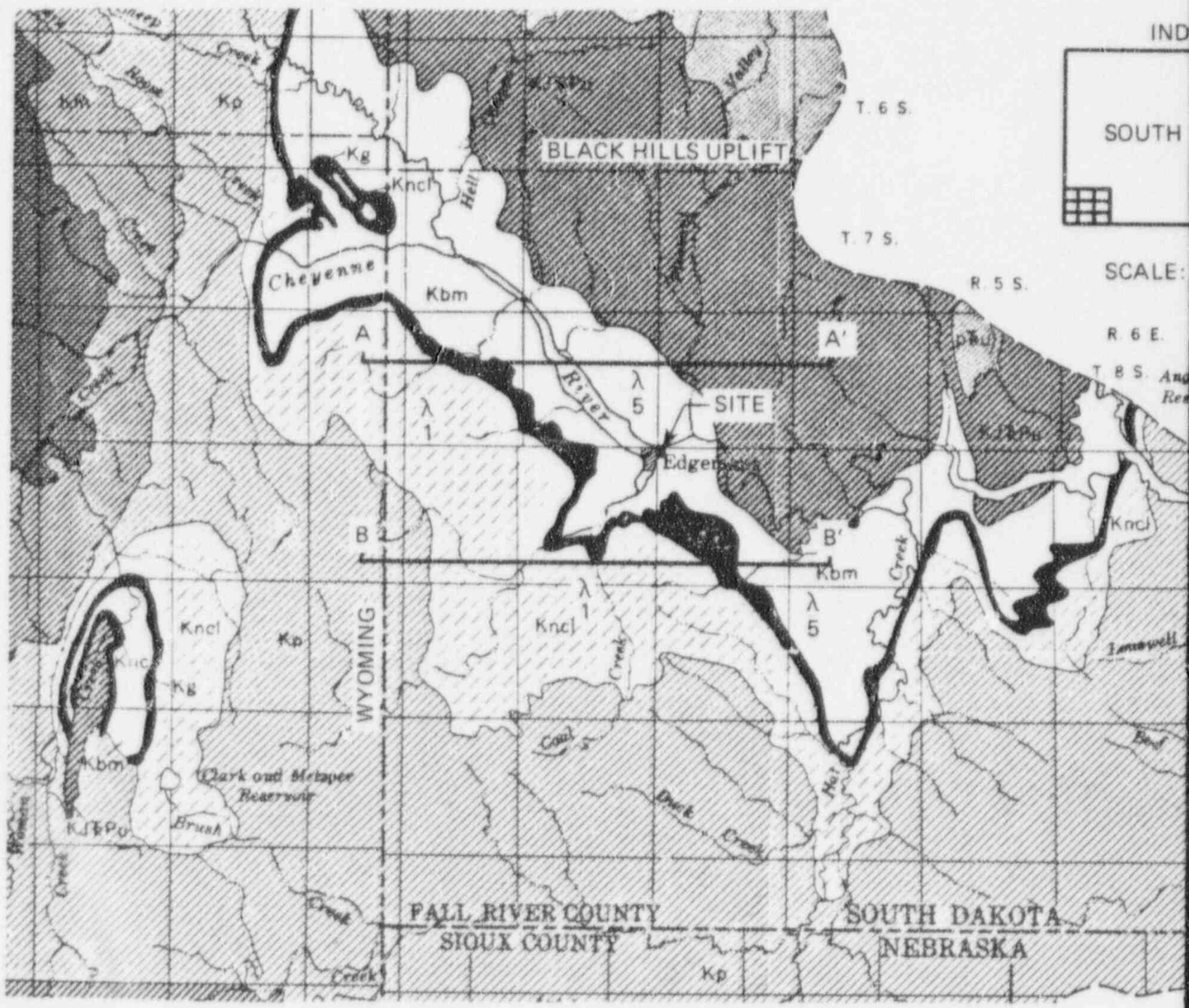


FIGURE 2-6. POPULATION DISTRIBUTION IN COTTONWOOD COMMUNITY

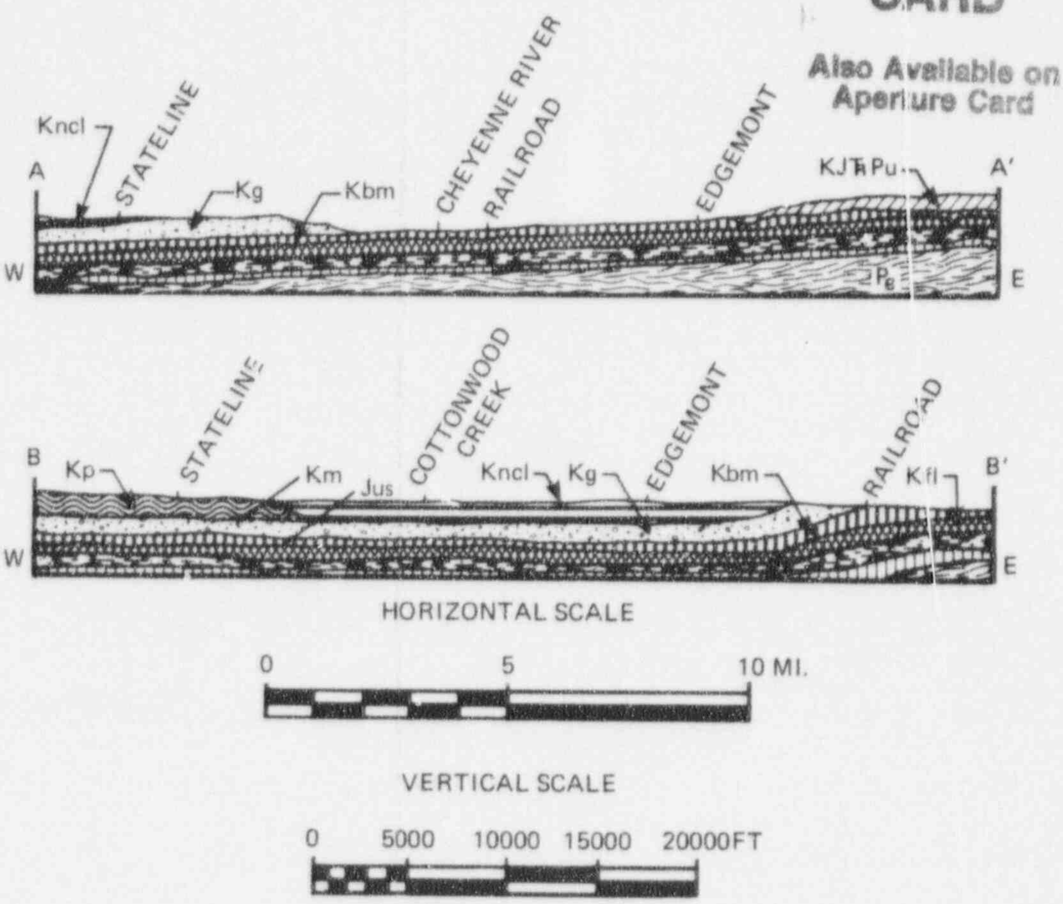
211-00



GEOLOGIC MAP
FALL RIVER COUNTY, SOUTH DAKOTA

FIGURE 2-7. GEOLOGIC MAP AND CROSS-SECTIONS

GEOLOGIC CROSS-SECTIONS



LEGEND

CRETACEOUS

- Kp – PIERRE SHALE
- Kncl – NIOBRARA FORMATION AND CARLILE SHALE
- Kg – GREENHORN LIMESTONE
- Kbm – BELLE FOURCHE AND MOWRY SHALES
- KJTRPu – SKULL CREEK SHALE, INYAN KARA GP., MORRISON FORMATION, JURASSIC, TRIASSIC AND PERMIAN FORMATIONS

Pє PRE CAMBIAN (CRYSTALLINE ROCKS)

λ 5 DIP DIRECTION/ANGLE

SOURCE: REF. 3

211-00

9612180430-03

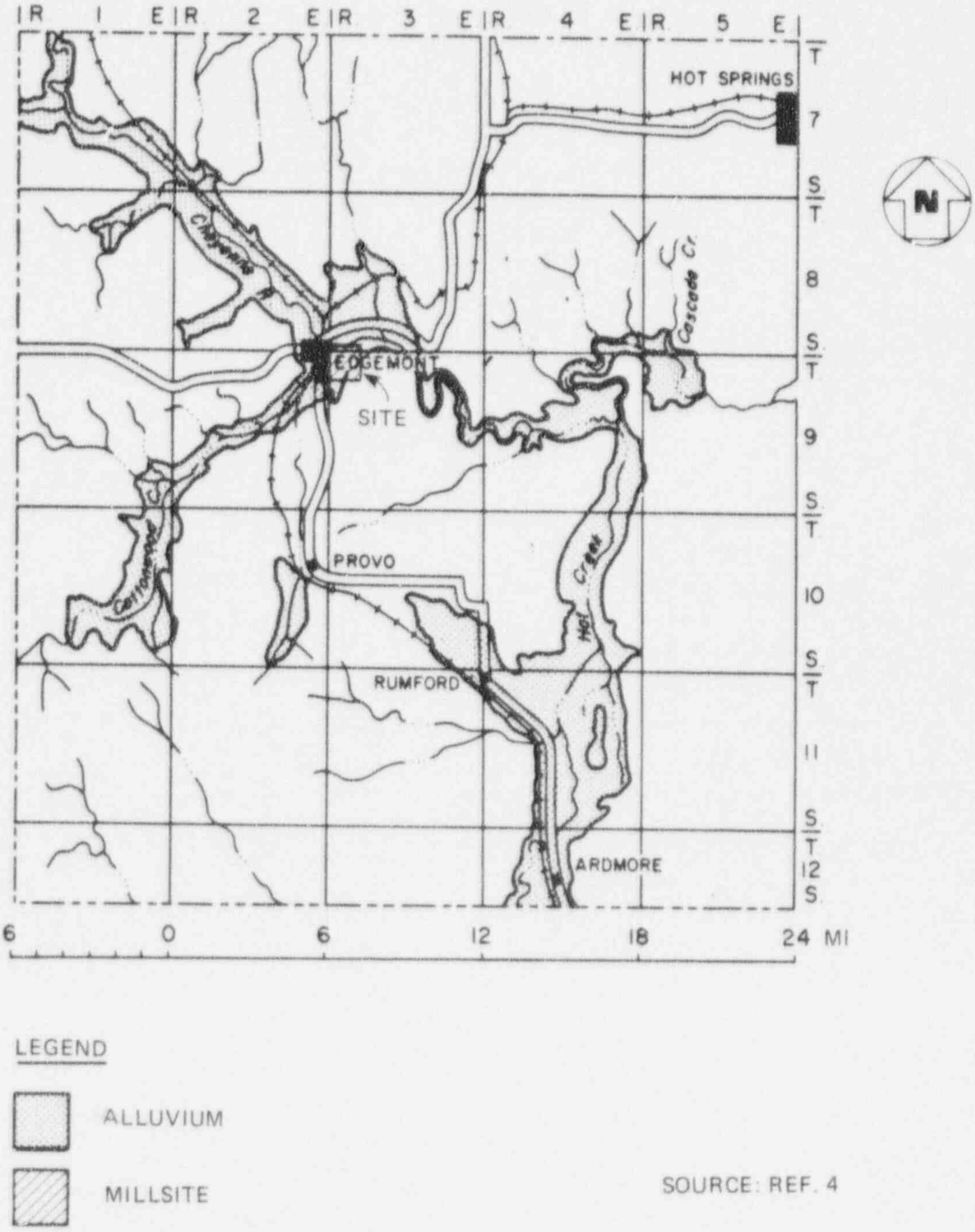


FIGURE 2-8. MAJOR DEPOSITS OF ALLUVIAL FILL IN WESTERN FALL RIVER COUNTY

211-00

PERIOD	FORMATION NAME	SYMBOL	COLUMN	LITHOLOGIC DESCRIPTION	THKNS IN FEET	HYDROLOGIC CHARACTERISTICS
Quaternary	Alluvium	Qal		Gravel, sand, and silt floodplain deposits. Alluvial terraces and windblown material	1-30	Good to excellent aquifer along floodplains, terraces generally non-productive except for scattered springs
Cretaceous	Pierre Fm.	Kp		Dark gray shale, weathering brown or buff and containing many fossiliferous concretions Scattered concretions which form "teepee buttes" Black fissile shale, cone-in-cone concretions	1000+	Relatively no value as an aquifer, locally large diameter wells in stream valleys may yield small amounts of highly mineralized water during wet seasons
	Niobrara Fm.	Kn		Gray calcareous shale, weathering yellow and impure chalk with Ostrea Congesta	100-225	No known wells
	Turner sand Carlile Fm. Wall Creek sand	Kcr		Light gray shale with large concretions Gray shale with thin sandstone layers Bed of impure limestone Thin sandstone	520-540	Relatively impermeable, possible small yields from Turner and Wall Creek sands
	Greenhorn Lms.	Kg		Thin bedded hard limestone, weathering creamy white, contains Inoceramus Labiatus	50	Too thin and dense to be an aquifer
	Belle Fourche Fm. Mowry Shale Graneros Group Newcastle sand Skull Creek Shale	Kgs		Light gray shale, bentonite, large concretions Light gray siliceous shale Thin brown-to-yellow sandstone Black shale	870	Newcastle sand may yield water, permeability is variable
	Fall River Fm.	Kfr		Interbedded red-brown massive sandstone and Carbonaceous shales	30-165	Largest producer in the area. Yields up to 60 gpm of highly mineralized water (flow). Water quality generally poor, sometimes yields hydrogen sulfide
	Fuson Shale Minnewasta Lms.			Gray-to-purple shale, thin shales Light gray massive limestone	0-180 0-25	
	Lakota Fm.	Klk		Coarse, hard, cross-bedded sandstone, buff-to-gray, coal beds locally near base	130-230	Relatively good aquifer from the lower Chilson member, up to 30 gpm artesian flow
	Morrison Fm.	Km		Green-to-maroon shale, thin sandstone	0-125	No known wells, possible aquifer
Jurassic	Unkpapa Fm.	Ju		Fine grained, massive, vari-colored sandstone	0-240	No known wells, possible aquifer
	Sundance Fm.	Jsd		Alternating beds of red sandstone and red-to-green marine shales	250-450	Produces small amounts of water from the sands suitable for domestic use
Triassic	Spearfish Fm.	TRs		Red silty shale, limestone, and anhydrite near the top Redbeds Gypsum locally near the base	400	Poor producer, small yields of sulfate water
? Permian	Minnekahta Lms.	Cmk		Pale brown, to gray dense, crystalline limestone	50	Locally secondary fracture porosity
	Opeche Fm.	Co		Red thinly bedded sandstones and shales, purple shale near top	100	No known wells
? Pennsylvanian	Minnelusa Fm.	Cml		Converse sand, red-to-yellow cross bedded sand Red marker, thin red shale near middle Leo sands, series of thin limestones Dolomite at bottom with basal laterite zone	755-1040	Permeability variable, tremendous flows of warm mineralized water recorded near the perifery of the Black Hills. Excellent potential
Mississippian	Pahasapa Fm.	Cps		Massive, light colored dolomite and limestone, cavernous in upper 100 feet	185-465	Most promising aquifer in the area. The 2 wells in this aquifer produce large amounts of water suitable for domestic use
Precambrian	Metamorphic and igneous rocks	P€		Granite, schists, quartzite, and slates	---	No potential

SOURCE: REF. 4

FIGURE 2-9. STRATIGRAPHIC COLUMN

211-00

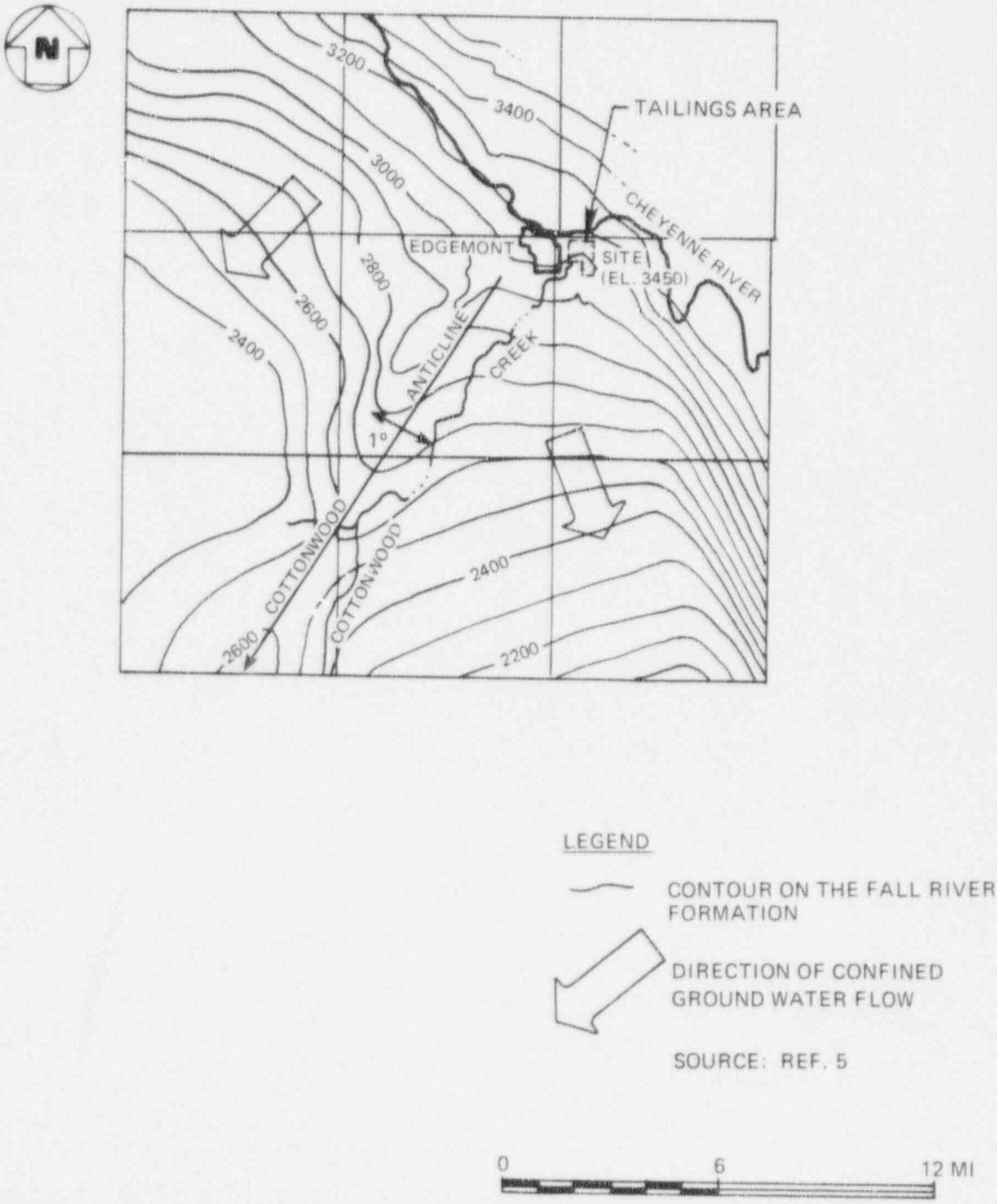


FIGURE 2-10. STRUCTURAL CONTOUR MAP AND CONFINED GROUND WATER FLOW

211-00

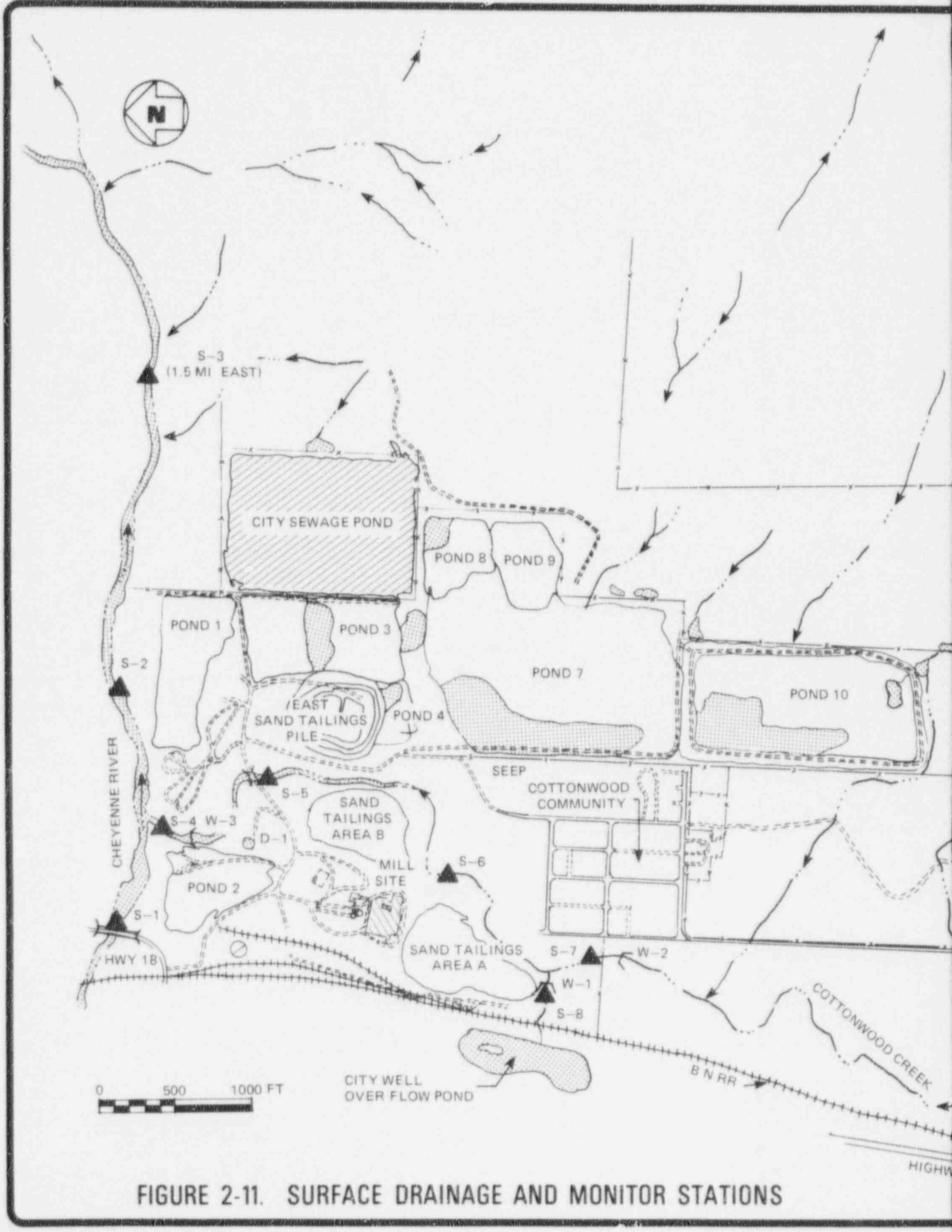
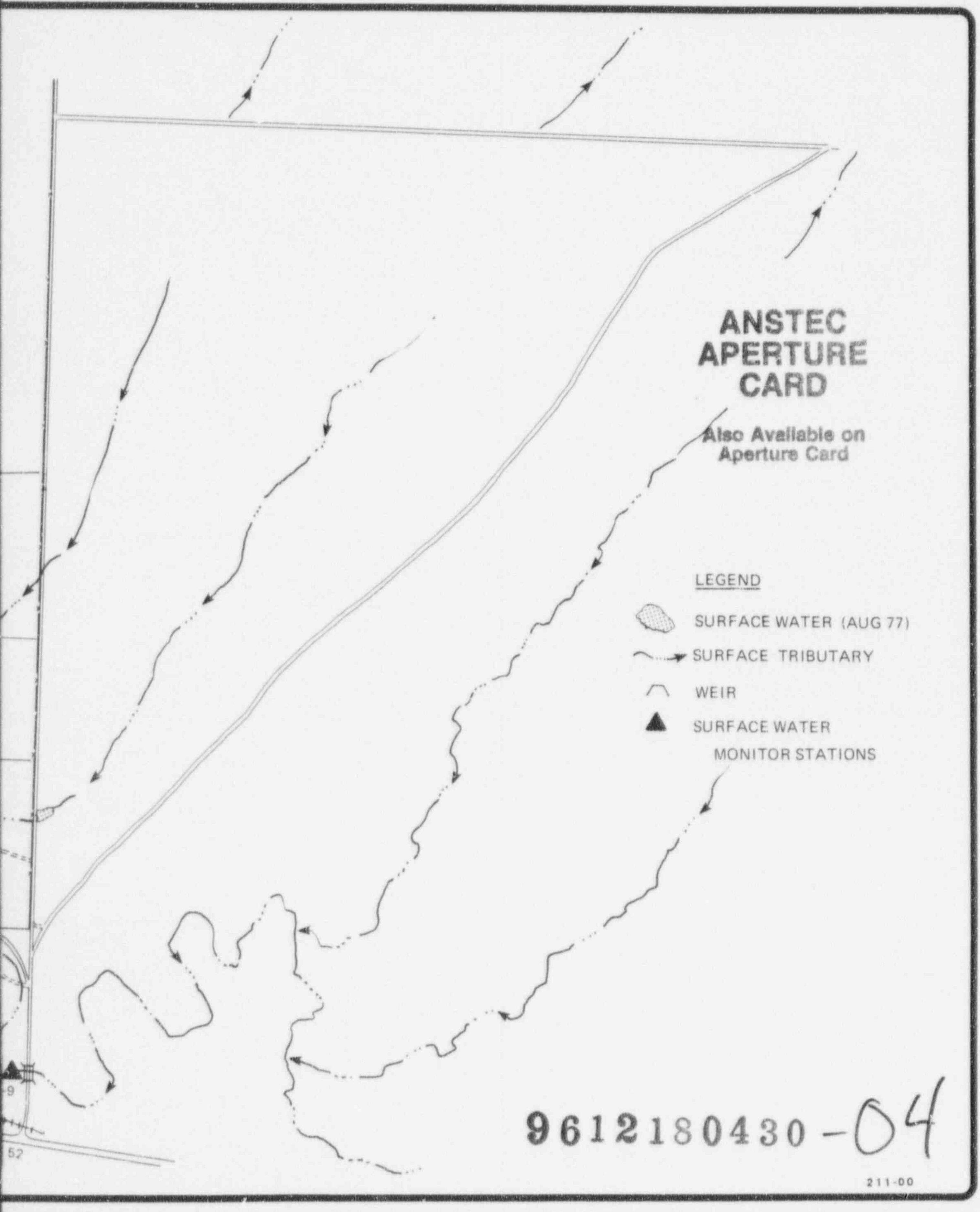


FIGURE 2-11. SURFACE DRAINAGE AND MONITOR STATIONS


ANSTEC
APERTURE
CARD
Also Available on
Aperture Card
LEGEND
SURFACE WATER (AUG 77)
SURFACE TRIBUTARY
WEIR
SURFACE WATER
MONITOR STATIONS
9
52
9612180430-04
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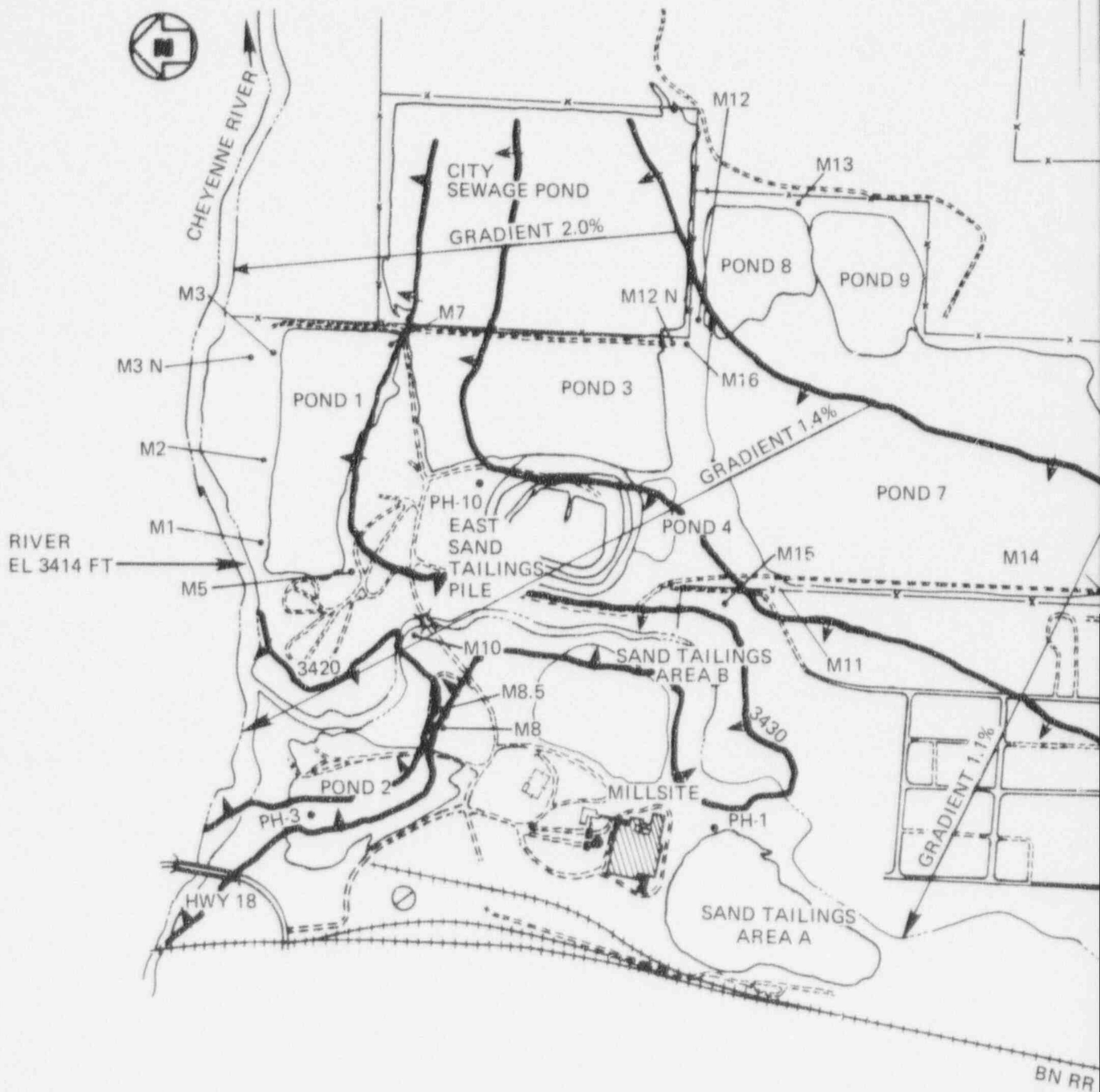

FIGURE 2-12. GROUND WATER LEVEL CONTOUR AND FLOW DIRECTION MAP

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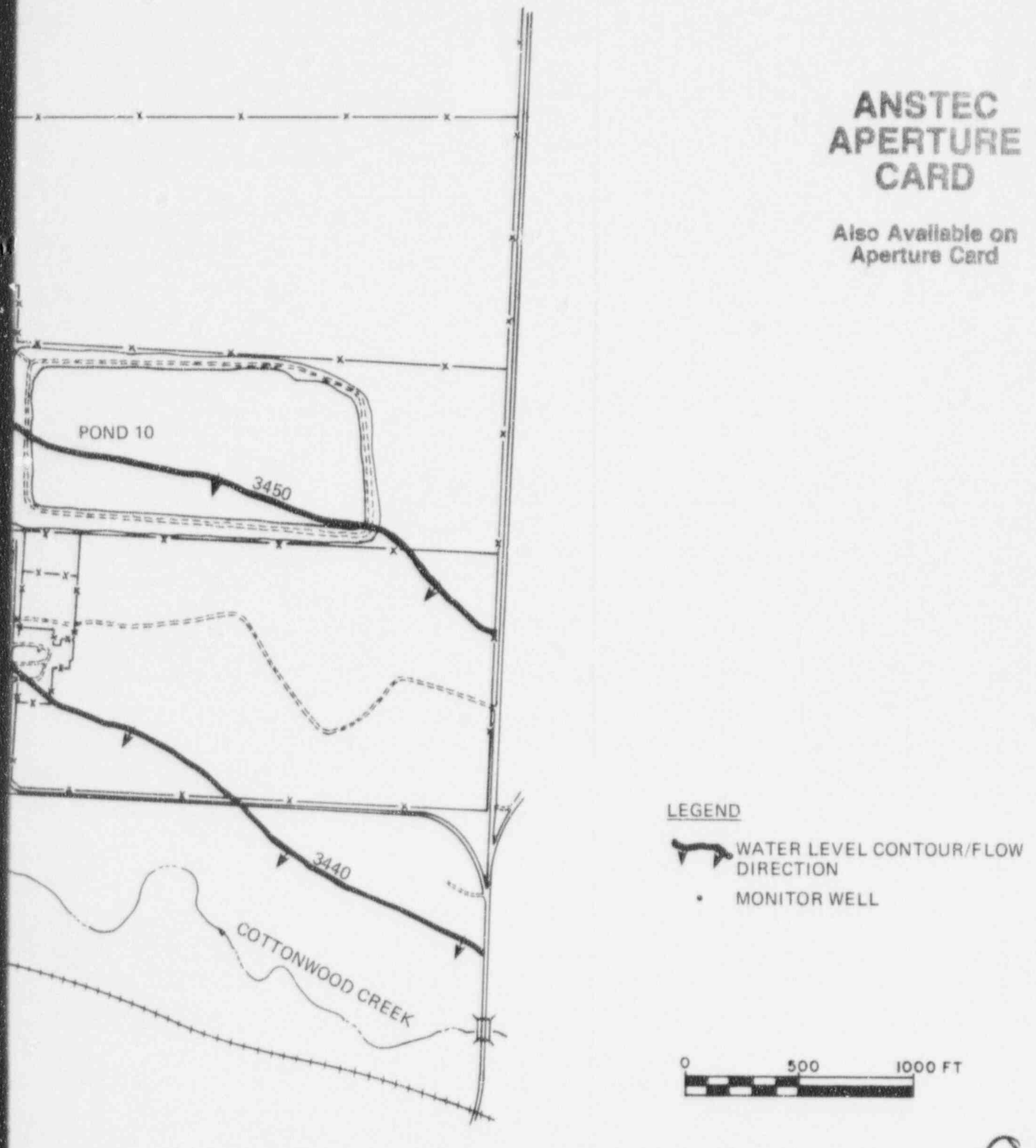

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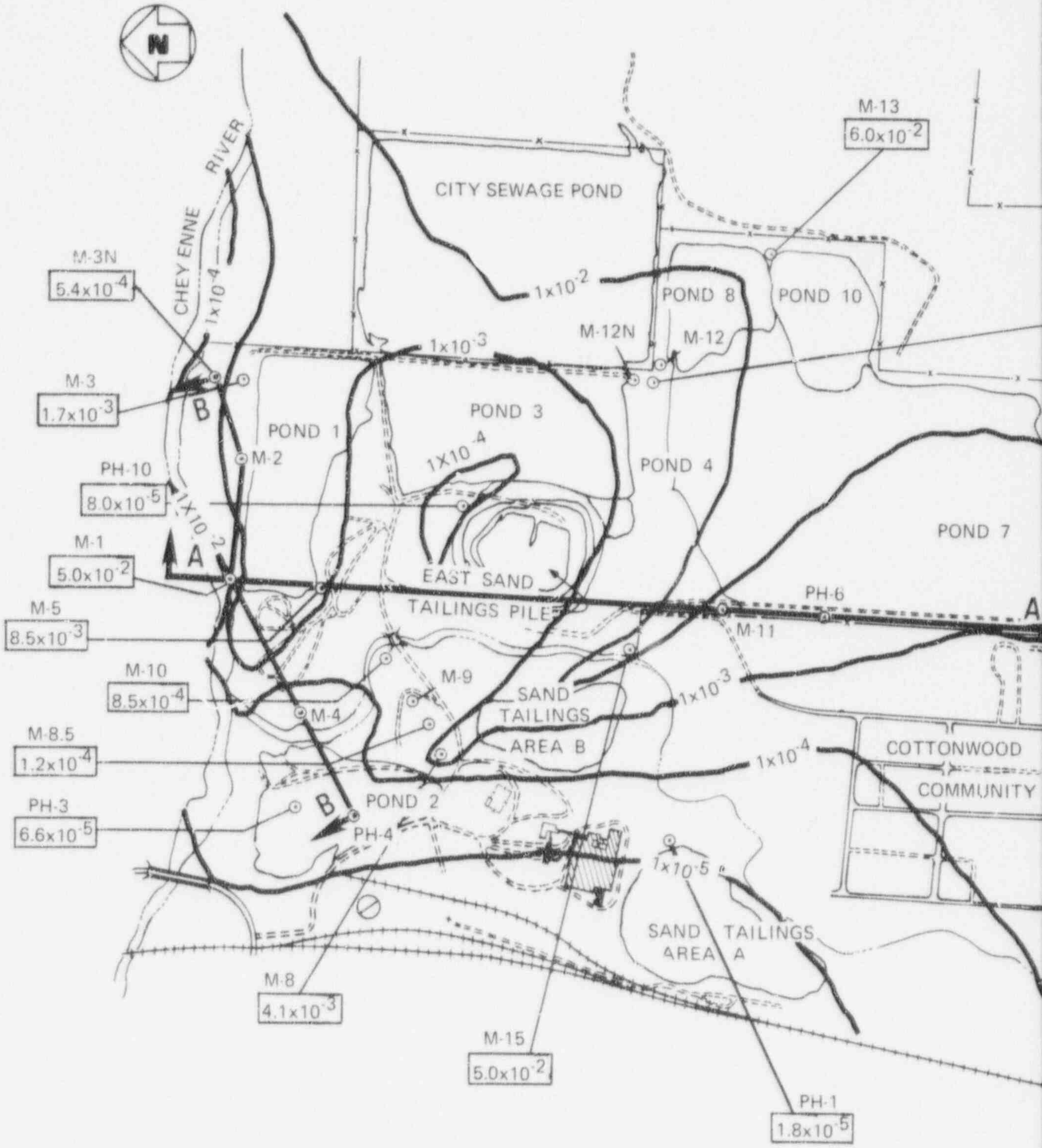
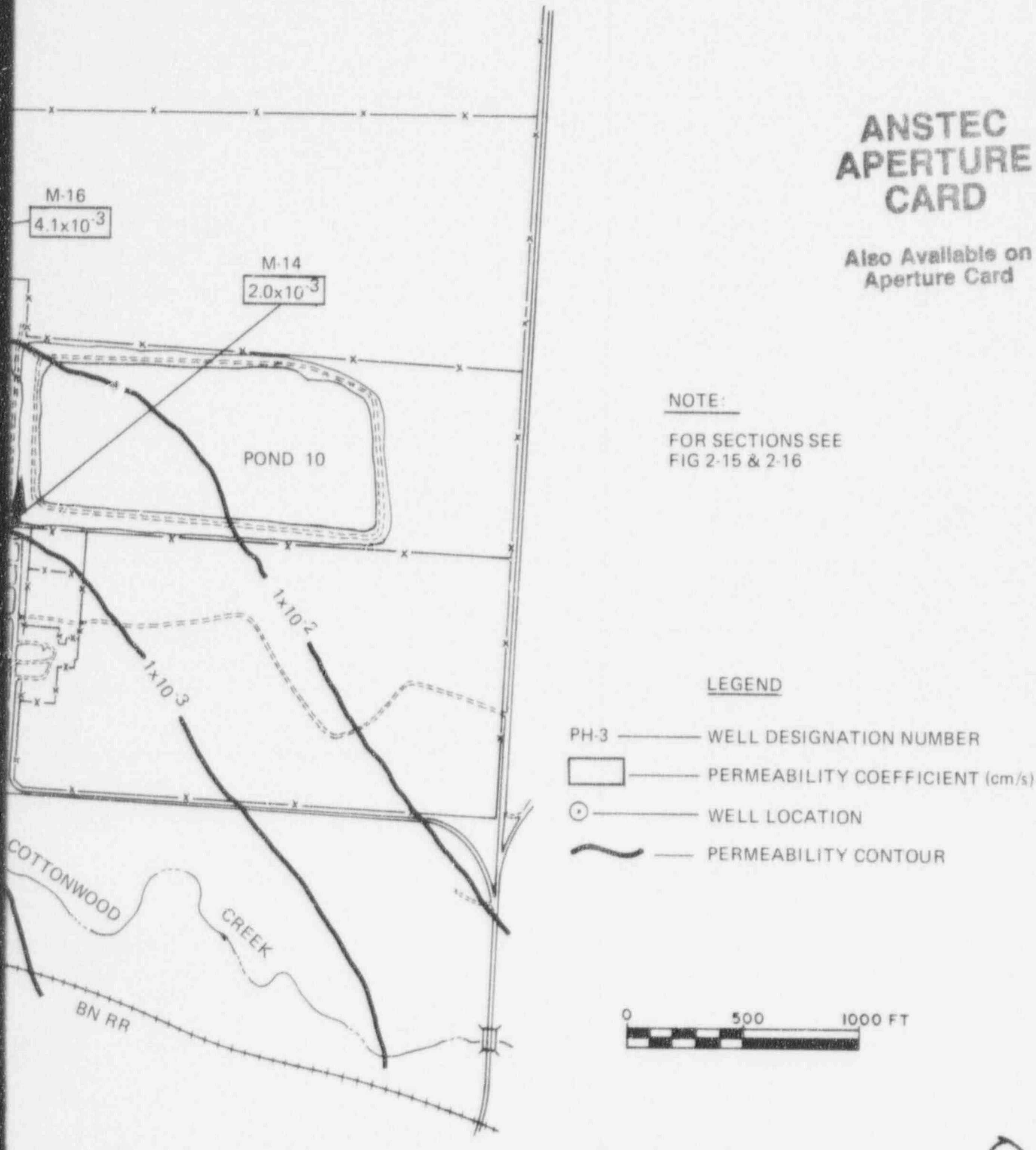


FIGURE 2-13. HORIZONTAL PERMEABILITY COEFFICIENT CONTOUR MAP

Ford, Bacon & Davis Utah Inc.



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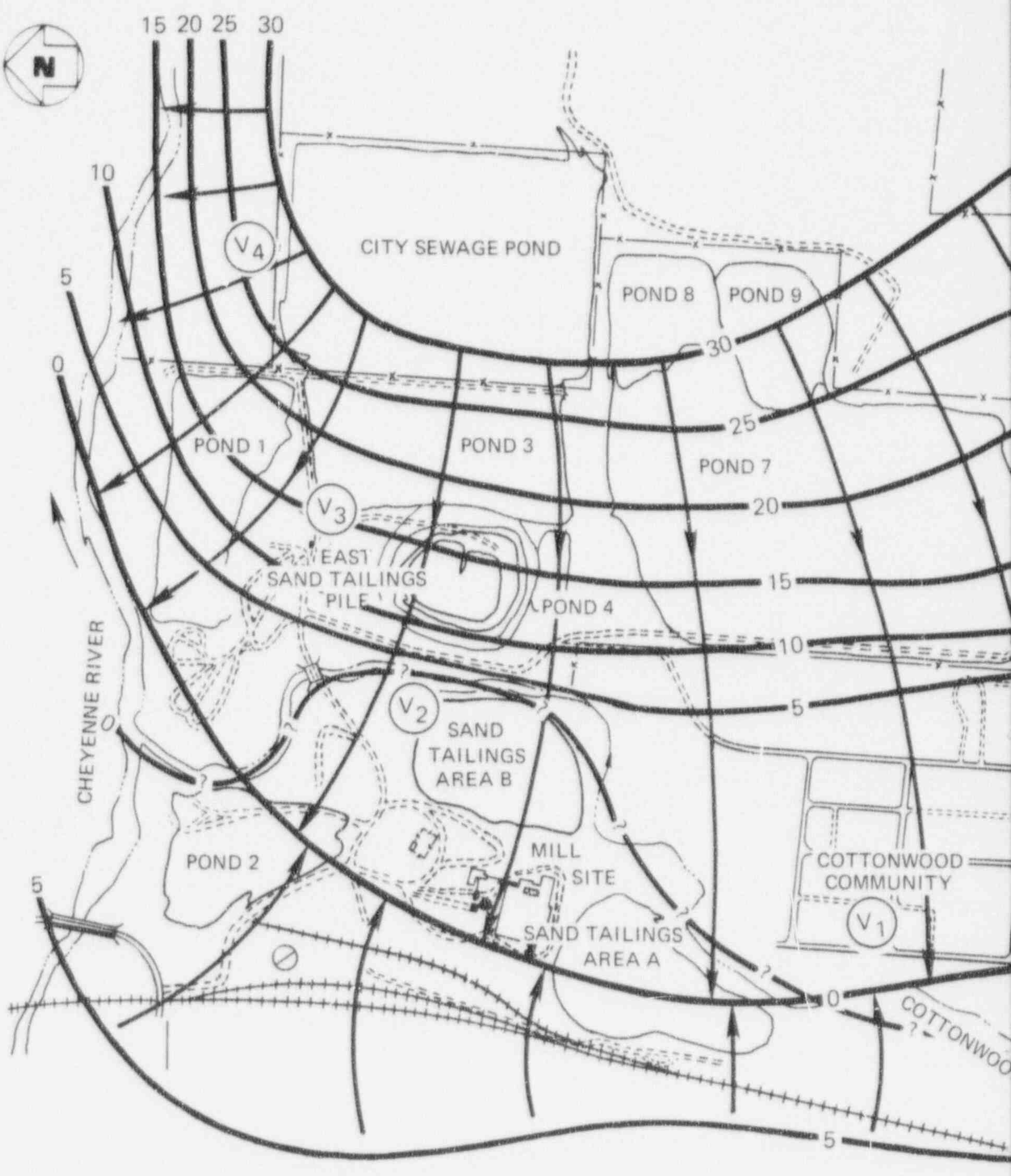
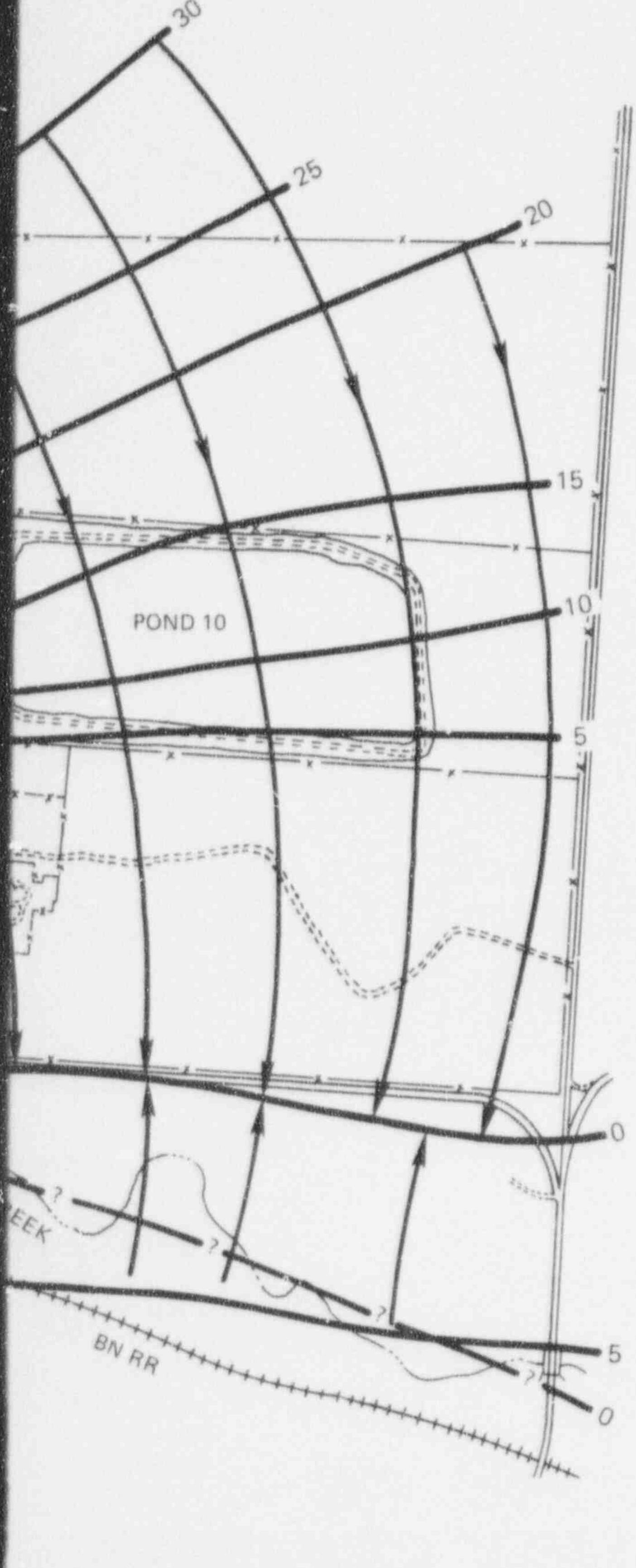


FIGURE 2-14. UNCONFINED GROUND WATER VELOCITY FLOW NET MAP



LOCATION	HORIZONTAL VELOCITIES
V_1	0.35 m/yr
V_2	4.4 m/yr
V_3	15.8 m/yr
V_4	27.0 m/yr

NOTES:

1. VELOCITIES CALCULATED FROM FIELD DATA AND CHECKED WITH INTERA FLOW MODEL
2. INTENT OF VELOCITY FLOW NET IS TO SHOW FLOW DIRECTION IN RELATION TO VELOCITY RATHER THAN HEAD POTENTIAL. LOW HEAD CONVERGENCE IS ESTIMATED AS SHOWN.

LEGEND

- 10 — EQUIPOTENTIAL LINE (VELOCITY) (m/yr)
- → VECTOR FLOW PATH
- (V_1) KEY FLOW ZONE
- —?— PROBABLE LOW GRADIENT CONVERGENCE POTENTIAL

0 500 1000 FT

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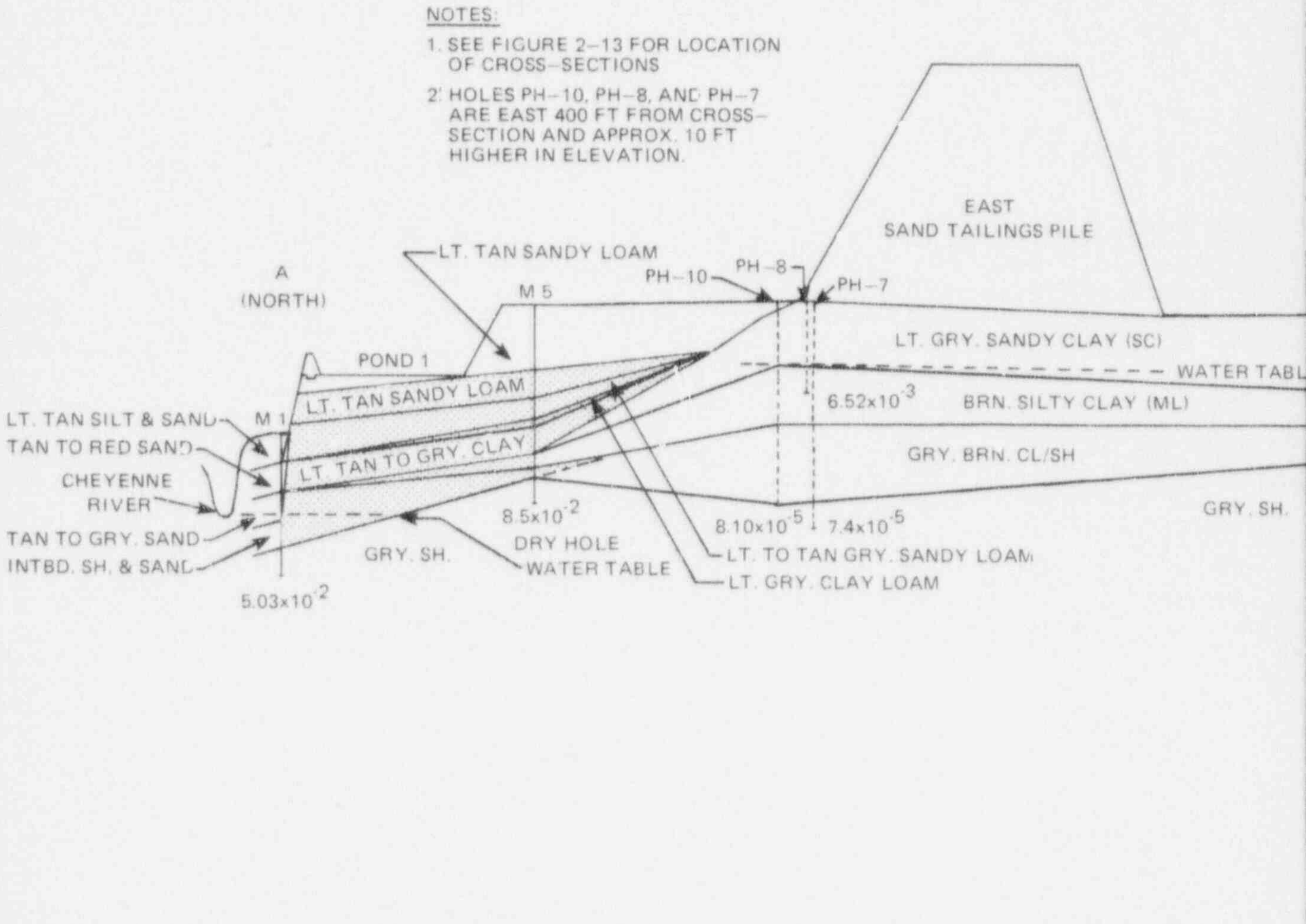
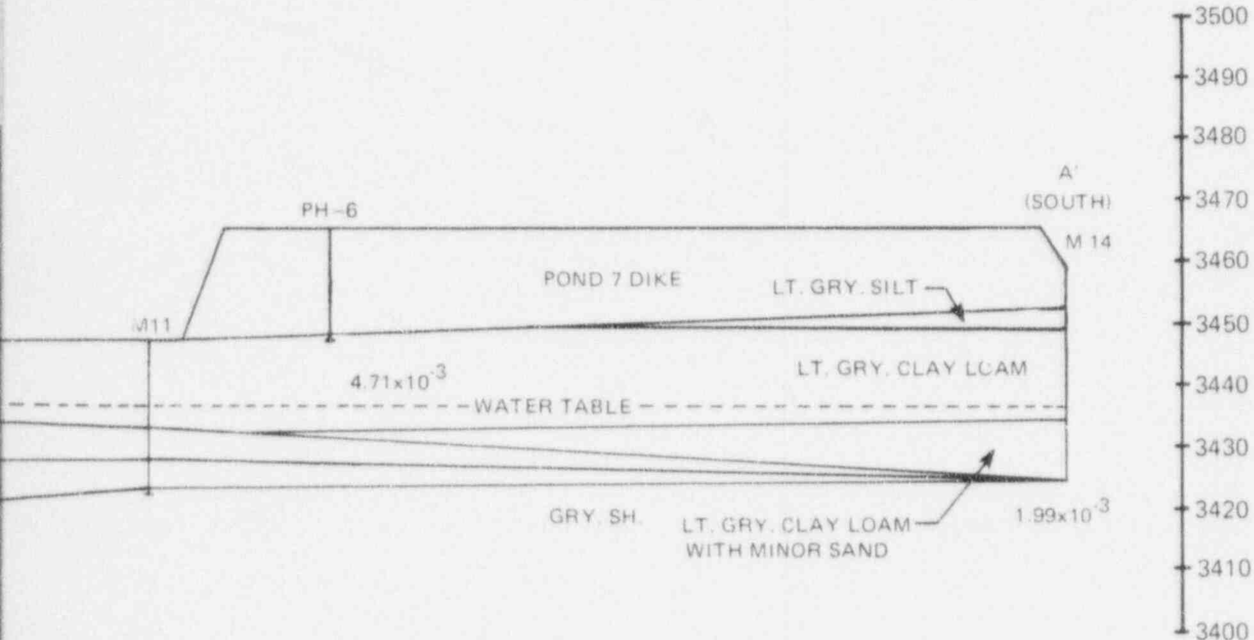
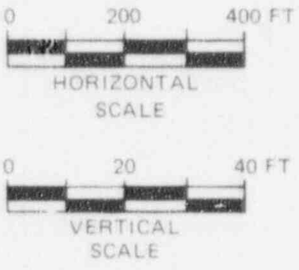


FIGURE 2-15. STRATIGRAPHIC SOIL PERMEABILITY CROSS-SECTION (A-A')



LEGEND
M 1 – MONITOR HOLE
PH–4 – PERMEAMETER TEST HOLE
5.03×10^{-2} – PERMEABILITY COEFFICENT (cm/s)
(ML) – SOIL CLASSIFICATION
CHEYENNE RIVER ALLUIAL SOIL SEDIMENTS
SOURCE: TVA/FB&DU



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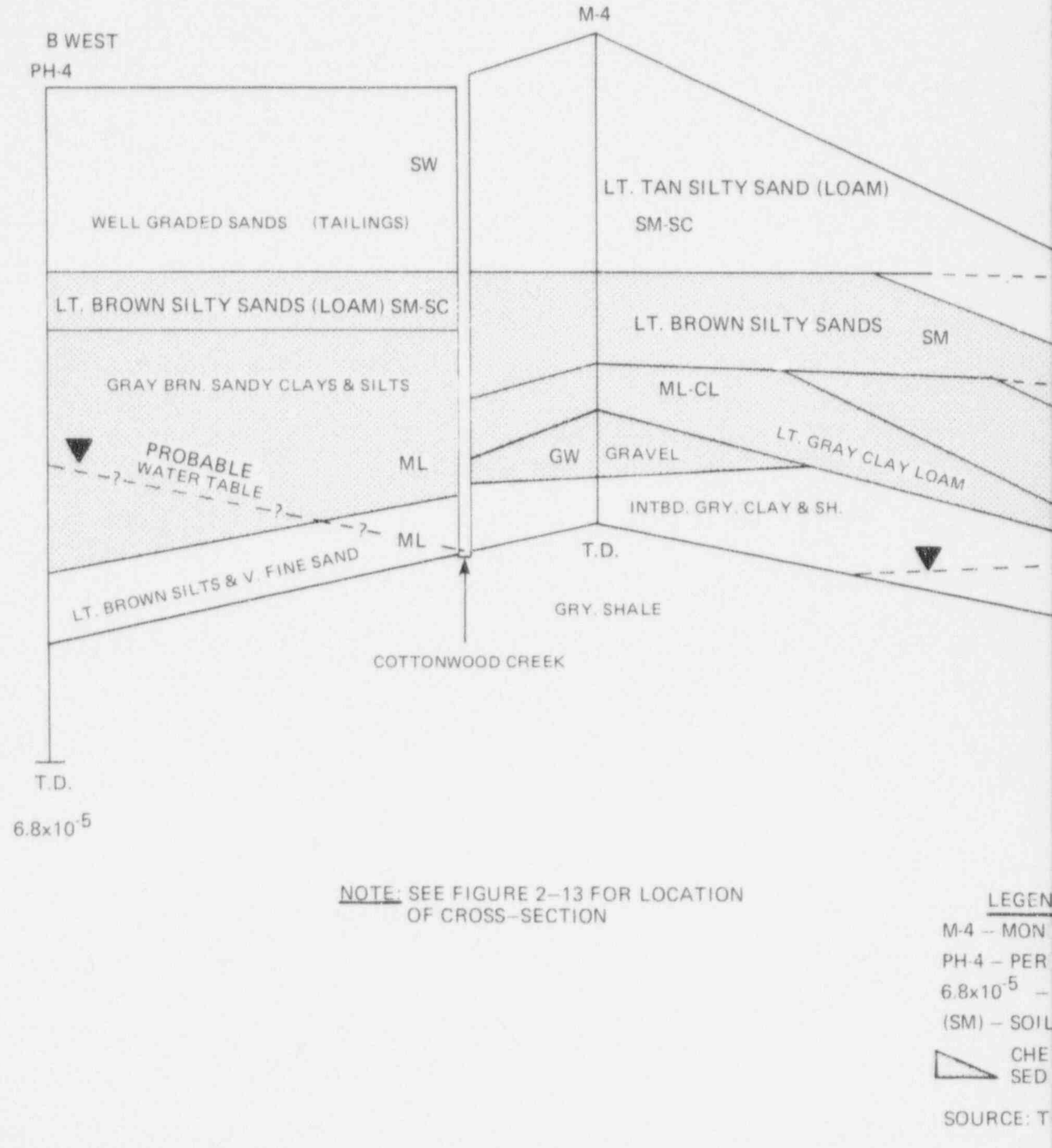

FIGURE 2-16. STRATIGRAPHIC SOIL PERMEABILITY CROSS-SECTION (B-B')

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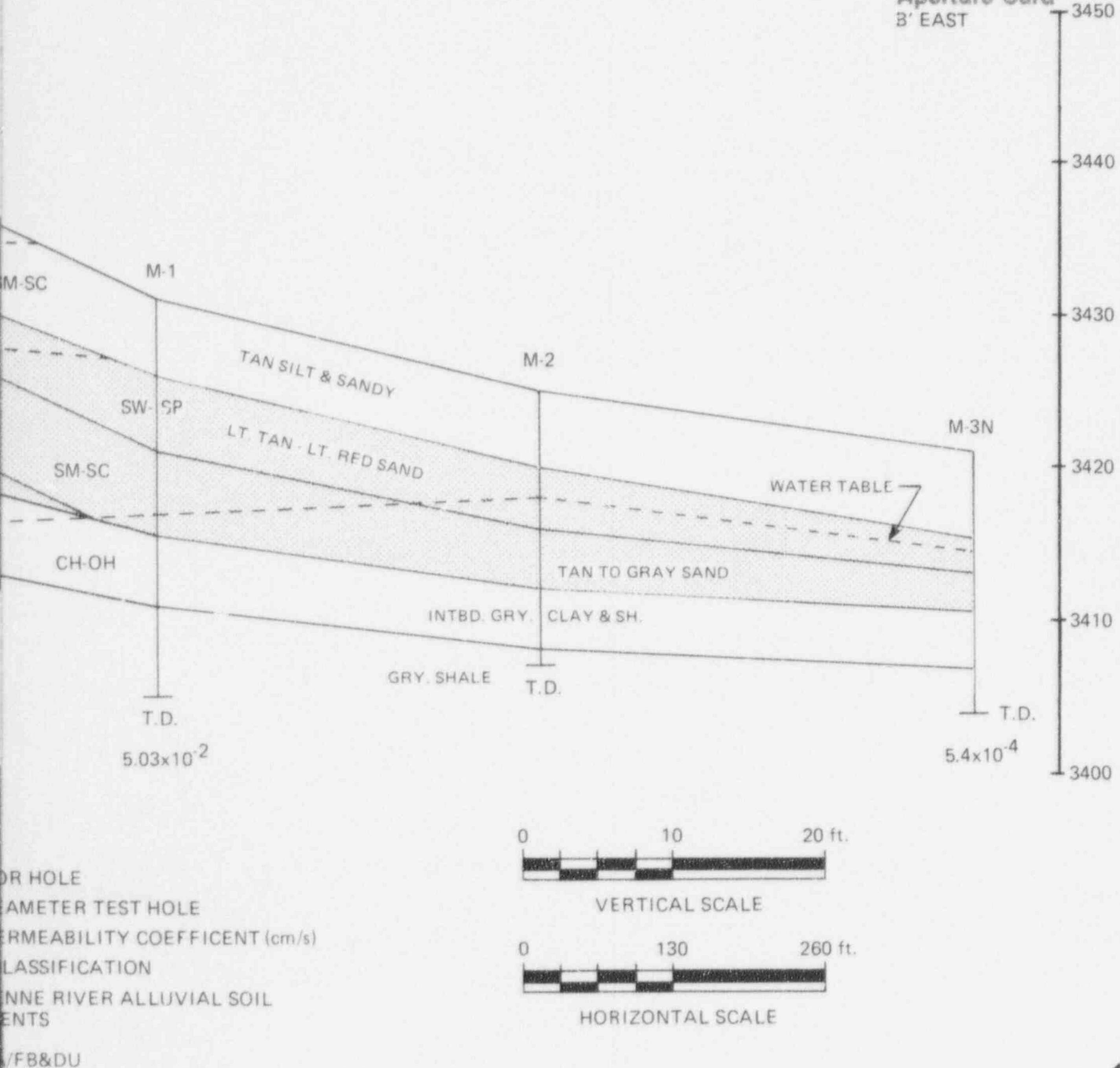

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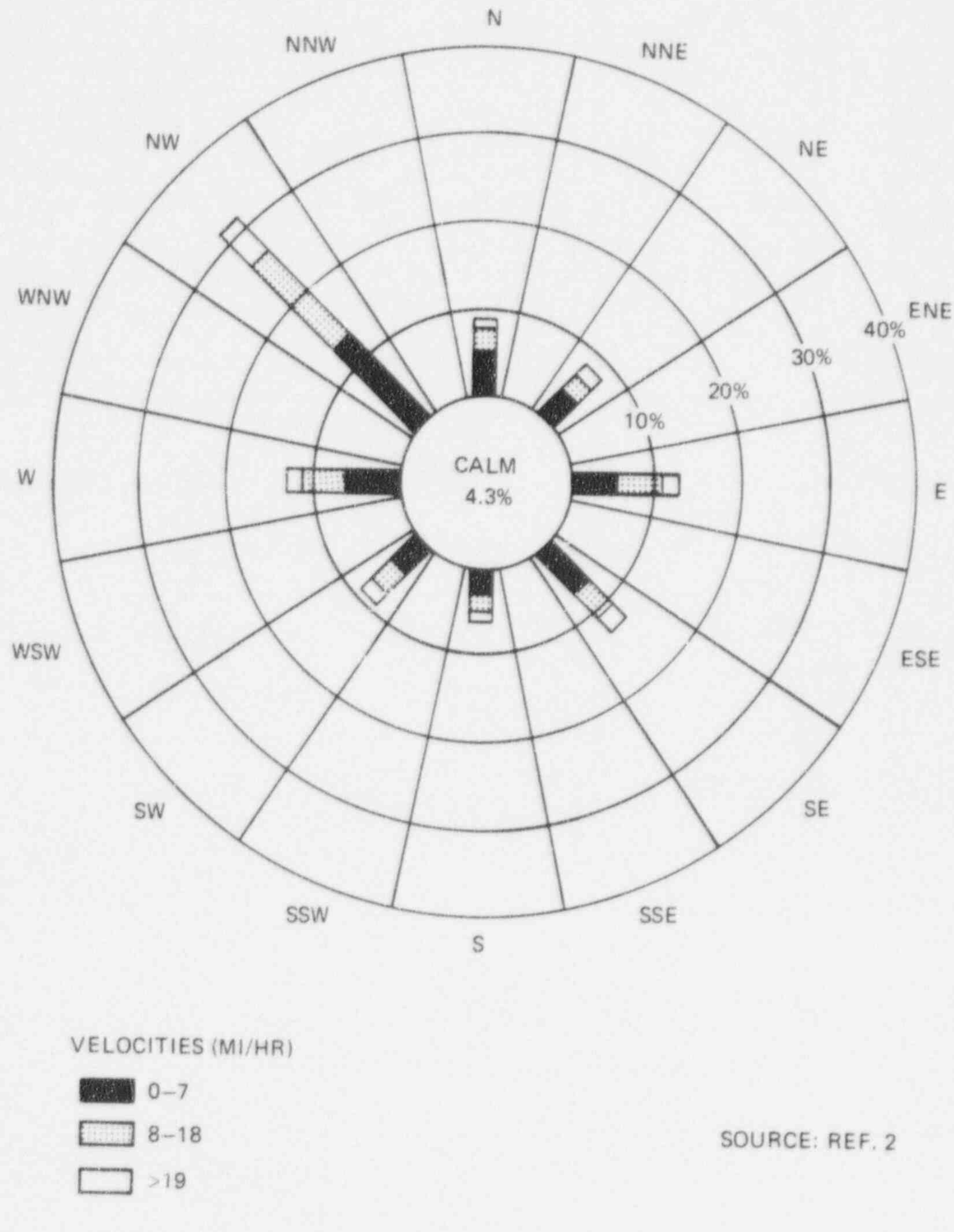

FIGURE 2-17. SURFACE WIND ROSE FROM BLACK HILLS ARMY ORDNANCE DEPOT

211-00

TABLE 2-1

TAILINGS AND RELATED MATERIALS
PRESENT ON SITE

Pile or Location	Material	Volume (yd^3)	Weight (tons)	Acres
1	Sand Tailings	43,000	64,000	
	Slime Tailings	25,000	40,500	
	Totals	68,000	104,500	7
2	Sand Tailings	295,000	438,000	
	Stabilization Cover	30,000	50,600	
	Totals	325,000	488,600	9.2
3	Slime Tailings	60,000	97,200	
	Slag Tailings	15,000	19,200	
	Totals	75,000	116,400	10.4
4	No Solids	--	--	0.6
Area Between 4 and 7	Sand Tailings	39,000	58,000	
	Stabilization Cover	9,700	16,400	
	Totals	48,700	74,400	2.4
7	Sand Tailings	85,000	126,000	
	Slime Tailings	115,000	186,300	
	Stabilization Cover	60,000	101,300	
	Totals	260,000	413,600	33.8
8	Slime Tailings	26,000	42,000	
	Vanadium Fly Ash Tailings	55,000	70,500	
	Totals	81,000	112,500	6.0
9	Tailings	50,000	75,000	
	Stabilization Cover	18,000	30,400	
	Totals	68,000	105,400	5.0

TABLE 2-1 (Cont)

TAILINGS AND RELATED MATERIALS
PRESENT ON SITE

Pile or Location	Material	Volume (yd^3)	Weight (tons)	Acres
10	No Tailings	--	--	
	No Cover	--	--	
	Totals	0	0	24.0
Sand Tailings Area A	Sand Tailings	185,000	275,000	
	Stabilization Cover	26,000	44,000	
	Totals	211,000	319,000	7.5
East Pile	Sand Tailings	520,000	772,000	
	Totals	520,000	772,000	11.0
Sand Tailings Area B	Sand Tailings	36,000	53,500	
	Earth Cover	14,300	24,100	
	Totals	50,300	77,600	6.5
Summary	All Tailings	1,546,000	2,317,400	
	Stabilization	158,000	266,800	
	Acres			123.4

Notes:

1. The estimated volume of materials in all contaminated dikes on site is 225,000 yd^3, or 365,000 tons. The amount of contaminated subsoil beneath the piles per foot of contamination is 150,000 yd^3, or 284,000 tons.

2. Assumed average weights of materials in lb/ft^3 are: sand tailings, 110; slime, 120; slag, 95; stabilization cover, 125; dikes, 125; and subsoil, 140.

TABLE 2-2

COTTONWOOD CREEK SURFACE FLOW DATA

Date	Time	2-ft Rect Wier 2 Upper Cottonwood		90° V-Wier 1 City Overflow		2-ft Rect Wier 3 Lower Cottonwood		Wier 1 + Wier 2	
		sec-ft	gpm	sec-ft	gpm	sec-ft	gpm	gpm	sec-ft
11/18/77	08:00	0.1831	82	0.125	56	0.6759	304	139	0.3081
11/18/77	16:20	0.2033	91	0.129	58	0.6759	304	150	0.3323
11/20/77	14:05	0.2623	118	0.109	49	0.6201	279	167	0.3711
11/21/77	15:20	0.3193	144	0.112	50	0.6201	279	194	0.4313
11/22/77	--	0.2907	131	0.112	50	0.5838	263	181	0.4027
11/23/77	15:20	0.2907	131	0.112	50	0.5835	263	181	0.4027
11/25/77	15:20	0.4622	208	0.129	58	0.7139	321	266	0.5912
11/26/77	14:40	0.4456	201	0.121	54	0.5481	247	255	0.5666
11/27/77	13:20	0.4130	186	0.121	54	0.5132	231	240	0.5340
11/30/77	08:00	Frozen	--	0.108	49	0.7370	332	--	--
Average		0.3189	144	0.118	53	0.627	282	197	0.4369

TABLE 2-3

PERMEABILITY COEFFICIENTS OF THE UNCONFINED GROUND WATER AQUIFER

Monitor Well	Coefficient of Permeability (cm/s)
M-1	5.03×10^{-2}
M-3	1.73×10^{-3}
M-3N	5.44×10^{-4}
M-5	8.50×10^{-3}
M-8	4.36×10^{-3}
M-8.5	1.22×10^{-4}
M-10	8.46×10^{-4}
M-13	6.07×10^{-2}
M-14	1.99×10^{-3}
M-15	5.04×10^{-2}
M-16	4.1×10^{-3}
PH-1	1.83×10^{-5}
PH-2	4.0×10^{-6} (a,b)
PH-3	6.6×10^{-5}
PH-4	6.8×10^{-5} (a,b)
PH-5	3.95×10^{-3} (b)
PH-6	4.71×10^{-3} (b)
PH-7/8	6.52×10^{-3} (b)
	7.4×10^{-5} (a,b)
PH-9	3.91×10^{-3} (b)
PH-10	8.10×10^{-5}

(a) Values determined by laboratory analysis on re-compacted soil samples[13]

(b) Vertical permeabilities

CHAPTER 2 REFERENCES

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

3.1 RADIOACTIVE MATERIAL CHARACTERISTICS

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

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

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

The activity and the total number of radioactive atoms of a particular type depend upon their creation rates as well as their

half life for decay. If left undisturbed, the radioactive components of the decay chain shown in Figure 3-1 all reach the same level of activity, matching that of the longest-lived initiating isotope. This condition is known as secular equilibrium. When the uranium is removed in the milling process, ^{230}Th, which is not removed, becomes the controlling isotope. After processing the ore for uranium, the thorium, radium, and other members of the decay chain remain in the spent ore solids in the form of a waste slurry. The slurry is pumped to tailings ponds. The sands and slimes that remain after evaporation of the solutions constitute the tailings piles. Generally, as at Edgemont, 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 still cause damage mainly to the skin or internal tissues when taken internally. Gamma rays, however, are more penetrating than X-rays and can interact with all of the tissue of an individual near a gamma-emitting material.

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

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

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

of 1 rad or a gamma dose of 1 rem.

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 of ^{226}Ra concentration, from the ^{238}U decay chain, in seven soil samples from five locations was 1.3 pCi/g. The samples were taken within 4 mi of the site. The ^{226}Ra, ^{230}Th, and ^{210}Pb concentrations in each of the background samples are listed in Table 3-2 and locations are shown in Figure 3-2. Sample C1 taken in Gull Hill Park was sandy soil and has a low radium content. The soil samples taken at canister locations C2 and C3 were typical of weathered shale, and are therefore more representative of the larger radium content in the shale in the vicinity of the Edgemont site, especially east of the site.

The average concentration of soluble ^{226}Ra in five well water samples within 3 mi of the site, not including the town of Edgemont, was 0.44 pCi/l, but the average soluble ^{226}Ra concentration in three wells in Edgemont was 4.0 pCi/l. Six background samples from surface waters within 1 mi of the site had an average soluble ^{226}Ra concentration of 0.54 pCi/l. These water sample analyses and others are discussed in paragraph 3.4.5. Additional sampling results were reported by the EPA in 1971[(1)] and 1973.[(2)]

Background values of ^{222}Rn concentration were measured at two locations, 3.3 mi south and 1.3 mi west of the mill building, using continuous radon monitors.[(3)] Week-long measurements plus two 24-hr measurements indicated an average radon concentration of 1.4 pCi/l in the area. The two week-long measurements individually averaged 1.7 and 1.2 pCi/l. The measurement locations and data are shown in Figure 3-3. The measurements at all background locations ranged from 1.1 to 1.7 pCi/l of ^{222}Rn.

Radon flux was measured at three background locations using charcoal canisters. The average radon flux was 2.8 pCi/m^2-s. Locations and individual values are shown in Figure 3-2. The average background flux value may be higher than normal because surface concentrations of ^{226}Ra in two soil samples were higher than those in the soil 6-in. deep. These surface soil sample concentrations were not used to obtain the average soil concentration. Also, the background measurements were made on shale which has a higher ^{226}Ra content than sandy or rocky soil. A canister placed on rocky soil (C1) was stolen, and therefore that flux determination was not included in the average flux.

Background gamma ray levels, as measured 3 ft above ground, also were determined at 11 locations within 5 mi of the site by

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(1) See end of chapter for references.

using a pressurized ion chamber (PIC) detector. An average value of 13 μR/hr was obtained. Cosmic rays are part of the measured background radiation levels. The locations and measured gamma radiation rates are shown in Figure 3-2. The contribution from cosmic rays is generally dependent upon the altitude and is approximately 5 μR/hr in the Edgemont area,[4] or approximately 40% 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 which can occur.

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

3.4.1 Radon Gas Diffusion and Transport

Measurements of the radon exhalation flux from the tailings using the charcoal canister technique[5] are listed in Table 3-3 and shown in Figure 3-4. The background radon flux in the area averaged 2.80 ± 0.66 pCi/m^2-s. Flux on the tailings ponds ranged up to a high of 970 pCi/m^2-s measured at pond 3. Measurements on ponds 8, 9, and 10 were a few times the average background flux. There was no rainfall during or immediately preceding the flux measurements, although the surface of some of the ponds were moist during the measurement period. Radon flux depends principally on radium content of tailings. In general, reported values of radon flux vary considerably from time to time at a single sampling location due in part to differing moisture in the soil, to changes in pile configuration between measurements, and to the difficulty in performing such measurements. These measurements are within the range of those obtained by the DOE Environmental Measurements Laboratory (EML) taken on the sand tailings area A and the East sand tailings piles.[6]

Radon gas above background has been detected at a distance of 0.7 mi west of the tailings site. During the August 1977 survey, winds blew from the pile towards Edgemont for several days although that is not the prevailing wind direction. Measurement locations and corresponding 24-hr average radon concentrations are illustrated in Figure 3-3. The average background radon concentration was 1.4 pCi/l for two background locations. To the west of the site, the average background value was 1.2 pCi/l.

Variations in radon concentration at two locations during the measurement period and the existing weather conditions are shown in Figures 3-5 and 3-6. The sample location for Figure 3-5 is outside of the mill office building on the north side. Figure 3-6 illustrates the measurements 0.4 mi west of the tailings site. Increased concentrations of ^{222}Rn at night may be observed in both figures. The 24-hr averages and 7-day averages include these diurnal variations. A plot of the radon concentration during a 7-day period, 3.3 mi south of the site, had increased radon concentration during two of the seven nights accounting for an average concentration higher than the baseline value. Thus, the higher-than-normal background values are partly the result of including such peaks. These 24-hr measurements were obtained during atmospheric conditions normal for that time of year (August and November). 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 velocity winds tend to disperse the radon and generally do not result in significantly higher measurements of radon concentration downwind from the tailings piles.

The radon concentration measurements are plotted in Figure 3-7 as a function of distance from the nearest edge of the tail-

ings piles. Also shown in the figure are the FB&DU model results. 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 piles with diffusion theory using radium soil concentrations, and pile configurations deduced from the drilling and survey data. Then, the radon transport off pile is calculated by Gaussian diffusion[7] plus wind drift conditions. Meteorology data were obtained from a weather station on pond 2 during the period of the tests as well as annual data from the Black Hills Army Ordnance Depot from 1962 to 1967.[8]

The model curve, not including background, was used to calculate potential health effects resulting from radon diffusion from the Edgemont tailings, and the health effects from groups of piles, shown in Figure 3-3, were summed to get the total Edgemont health effects.

3.4.2 Direct Gamma Radiation

The external gamma radiation (EGR) levels measured on the tailings piles and around the site are shown in Figures 3-8 and 3-9. These measurements include background of about 13 μR/hr and were taken with a calibrated Geiger Mueller detector and a PIC detector. The highest gamma radiation rate of the Edgemont piles (3,780 μR/hr) was measured on the eastern portion of pond 1. Gamma radiation above 1,000 μR/hr was measured on ponds 1, 2, 3, and 7. Gamma measurements on stabilized piles or ponds ranged between 19 and 320 μR/hr or an order of magnitude less than the gamma radiation found on unstabilized piles. Some soil has been excavated along the edge of pile 2, which had apparently disturbed the pile surface cover. Gamma measurements as high as 1,080 μR/hr were found in this area. The eastern portion of pond 7 was being covered with about 3 ft of soil during the time these gamma measurements were being taken. As shown in Figure 3-8, one gamma measurement transverse was made across both stabilized and unstabilized areas on pond 7. The stabilization cover reduced the measured gamma radiation by more than an order of magnitude. In the mill area gamma radiation was measured from 26 μR/hr, two times background, to 190 μR/hr.

Gamma rate measurements away from the tailings piles, taken at 100-yd intervals, reached background levels at about 0.1 mi or less to the west towards Edgemont and to the south. One and one-half times the average background gamma rate was reached 100 yd north of the Cheyenne River, and 0.25 mi east of ponds 1 and 8. Towards the southeast, where wind has carried tailings, the gamma rate was about twice background, one-third of a mile from pond 9. In Figure 3-9, these gamma radiation rate measurements are shown for the vicinity of the Edgemont tailings piles. The reduction of gamma radiation as a function of distance from the piles is shown in Figure 3-10.

3.4.3 Radiation Measurements Inside Mill Structures

A preliminary radiological survey of the buildings on the Edgemont site was performed to determine the magnitude of the contamination of the structures and processing machinery. Measurements were taken of direct surface activity, gross smearable surface activity, and beta-gamma dose rates at 3 ft above the surface.

A Technical Associates Model PUGIAB and a PAS 9 100 cm^2 alpha scintillation detector were used to make the measurements of alpha contamination. The detector has an area of 100 cm^2 of which about 30% is shielded by a grid protecting the detector. A smear area of 1 ft^2 was generally used to determine smearable contamination.

The measurement locations in the mill and office buildings are illustrated in Figure 3-11, and the measured values are listed in Table 3-4. The measurements indicate alpha contamination levels ranging from 175 to 5×10^5 dpm/100 cm^2 with average contamination levels greater than 10^3 dpm/100 cm^2. This exceeds the NRC criteria for unrestricted use of such facilities given in Appendix B.2 for surface activity and fixed contamination. Generally, the areas of high smearable contamination were on or near highly contaminated processing equipment. Uncorrected surface dose rate measurements on the floor adjacent to the yellowcake dryer indicated beta-gamma dose rates of 150 mR/hr at the surface. At 3 ft the dose rate in the dryer area reached 10 mR/hr.

The concrete has been etched or eroded in most areas and contamination has permeated into the concrete and probably into the soil beneath the foundation in a few areas. Surveys of the eroded concrete indicated alpha levels of 10^3 to 10^4 dpm/100 cm^2.

Measurements on vertical surfaces showed alpha activity in the range of 10^2 to 10^4 dpm/100 cm^2. Decontamination would require cleaning with commercial decontamination solvents, sand blasting, or wire brushing.

The upper floors of the mill building also were moderately contaminated, especially near the resin tanks, the dryer, and the air scrubber.

Surveys of the FeV building, the oil storage area, the garage, and other mill buildings indicated alpha levels ranging from 350 to 1,000 dpm/100 cm^2.

The alpha survey of the office building showed activities of 350 to 525 dpm/100 cm^2 on the floors, but little or no contamination was found on the vertical surfaces surveyed.

In general, contamination levels in buildings on the site exceeded the alpha activity permitted for release of the buildings for unrestricted use. Thus, the buildings would have to be decontaminated or demolished and buried. Decontamination of equip-

ment would be decided upon an individual basis considering the cost of decontamination and the usefulness and value of the equipment.

3.4.4 Windblown Contaminants

The approximate extent of windblown contamination is outlined in Figure 3-9. The location of the line was determined primarily from measurements made with a scintillation detector 1 ft above the ground surface with and without a 0.5-in.-thick lead shield between the detector and the ground. The difference between the two readings (Δ) is a measure of the extent of surface contamination.[9] Some difference in readings exists even at background locations as a result of natural radioactivity in the soil. The line in Figure 3-9 was drawn where the Δ characteristic of background was reached during each gamma measurement traverse away from the site. The line does not indicate background gamma rates because gamma shine from the tailings piles and from windblown tailings inside the line add to the background gamma rate at measurement locations on and beyond the line.

Soil samples were taken at 200-yd intervals along the gamma measurement traverses from the surface and 6 in. beneath the surface. The ^{226}Ra concentrations in these samples and additional samples collected by the TVA are shown in Figure 3-12, and Table 3-5 lists ^{230}Th and ^{210}Pb concentration in addition to the ^{226}Ra concentration. The extent of soil contamination is generally in agreement with the determination of the extent of windblown tailings by the scintillation counter Δ measurement. However, a relatively high value of ^{226}Ra in a surface sample 400 yd east of pond 8 is outside the line, although the Δ measurement at that location was not greater than the background Δ value. EPA reported additional sample analyses in the 1973 report[2] and indicated that windblown tailings were found in the backyard of the house immediately west of pond 2.

The concentration of radioactive particulates in air has been sampled periodically at several locations by the TVA.[6] To calculate individual and population doses from the air pathway, the transport of radioactive airborne particulates has been modeled in a manner similar to that used for radon transport. Input parameters were adjusted so that the model predictions fit the air particulate measurements using weather data measured on pond 2. (See Appendix A.1.) Then, radioactive airborne particulate concentrations were calculated at locations in the Cottonwood Community and in Edgemont using annual meteorology data from Black Hills Army Depot because only limited air particulate measurement data were available and an annual measurement program such as that of Regulatory Guide 4.14 has not been initiated. The results of the model calculations of ^{226}Ra particulate concentration are plotted in Figure 3-13. Airborne particulate fallout on the ground also was calculated to determine dose to the population from the resulting gamma radiation. These

particulate fallout rates are also plotted in Figure 3-13 at the same locations where the airborne concentrations were determined.

3.4.5 Surface and Ground Water Contamination

Water samples have been collected periodically by the TVA from surface waters near the site and from monitor wells on the site.(6) During the two field surveys conducted by FB&DU, additional water samples were collected from the Cheyenne River, Cottonwood Creek, monitor wells and from wells off the site owned by individuals and by the City of Edgemont. This additional information was used for determining a radium balance in Cottonwood Creek (Appendix A.2) to determine if significant additions of radium enter the creek as it passes through the Edgemont site and the effect of the site on the Cheyenne River. The radium balance showed little if any addition of radium to the creek from the tailings ponds via the ground water. Analyses of water from monitor wells were performed as part of the effort to determine any contribution of contaminants to the ground water by the tailings piles. This ground water eventually reaches the Cheyenne River.

Analyses of water samples collected during the field survey periods in August and November of 1977 are presented in Figures 3-14 and 1-15 and Tables 3-6 and 3-7. Additional data from a water quality monitoring program conducted by the TVA is included in Table 3-6. EPA also has collected and analyzed samples from the area.(1,2)

Figure 3-14 shows the location and ^{226}Ra concentration in water samples taken off site. Figure 3-15 presents similar data for water samples taken on the site. A listing of the ^{226}Ra, ^{230}Th, and uranium concentrations in the water samples is given in Table 3-6. Chemical analyses for the samples are listed in Table 3-7.

Data on radium content of water samples taken over a period of several years are shown in Figure 3-16 for nearby surface waters.(1,2,6) Ground water data from monitor wells drilled by TVA, shown in Figure 3-17, extend over only 3 yr. Surface water data reflect seeps and accidents such as pipe breaks, and trends are difficult to identify. Trends cannot be established with the limited ground water monitoring data but the analyses of water from monitor wells M-11 and M-14 should be watched closely.

Other than water samples from drill holes or tailings ponds, the ^{226}Ra concentrations in the water samples listed in Table 3-6 are all below the EPA Interim Drinking Water Regulation level of 3 pCi/l, except water from the Edgemont water supply well (4.1 pCi/l), the well flowing into the pond in the city park (4.3 pCi/l), and the Burlington-Northern well (3.6 pCi/l). The latter three samples are from deep wells not affected by the tailings piles. These artesian wells draw water from the Fall River formation, one of the host formations for uranium in the Black Hills.

The ^{226}Ra concentration in all other domestic wells sampled was below 1 pCi/l.

In Table 3-7, comparison of the heavy metal content of water samples with the maximum contaminant levels (MCL) in the Interim Drinking Water Regulations shows that only a few surface and ground water samples (ESD W) exceed the MCL for heavy metals. Samples ESD W-67 and ESD W-69, from standing water on site, exceed several of the heavy metal MCL. Lead content of surface water in the area is generally high but not attributable to the tailings site since upstream samples also are high in lead.

Water samples from several of the monitor wells (ESD M) exceed the MCL. Analyses indicate that seepage from pond 1 reaches monitor wells M-1, M-2, M-3, and M-3N between pond 1 and the Cheyenne River. Surface water analyses from the Cheyenne River upstream (S-52 and S-70) and downstream from the site (S-54 and S-55) show downstream increases in nitrate, zinc, and cadmium. Monitor wells M-1, 2, and 3 are located in an area where fairly high permeability coefficients and the highest horizontal flow velocities are found.

The average soluble ^{226}Ra concentration in 10 samples including TVA data[6] from the Cheyenne River upstream from the site was 0.28 pCi/l, while the average concentration in two samples downstream from the site was 0.42 pCi/l. Cottonwood Creek inflow accounts for the major portion of this increase, but the increased ^{226}Ra in Cottonwood Creek is primarily from the overflow of the pond in the Edgemont city park.

Seepage from pond 7 is evident in the analyses of water from monitor well M-14 and to a lesser extent in M-11. However, comparison of analyses of an upstream sample from Cottonwood Creek (S-51) and downstream samples (S-56 and S-57) indicate increases only in manganese and zinc as the creek flows by the tailings piles. The increase in ^{226}Ra content is due primarily to the city water supply overflow into Cottonwood Creek.

In summation, the site does not contribute effluents to the Cheyenne River that make it unsuitable for drinking water by exceeding current regulations for radioactivity and chemical concentrations.

Appendix A.2 includes water pathway analyses of radioactive pollutants to Cottonwood Creek, the Cheyenne River, and Cottonwood Community. These dose analyses show that the water pathways are not the critical pathways.

3.4.6 Soil Contamination Beneath Tailings

The amount of ^{226}Ra activity in the tailings and the extent of leaching of radium from the tailings into the soil were determined by drilling auger holes in and around the tailings piles and into the soil beneath them. The radioactivity profile was

measured in these holes with a Geiger tube probe with a lead shield that collimates the radiation. Soil samples also were taken from selected holes for radiometric analyses. The locations of the auger holes are shown in Figure 2-3, Chapter 2.

Typical ^{226}Ra activity profiles in the Edgemont tailings and subsoil are shown in Figures 3-18, 3-19, and 3-20. Figure 3-18 is the ^{226}Ra profile in hole ESD-4 in the sand tailings area A. The ^{226}Ra concentration drops rapidly to six times the average ^{226}Ra background concentration but then decreases slowly to background over a depth of 10 ft.

Figure 3-19 illustrates the ^{226}Ra profile in hole ESD-1 drilled through pond 2. The ^{226}Ra decreases to twice the average background concentration about 4 ft below the tailings subsoil interface. There appears to be an additional layer of slight contamination to 13 ft below the interface. The ^{226}Ra concentration profile in hole ESD-10 through pond 9 is shown in Figure 3-20. The ^{226}Ra activity is relatively low in the tailings (60 pCi/g) but it appears that leaching to a depth of 3 ft below the tailings subsoil interface has occurred as indicated by the ^{226}Ra analyses of Shelby tube samples.

Since the drill rig could not be moved onto the unstabilized ponds, a hand auger was used to sample the pile and to provide a hole for logging with the gamma probe. In most cases, water was reached within 6 ft below the surface and the hole could not be kept intact for logging below the water table. Thus, the depth of ^{226}Ra contamination beneath those piles was not determined in this assessment.

Tables 3-8A and 3-8B contain results of analyses of soil samples from the tailings ponds. Table 3-8A includes analyses of vertical composite samples collected during drilling or augering of the tailings ponds and piles. Table 3-8B includes analyses of samples collected by the TVA from the surface and at depth in the various ponds and piles.

In general, ^{226}Ra contamination in the subsoil reached depths of 5 to 6 ft with a range of 2 to 13 ft in the holes measured.

3.4.7 Radium Concentration in Vegetation

Samples of pasture grass were collected from nine locations in the vicinity of the Edgemont site. The leafy material was individually packaged separate from the roots and soil to prevent contamination of the edible portions of the plants. Before ashing the leafy material for radium analyses, it was washed to remove dust adhering to the leaves. The wash water was then also analyzed to determine the extent of contamination by windblown tailings. In Figure 3-21, the locations of the samples and the ^{226}Ra concentration in the plants and that washed from the plants in terms of dry plant material weight are shown. In a few cases, at locations along the east site boundary, soil samples in which

the grass was growing were analyzed for ^{226}Ra content. These are also shown in Figure 3-21.

All the samples along the eastern edge of the site contained more than 1 pCi of $^{226}Ra/g$ of dry plant material. The highest radium concentration in the grass samples (9.2 pCi/g) was taken from the soil sample with the highest ^{226}Ra concentration (74 pCi/g). All other samples collected contained less than 1 pCi of $^{226}Ra/g$. The wash water contained only small amounts of ^{226}Ra indicating little windblown contamination or tightly adhering contamination.

A background grass sample taken 5 mi west of the site contained only 0.11 pCi of $^{226}Ra/g$, but had relatively high radium content in the wash water equivalent to 0.12 pCi/g of dry vegetation which cannot be explained. Background samples collected and analyzed by the TVA from the Edgemont airport had ^{226}Ra concentrations from 0.14 to 0.28 pCi/g. Samples from Gull Hill Park to the east of the site contained ^{226}Ra concentrations from 0.16 to 0.85 pCi/g of dry vegetation.

Tomato plants were obtained from Cottonwood Community and from a location in Edgemont near the high school. There was no apparent difference in radium uptake in the leafy portion of the two plants, but the surface radium contamination from the Cottonwood Community leaf samples was 18 times larger than that in the sample taken near the high school.

3.4.8 Off-Site Tailings Use

Some of the uranium tailings have been moved physically from the site and used as fill material under and around structures in Edgemont and Provo. These locations have been identified[10] by a mobile survey and follow-up gamma surveys of individual locations. The locations and survey results are discussed in Chapter 7 where remedial action is considered. The locations at which tailings are on vacant lands or are greater than 10 ft from structures were not subject to the criteria used in this assessment, but could constitute a problem in the future.

3.5 POTENTIAL HEALTH IMPACT

The health impact on individuals and on the population near the Edgemont millsite was analyzed using two different approaches. The first approach follows NRC Regulatory Guide 1.109 as used in environmental statements for uranium milling operations to calculate annual doses to man. Methods and equations are specified in the guide for calculating dose in man from various release pathways for radioactive effluents.

The second approach is the one used to calculate health effects in man, primarily lung cancer, that was employed in the Phase II, Title I engineering assessment of 22 inactive uranium

tailings sites for DOE. At these sites, the primary health impact on the population near the tailings sites was due to inhalation of radon transported from the site. The radon concentration versus distance was converted to working levels (WL) and epidemiological data were used to calculate health effects in the population. This approach is included in the report so that comparisons can be made easily between the health impact of the Edgemont site and that of the other 22 sites already investigated.

3.5.1 Radiological Impacts

The sources of radiological impact to the vicinity of the Edgemont milling site are the natural radiation background of the area (discussed in paragraph 3.3), the tailings, the stockpiled ore, and the contaminated str ures (paragraph 3.4).

3.5.1.1 Radiological Impacts rom Background

The natural radiation environment in the Edgemont area is a result of cosmic radiation, cosmogenic radioactivity, and terrestrial radioactivity (see paragraph 3.3).

The intensity of cosmic radiation is a function of altitude and geomagnetic latitude. In South Dakota the dose equivalent due to the cosmic radiation is approximately 40 mrem/yr to the whole body.(4) The dose equivalent from cosmogenic radioactivity, primarily ^{14}C, is about 1 mrem/yr(11) to the whole body.

Terrestrial radiation is mainly from the primordial radionuclide ^{40}K and from the three radioactive decay series originating with ^{238}U, ^{235}U, and ^{232}Th. The average concentration of ^{238}U in the soils around Edgemont is 1.3 pCi/g; the concentrations of ^{232}Th and ^{40}K are estimated as 1 pCi/g each. At a height of 1 meter, the exposure rates due to these radionuclides are 18 mR/yr from the ^{238}U series, 15 mR/yr from the ^{232}Th series, and 1.4 mR/yr from ^{40}K.(11)

An average radon flux of 2.8 pCi/m^2-s for the Edgemont vicinity was calculated from the data in Table 3-3. The annual quantity of background ^{226}Ra-generated radon released from an area equal to the Edgemont site is about 43 Ci. The mean concentration of radon in air is estimated to be in the range 0.8 to 1.2 pCi/l. With normal conditions, a continuous exposure would deliver a dose of 800 to 1,200 mrem/yr to the segmented bronchi.

An annual average concentration of particulates in South Dakota air was not available. An estimate of 4×10^{-5} pCi/m^3 of ^{226}Ra, ^{232}Th, and ^{230}Th was used.(12) The dose from these particulates to the lung, under normal background conditions, would be about 2 mrem/yr, and the dose to the bone would be less than 1 mrem/yr.

Ingestion dose to each resident of Edgemont from ^{226}Ra in

the drinking water supply produces an annual dose to the bone of 88 mrem/yr and 8.8 mrem/yr to the whole body.

The medical whole-body dose rate for South Dakota is estimated to be 75 mrem/yr per person.[13] The U.S. average rate for the year 1980 is estimated to be 86 mrem/yr per person.[14] For the Edgemont area, the radiation dose rate to the whole body from the background environment is estimated to be 126 mrem/yr per person, as shown in Table 3-9.

3.5.1.2 Radiological Impacts from the Tailings

Radiation doses were estimated for individuals and for the general population living near the Edgemont site. These estimates were calculated on the basis of recommendations[15] of the International Commission on Radiation Protection (ICRP) and the report of the Task Group on Lung Dynamics for Committee II of ICRP.[16]

The following information was used in the dose determinations:

(a) Estimates of radioactive releases presented in paragraph 3.4

(b) Site meteorology and hydrological conditions discussed in paragraph 2.7

(c) Land-use information and population distribution discussed in paragraph 2.6 and Chapter 4

3.5.1.3 Exposure Pathways

Figure 3-22 illustrates the exposure pathways applicable to the contamination mechanisms described in paragraph 3.4. Actual site measurements were used when available as a basis for the estimate of each pathway and/or as a check on the validity of the methodology used.

The dose commitments to man were estimated based on radioactive effluent discharges to the environment using actual locations and characteristics of the millsite environs, and on the actual pathways by which members of the public can be exposed to the discharges. Included in the analyses are the dose-commitment evaluations of the different categories:

(a) Pathways associated with particulate releases to the atmosphere

(b) Pathways associated with gaseous releases to the atmosphere

(c) Pathways associated with the seepage of liquid effluents to ground water

For the Edgemont site the pathways of importance for producing the most significant dosages to individuals are the inhalation of radon, radon daughter products, and radioactive dust particles, and external radiation exposure. Another pathway is the ingestion of radionuclides in beef and vegetables. All other exposure pathways contributed much less significant dose commitments.

3.5.1.4 Radiation Dose Commitments to Individuals

A summary of the predicted doses to individuals at selected off-site locations where doses are calculated to be largest are listed in Table 3-9. Estimates are presented for the significant exposure pathways discussed in paragraph 3.4. The highest doses received by individuals from inhalation of radon drifting away from the site occur in the Cottonwood Community.

The predicted annual dose commitments to an individual in full-time residence at Cottonwood Community are 240 mrem/yr to the whole body, 460 mrem/yr to the lungs (excluding dose to the bronchial epithelium), 375 mrem/yr to the bones, and 1030 mrem/yr to the bronchial epithelium. At locations farther from the site, individuals will receive lower doses than estimated for Cottonwood Community.

A brief discussion of the various pathways for radiation exposure to individuals near the site are presented in the following paragraphs.

3.5.1.4.1 Internal Exposure

Air Pathway:

The concentration of ^{226}Ra in air resulting from airborne releases from the Edgemont site are shown in Figure 3-13 at locations in Cottonwood Community and the City of Edgemont. The annual radiation dose commitments to the nearest resident from inhalation of uranium, ^{230}Th, ^{226}Ra, and ^{210}Pb are given in Table A-3 of Appendix A.

Calculation of the dispersion of airborne pollutants around the Edgemont locale is difficult, and the accuracy of the results is unproven. The topographical barriers to pollutant dilution make the application of conventional disperson models questionable.(17) The models used are those proposed by Slade;(7) the results obtained are probably conservative. Input parameters in the air particulate concentration model were adjusted so that the model output fit the available TVA air particulate measurements. (See Appendix A.1.) Model calculations of air particulate concentrations were then performed using annual meteorology data from the Black Hills Ordnance Depot.

Dose to the bronchial epithelium from radon inhalation was determined from calculated radon concentrations, also shown in Figure 3-13, and from the dose conversion of 1 pCi/l continuous

inhalation produces 1 rem/yr dose to the bronchial epithelium.* For the nearest individual, this dose is 1030 mrem/yr above background.

Water Pathway:

Water from the site containing dissolved solids could travel along the unconfined aquifer towards Cottonwood Community. While the drinking water used by the community is from the city's system, there are wells drilled into this aquifer. Conservative estimates of the maximum potential dose from this pathway were obtained by assuming an individual uses water from this source as his drinking water supply. Even with this conservative estimate, the dose from this pathway is minor. However, the municipal water supply results in a bone dose of 88 mrem/yr to an individual from its ^{226}Ra content.

A contamination and mass flow balance was performed on all input and outlets from Cottonwood Creek. The analysis of the measured flow and ^{226}Ra concentration data indicated no major sources of ^{226}Ra contamination to Cottownwood Creek from ground water. Similar balances were performed for ^{230}Th, Fe, V, Ba, Mo, sulfates and total dissolved solids and they support the radium balance. Details of the analyses are included in Appendix A.2. The water pathway from pond 1 to the Cheyenne River is also analyzed in Appendix A.2. Both of these analyses indicate that the water pathway is not a critical pathway for population exposure.

Food Pathway:

The largest dose commitment to individuals from the food pathway would occur if beef were eaten exclusively from cattle that grazed in the windblown tailings area southeast of the tailings area. Thus, a rancher could slaughter one of the two cattle that the windblown tailings area could support annually, for his own use. This would lead to the dose commitment shown in Table 3-9 and Appendix A.3. Consumption of the two beef cattle anywhere would lead to a population dose commitment that is included in Appendix A, Table A-5.

Consumption of vegetables grown in Cottonwood Community also leads to a small annual dose commitment from uptake of radionuclides in the vegetables resulting from desposition of airborne particulates. The calculated dose assumes that airborne particulates are washed from the vegetables and that one half of the leafy vegetables consumed annually are homegrown in Cottonwood Community. The dose commitment to the nearest resident is shown in Table 3-9 under the ingestion pathway. The food pathway is not a critical pathway.

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*Differences of opinion exist concerning the numerical value of this dose conversion factor.

3.5.1.4.2 External Exposure

Estimates of the external exposure received by the nearest residence were determined from the measured 38 μR/hr exposure (25 μR above background of 13 μR/hr), measured with the PIC detector in Cottonwood Community. The results of this estimation also are given in Table 3-9. The whole body exposure of 220 mrem/yr represents a major fraction of the total dose commitment from the millsite to the nearest resident.

3.5.1.5 Radiation Dose Commitments to Populations

The estimated annual whole body and organ-specific dose commitments to the 2,000 residents of Edgemont, South Dakota, are presented in Table 3-10 as a sum of the pathway dose commitments detailed in Appendix A, Table A-5. Natural background annual dose commitments also are listed in Table 3-10 for comparison.

The population dose commitment due to the Edgemont site range from 8 to 16% of the natural background dose commitment for whole body, bone and bronchial epithelium dose. For the lung the dose commitment due to the site is about 50% of the natural background dose.

3.5.2 Phase II - Title I Approach to Estimating Health Effects

3.5.2.1 Assumptions and Uncertainties in Estimating Health Effects

Since radiation exposure from ^{222}Rn daughters 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 often are expressed in terms of rems; however, estimates of the WLM-to-rem conversion factor for internal lung exposure to alpha particles from ^{222}Rn daughters vary by over an order of magnitude. 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 absolute risk estimator used in this assessment is that given in the report of the National Academy of Sciences Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR report).[18] This report presents risk estimators for lung cancer derived from epidemiological studies conducted on two groups of miners, namely:

3 cancers per year per 10^6 person-WLM exposure for uranium miners

8 cancers per year per 10^6 person-WLM exposure for fluorspar miners

Therefore, the average of these two values was chosen as the risk estimator for use in this study. This estimator then is:

6 cancers per year per 10^6 person-WLM exposure

A dose from a given ingestion or inhalation of radionuclides varies widely due to differences in age (infants-adults), physical size, etc. This and other components of natural biological variability which exist among members of any given population, as well as the differences between exposure conditions in residences and mines, give rise to an uncertainty on the order of a factor of 3 in this parameter.[19]

The commitment, then, of 6 cancers per year has a statistical basis and relates to a total population exposure of 10^6 person-WLM. If a cancer does occur it likely will be evident during the 30-yr period following the initial exposure and latency period.[20] When the exposure is continual over an individual's lifetime, this commitment is cumulative and the risk per year increases to an ultimate value of 6 times 30 or:

180 effects per year for 30 x 10^6 person-WLM
total cumulative exposure

This mathematical expression also can be interpreted in terms of the average annual risk to an individual per unit of exposure. For example, an individual with a continuous exposure of 1 WLM annually has about a 2 x 10^{-4} probability each year of developing lung cancer from this exposure. Several investigations have been reported recently concerning the association between lung cancer incidence and RDC exposures in miners.[19,21,22] These investigations yielded risk estimator values consistent with the risk estimator used in the present assessment. It has been stated that the relative risk estimator could be about a factor of 3 larger than the absolute risk estimator.

For the purposes 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 pCi/l of ^{222}Rn = 0.005 WL

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

The exposure rate in terms of WLM/yr can be obtained from a continuous 0.005 WL concentration (equivalent to 1 pCi/l ^{222}Rn concentration) as follows:

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

Therefore, a radon concentration of 1 pCi/l is equivalent to a continual RDC exposure of 0.25 WLM/yr. If the conversion factor of 5 rem/WLM is applied to this result,(18) then the relationship 1 pCi/l = 1.25 rem/yr is obtained. This value is 25% higher than the factor used in paragraph 3.5.1.4.1.

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

100 effects per year for 10^6 person-rem continuous exposure to gamma radiation

In this assessment it is assumed that a gamma exposure of 1 R in air is equivalent to a dose of 1 rem in soft tissue.

3.5.2.2 Health Effects Calculations

The model curve of radon concentration-versus-distance not including background (Figure 3-7) is used to determine the health effects due to radon from the pile. First, an indoor radon daughter concentration is deduced from the outdoor radon concentration curve using the conversion factor 1 pCi/l of ^{222}Rn outside equals 0.25 (WLM/yr) inside, then, the resulting RDC distribution is multiplied by the risk estimators given previously to yield the health effect risk per person as a function of distance from the pile. The estimated annual radiation induced lung cancer risk due to the pile is given in Figure 3-23 as a function of distance from the edge of the pile for prolonged continuous exposure. The curve shown in the figure represents the estimated annual radiation-induced risk from the tailings pile plus the average lung cancer risk per year from all causes for residents of the State of South Dakota.(23)

Health effects from total population RDC exposures for the area within 1 mi from the perimeter of the tailings pile are obtained by multiplying the health effect risk per person from the curve given in Figure 3-23 by the population distribution as a function of distance from the pile. The results are given in Table 3-11. Annual lung cancer events are calculated using estimated population data for 1975. There were at that time 2,000 persons living within 1 mi of the perimeter of the tailings pile, and it has been assumed that no growth has occurred since that time.

Health effects were determined for both a yearly and cumulative basis. Two population predictions were used: static, and a doubling by 1985 followed by a 0.16% growth rate. The health effects rate continues after 25 yr but the population projections after that time are very speculative.

The health effect values are obtained by converting the appropriate radon concentrations in the area within 1 mi of the tailings pile to an equivalent WLM/yr and multiplying it by 180 effects per year per 10^6 person-WLM and by the population. If the relative risk estimator is used, the health effect estimates are correspondingly larger than the ones given in Table 3-11. The uncertainty in the health effects estimation is about a factor of 4.

3.6 REMEDIAL ACTION CRITERIA

Radiological criteria established for this engineering assessment for possible remedial action at the site are divided into four categories: NRC guidelines for decontamination of facilities for unrestricted use, NRC performance objectives for post-operational reclamation of uranium tailings, EPA guidelines for decontamination of open land areas adjacent to the tailings ponds, and the Surgeon General's criteria applicable to structures with tailings underneath them or within 10 ft.

3.6.1 NRC Guidelines for Facility Decontamination

The decontamination criteria applicable to the mill buildings, if they are to be decontaminated for unrestricted use, are described in Appendix B.1. These criteria deal with surface contamination found on floors, walls, and ceilings and surfaces of processing equipment. Although the Edgemont mill processed ore containing natural uranium, the most restrictive release limits apply since ^{226}Ra and ^{230}Th are present as contaminants from the ^{238}U decay chain.

3.6.2 NRC Tailings Management Performance Objectives

The NRC has formulated performance objectives for tailings management.(24) These objectives are applicable to present and future milling operations under NRC license and are listed below.

Siting and Design:

(1) Locate the tailings isolation area remote from people such that population exposures would be reduced to the maximum extent reasonably achievable.

(2) Locate the tailings isolation area such that disruption and dispersion by natural forces is eliminated or reduced to the maximum extent reasonably achievable.

(3) Design the isolation area such that seepage of toxic materials into the ground water system would be eliminated or reduced to the maximum extent reasonably achievable.

During Operations:

(4) Eliminate the blowing of tailings to unrestricted areas during normal operating conditions.

Post Reclamation:

(5) Reduce direct gamma radiation from the impoundment area to essentially background.

(6) Reduce the radon emanation rate from the impoundment area to about twice the emanation rate in the surrounding environs.

(7) Eliminate the need for an ongoing monitoring and maintenance program following successful reclamation.

(8) Provide surety arrangements to assure that sufficient funds are available to complete the full reclamation plan.

Some of these performance objectives cannot be met at the Edgemont site, primarily those relating to siting and design. Post reclamation objectives (5), (6), and (7) should be achieved at the present site and remedial action alternatives discussed in Chapter 9 are intended to meet these objectives. If the tailings are moved to another site for long-term storage, all of the applicable performance objectives should be met.

3.6.3 Cleanup of Site and Open Land Areas

Criteria for cleanup of open land areas were formulated by EPA and utilized in the Phase II - Title I assessment of inactive uranium mill tailings sites.(25) Cleanup of windblown and/or water eroded tailings beyond the fence of the site should proceed according to the following criteria:

(a) If gamma levels are less than 10 μR/hr above background, the land may be released for unrestricted use.

(b) If gamma levels exceed 10 μR/hr above background, cleanup should reduce the radium soil concentration to no more than twice background.

(c) If tailings removal is not practicable, residual gamma levels should in any part of the area not exceed 40 μR/hr above background.

3.6.4 Off-Site Remedial Action at Structures

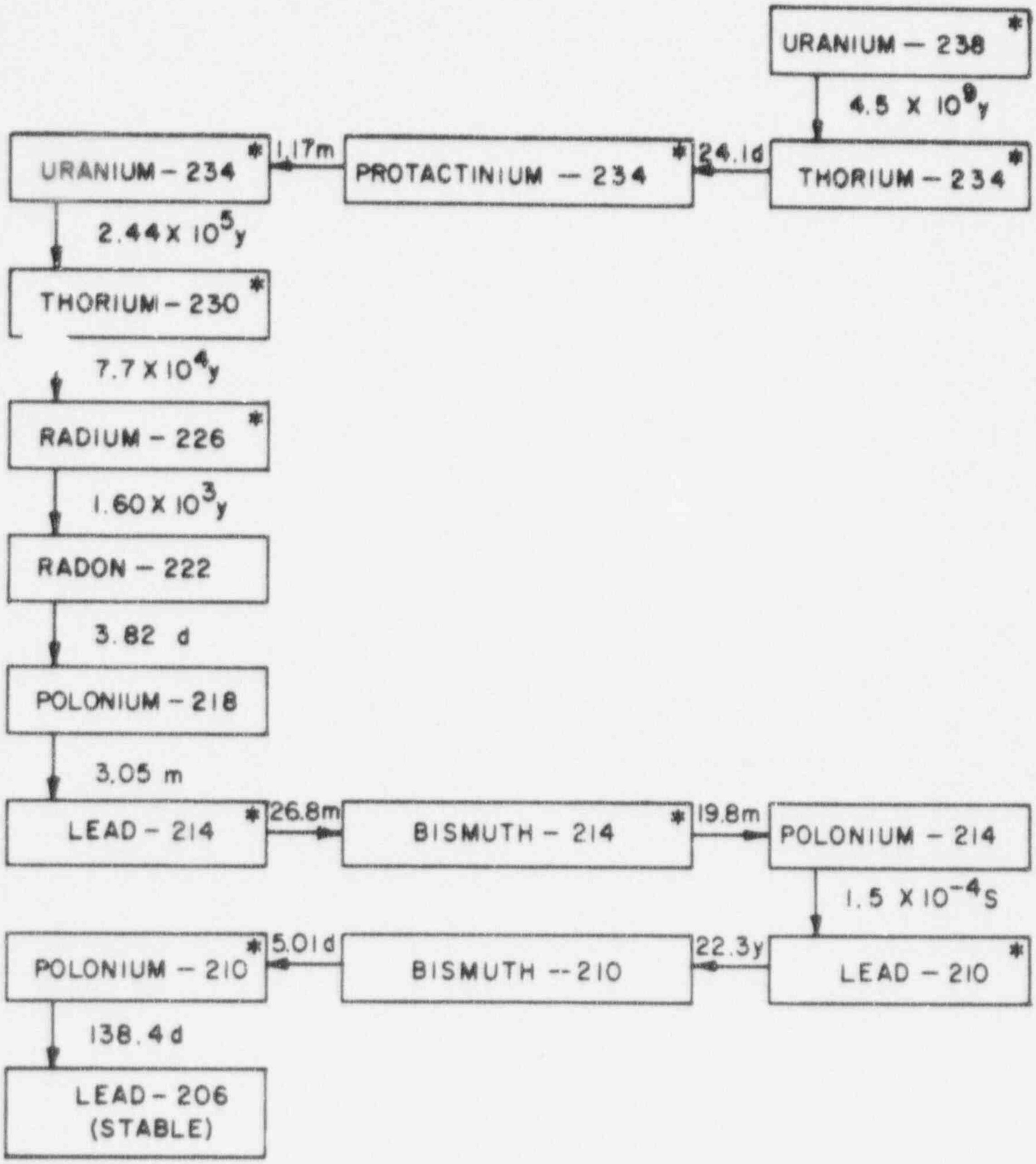
If remedial actions are initiated at tailings locations off the site, then the criteria which apply to the structures are the

guidelines published by the Surgeon General of the United States. These guidelines recommend the following graded levels for remedial action in terms of the EGR levels and indoor RDC levels above background found within the dwellings constructed on or near uranium mill tailings:

EGR, mR/hr	RDC*, WL	Recommendation
Greater than 0.1	Greater than 0.05	Remedial action indicated
From 0.05 to 0.1	From 0.01 to 0.05	Remedial action may be suggested
Less than 0.05	Less than 0.01	No remedial action indicated

*Based upon yearly average values from 6 air samples of at least 100-hr duration taken at a minimum of 4-wk intervals throughout the year.

The Surgeon General's guidelines are included as Appendix B.2.



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

211-00

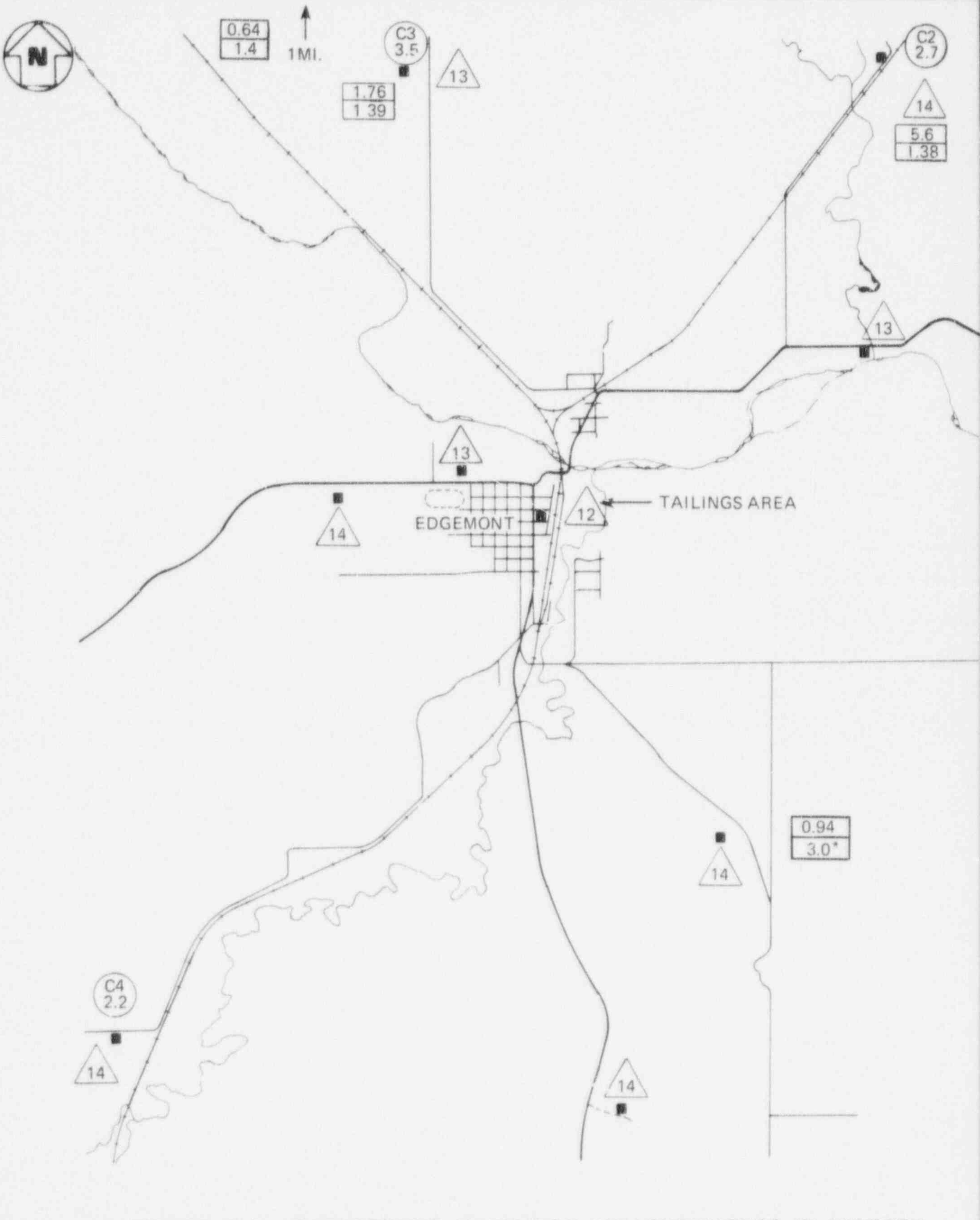
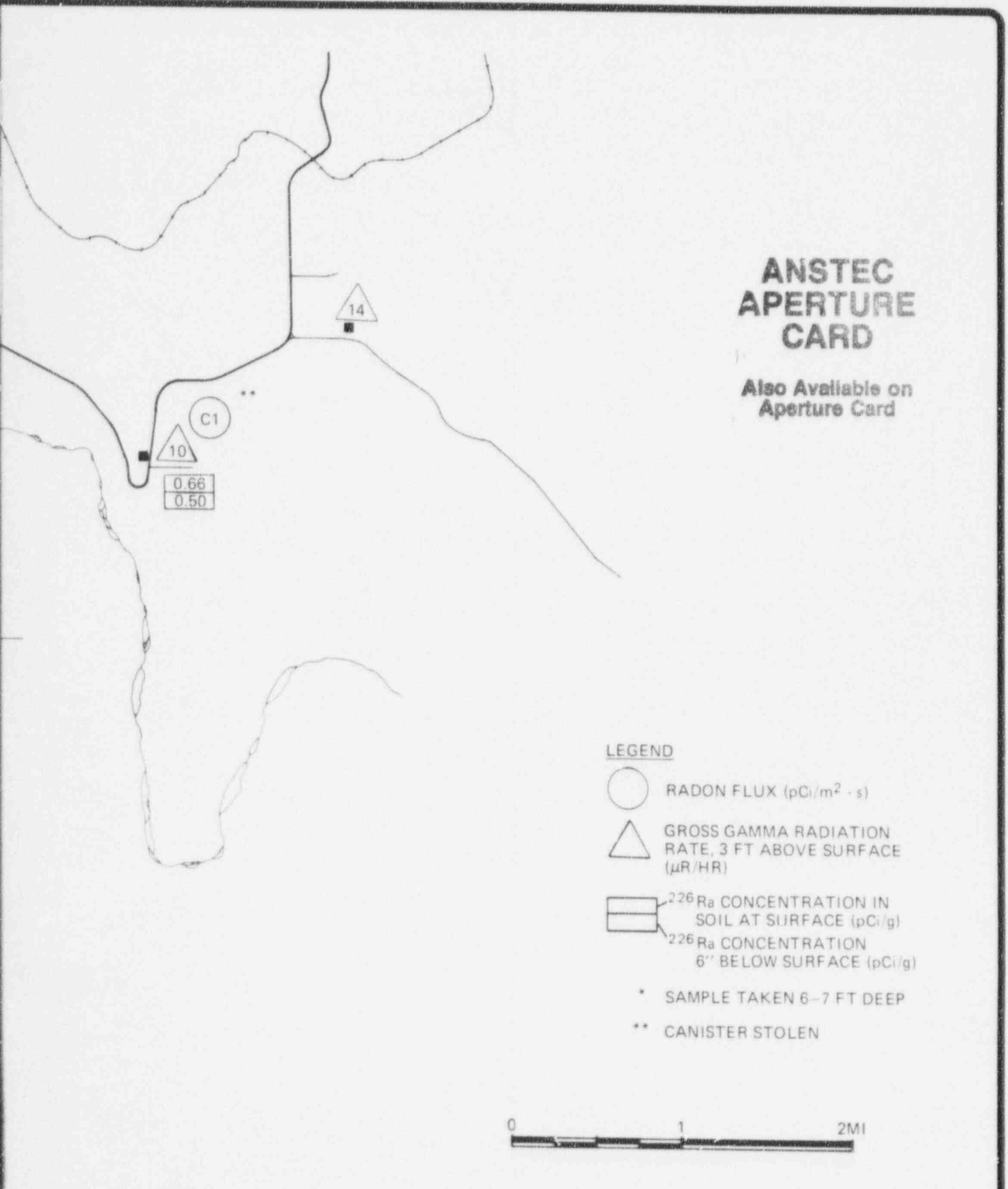


FIGURE 3-2. BACKGROUND RADIATION MEASUREMENTS IN VICINITY


14
C1
**
10
0.66
0.50
LEGEND
RADON FLUX (pCi/m² · s)
GROSS GAMMA RADIATION RATE, 3 FT ABOVE SURFACE (μR/HR)
226Ra CONCENTRATION IN SOIL AT SURFACE (pCi/g)
226Ra CONCENTRATION 6" BELOW SURFACE (pCi/g)
* SAMPLE TAKEN 6-7 FT DEEP
** CANISTER STOLEN
0
1
2MI
211-00

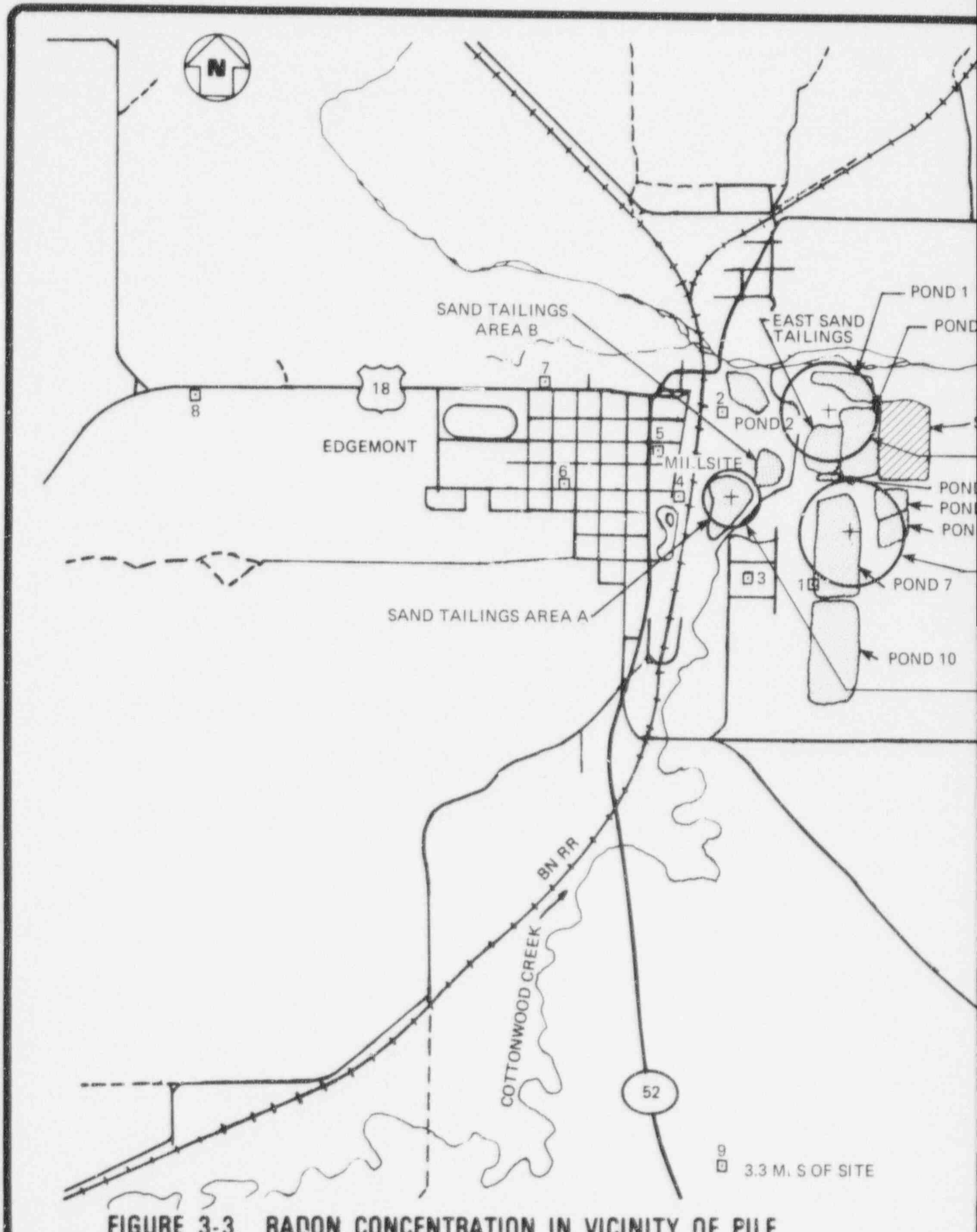
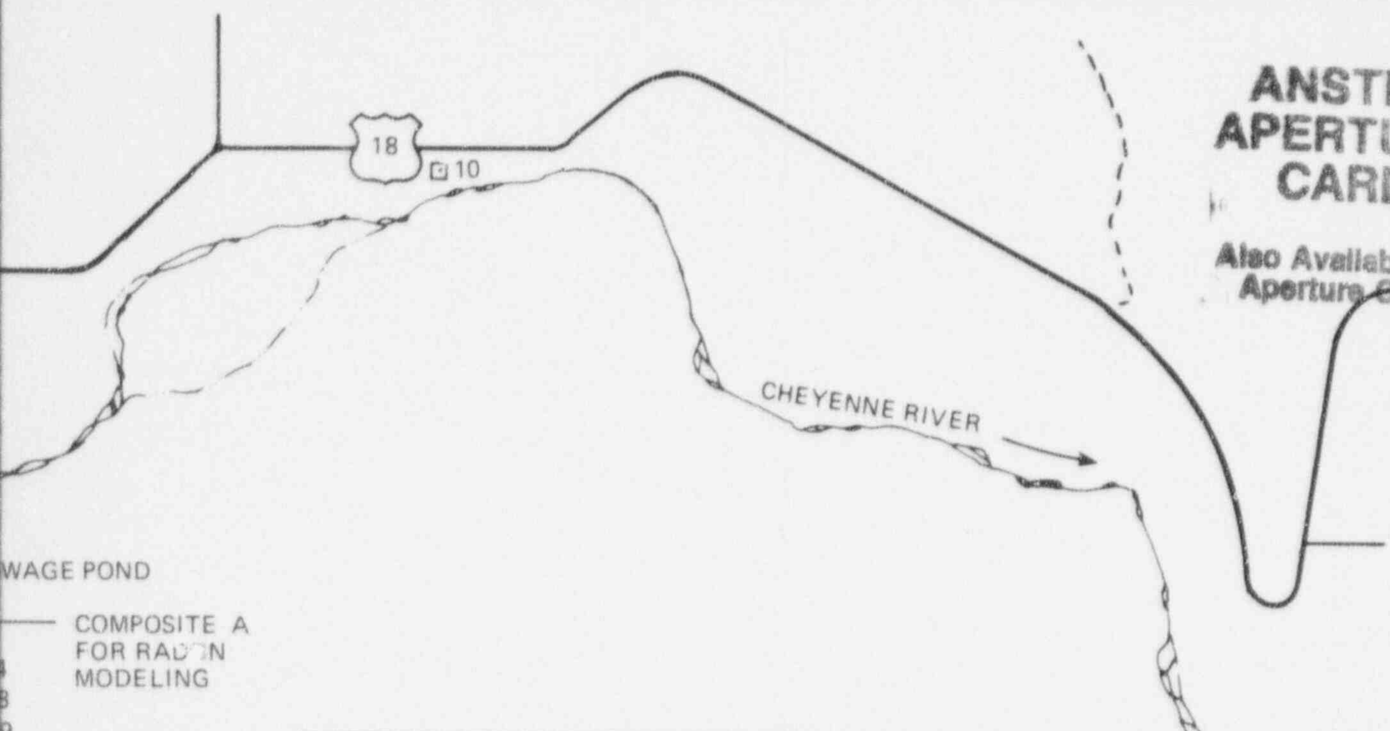


FIGURE 3-3. RADON CONCENTRATION IN VICINITY OF PILE



DATE	SITE	24 HR (INDOOR) (pCi/l)	24 HR (OUTDOOR) (pCi/l)	WIND SPEED (KNOTS)	WIND DIREC-TION	LOCATION
1977						
8/18	1	——	2.7	5	W	SE CORNER OF POND 7
8/15	2	3.4	1.4	7	E	MILL OFFICE 0.1 MI W OF SITE
8/22	3	1.1	1.7 (3.3)	8	NW	COTTONWOOD 0.15 MI S+W OF SITE
8/16	4	1.7	1.2	8	SE	RR STATION 0.2 MI W OF SITE
8/16	5	1.2	0.82 (1.2)	8	SE	CAR DEALER 0.4 MI W OF SITE
8/21	6	2.2	1.6	5	E	0.6 MI W OF SITE
8/15	7	0.41	1.3	7	S	MOTEL 0.7 MI W OF SITE
8/19	8*	1.8	1.5 (1.2)	4	W	1.3 MI W OF SITE
8/20	9*	1.5	1.1 (1.7)	6	W	3.3 MI S OF SITE
8/19	10	1.2	**	5	NW	1.8 MI NE OF SITE

0 1000 2000 3000 4000 5000 FT

* USED FOR BACKGROUND DETERMINATION
** UNIT DAMAGED DURING MEASUREMENT PERIOD
( ) 7-DAY MEASUREMENT PERIOD – NOV. 1977

NOTE: 24–HR MEASUREMENT PERIODS FOR 2 RADON UNITS DO NOT ALWAYS RUN CONCURRENTLY EACH DAY.

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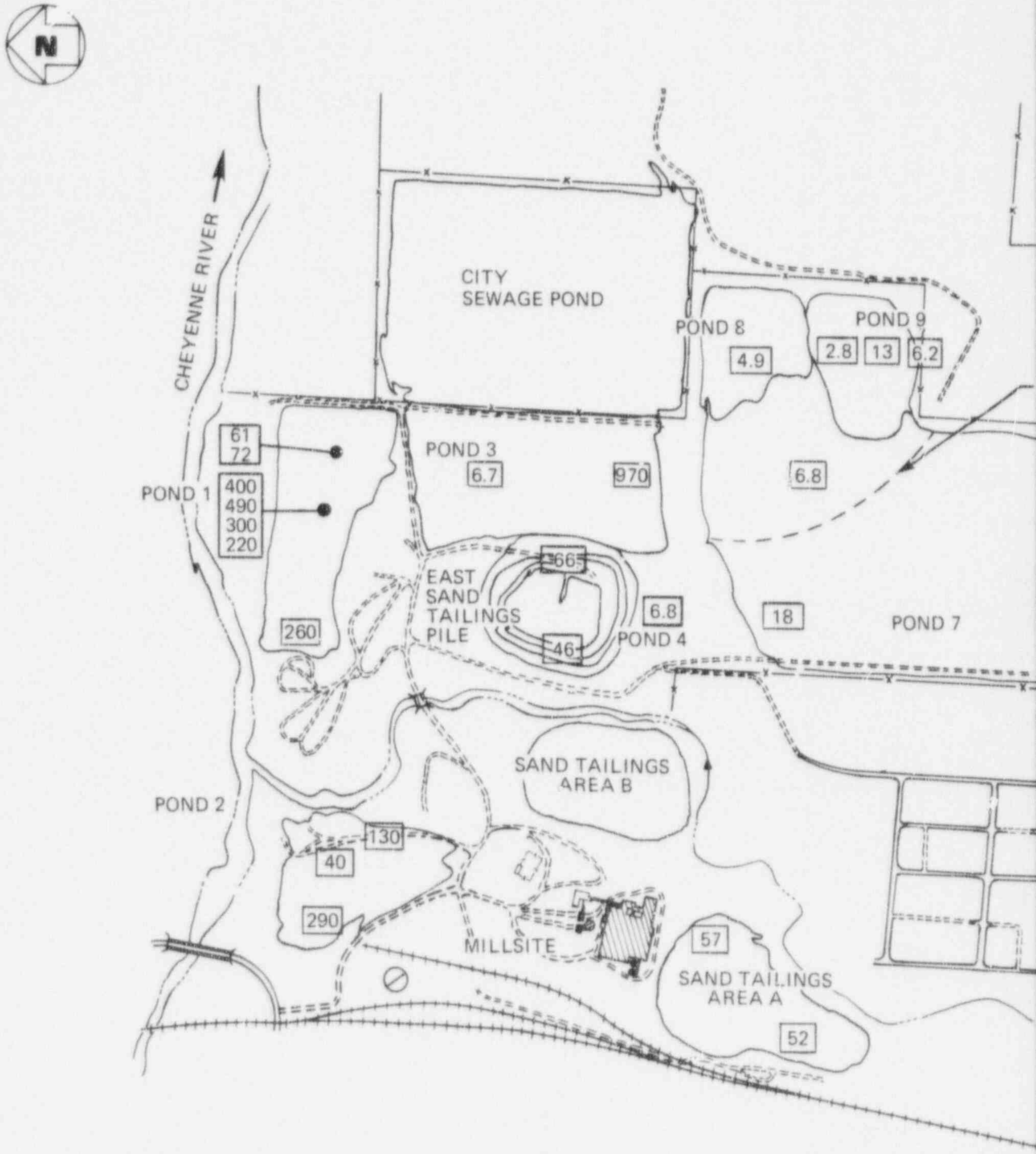
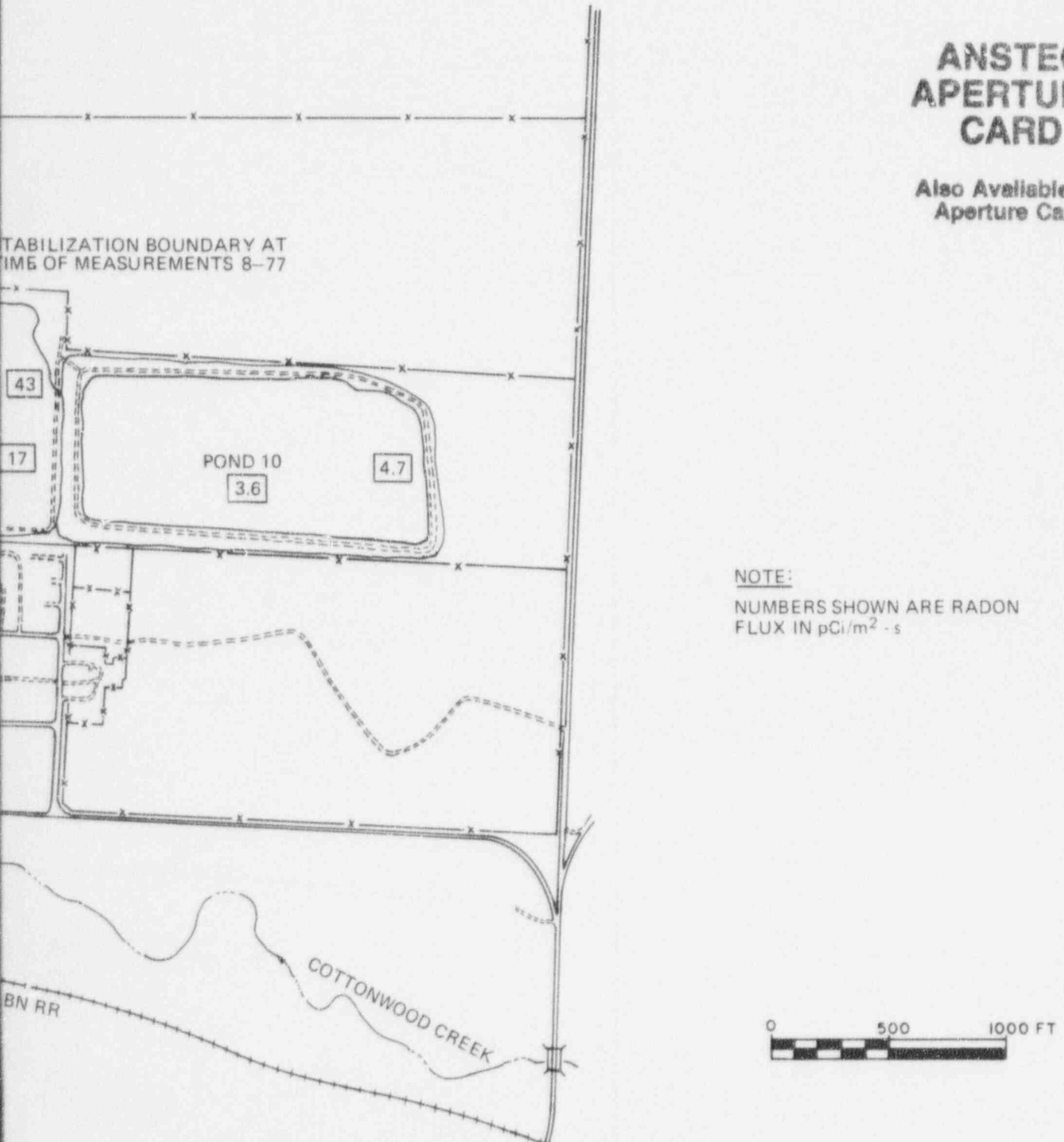


FIGURE 3-4. RADON FLUX MEASUREMENTS ON SITE



NOTE:
NUMBERS SHOWN ARE RADON FLUX IN $pCi/m^2 \cdot s$

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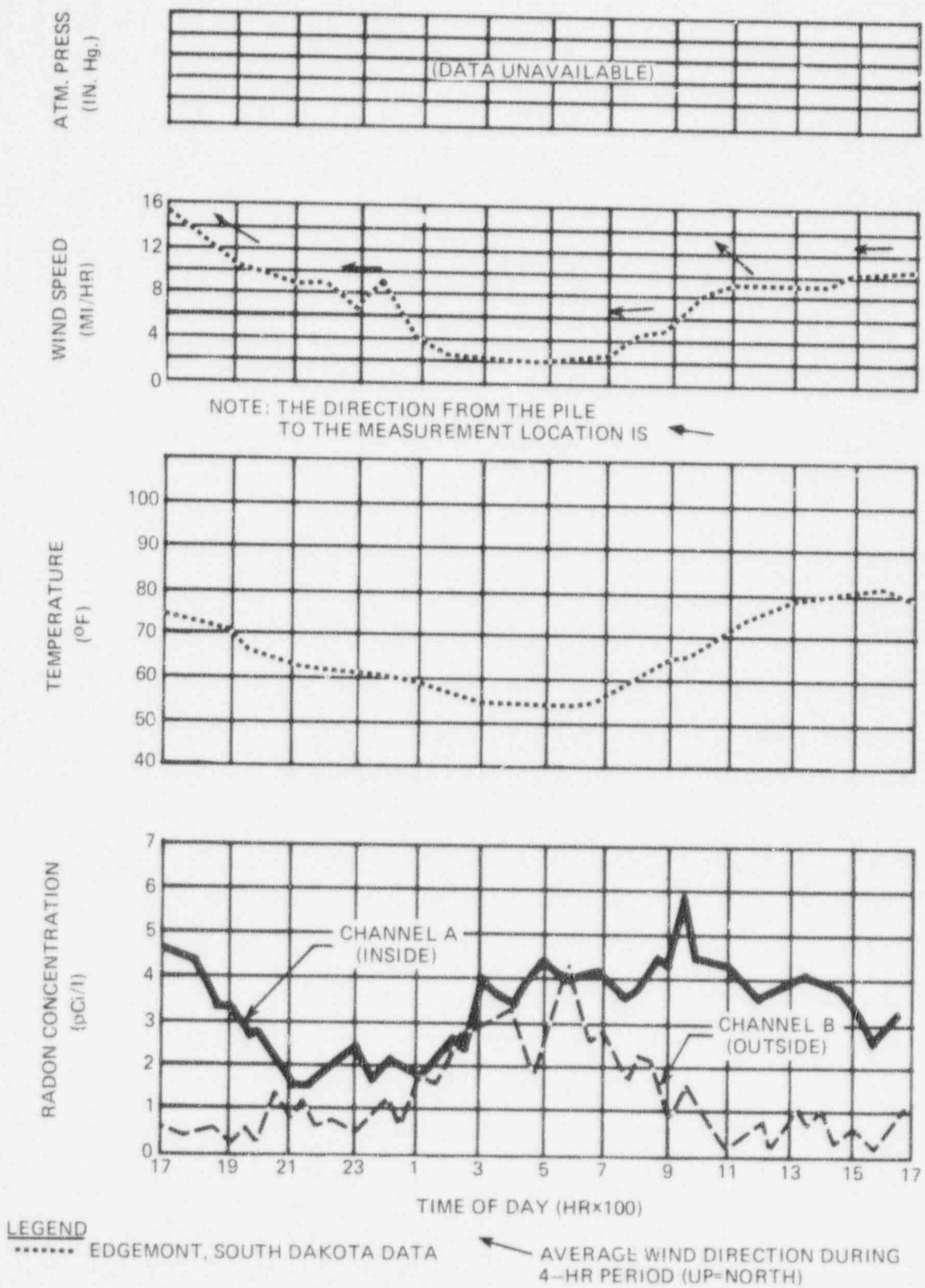


FIGURE 3-5. 222 Rn AND ATMOSPHERIC TRANSIENTS AT MILL OFFICE ON AUGUST 15, 1977

211-00

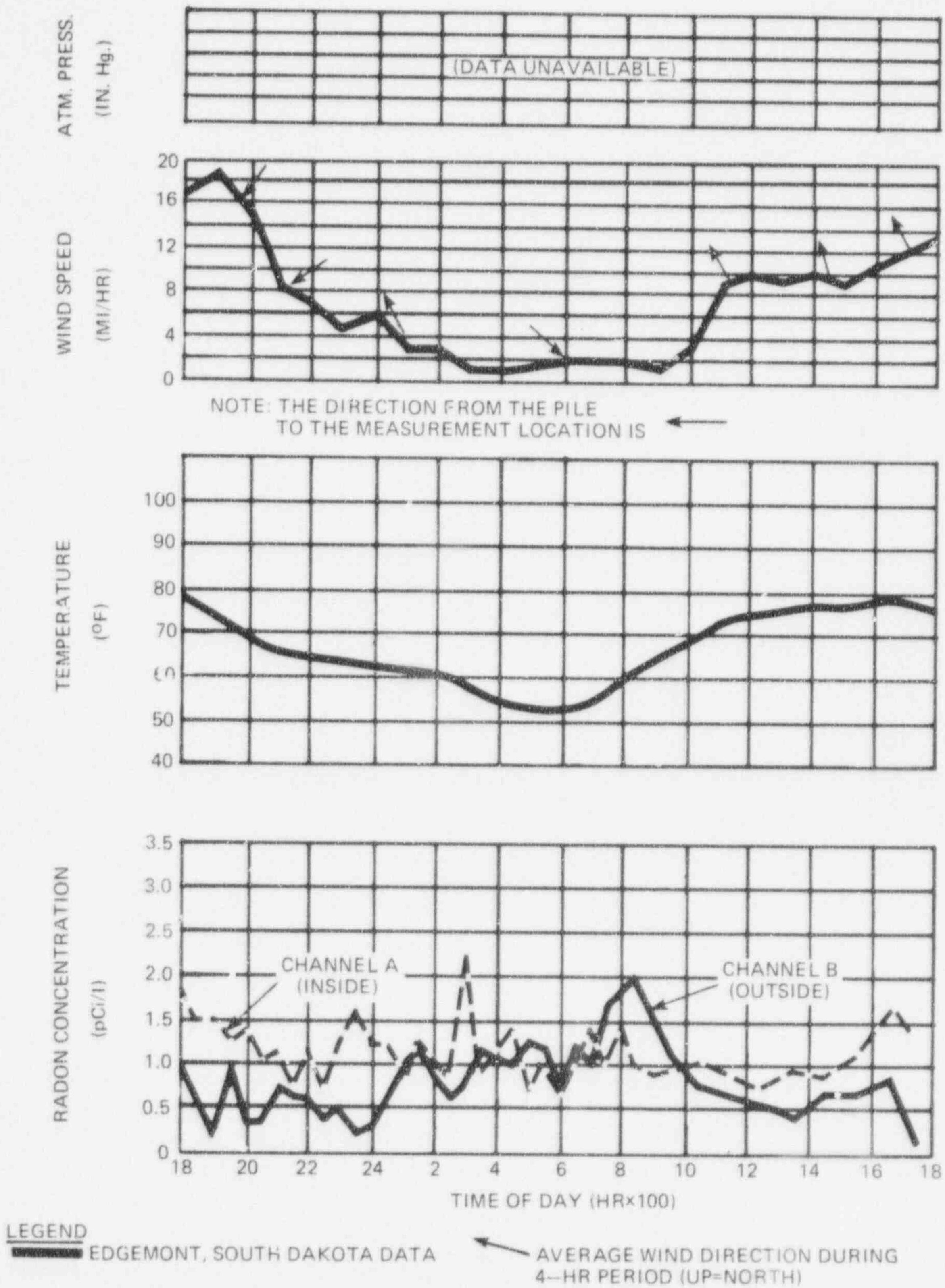


FIGURE 3-6. 222 Rn AND ATMOSPHERIC TRANSIENTS 0.4 MI WEST OF SITE ON AUGUST 16, 1977

211-00

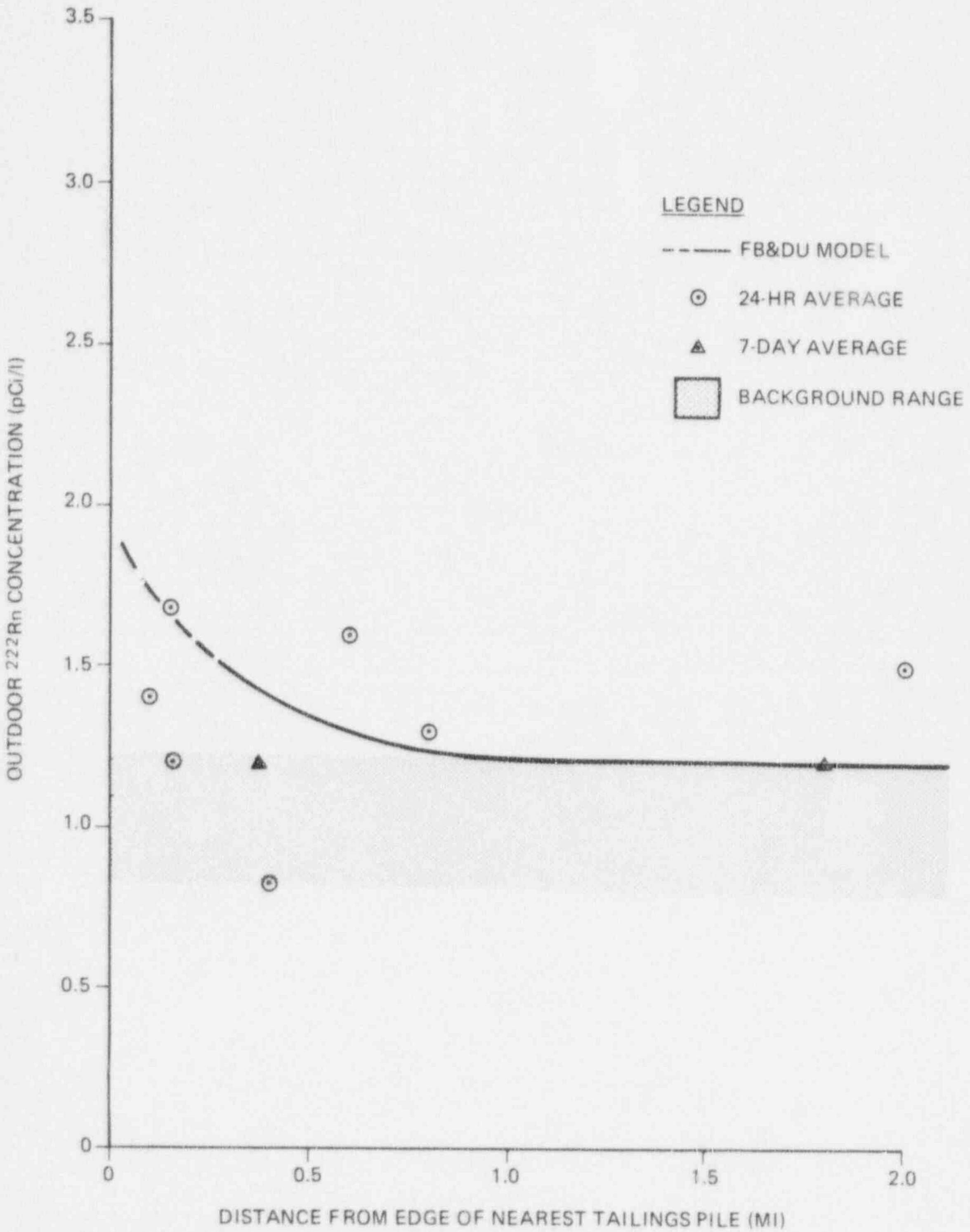


FIGURE 3-7. REDUCTION OF OUTDOOR 222Rn CONCENTRATION WITH DISTANCE TO THE WEST OF THE TAILINGS PILES

211-00

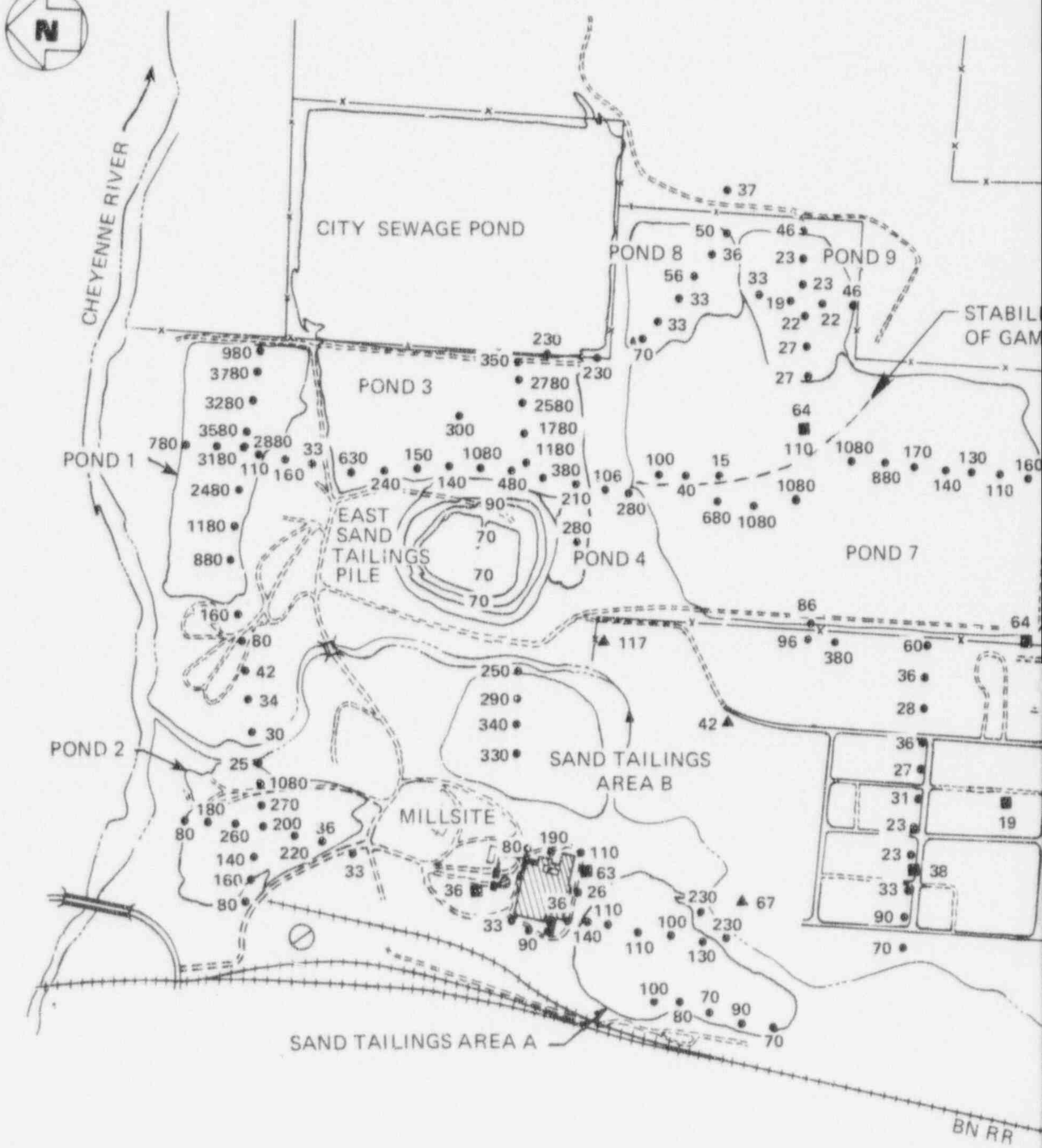
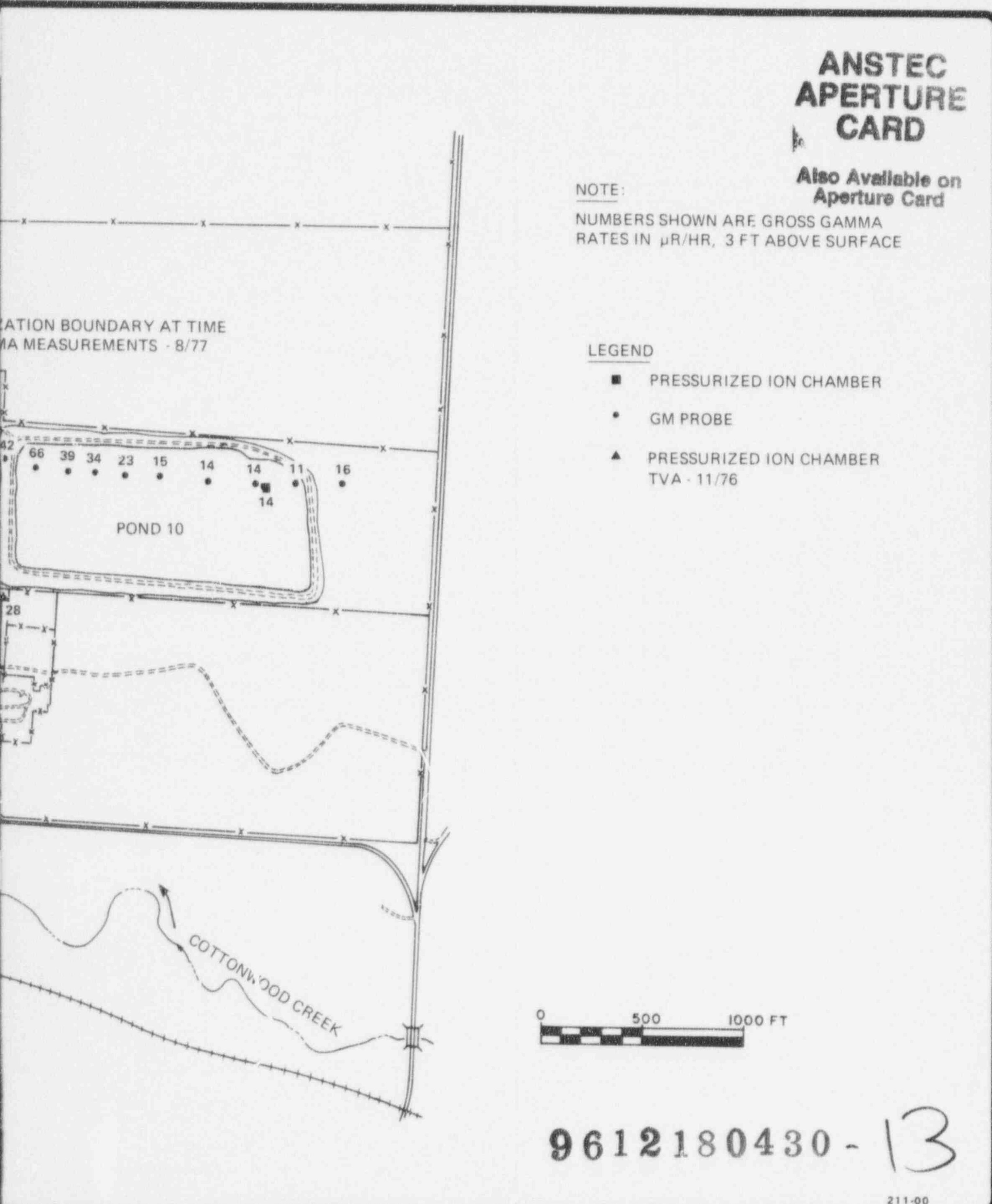


FIGURE 3-8. GAMMA LEVELS ON SITE



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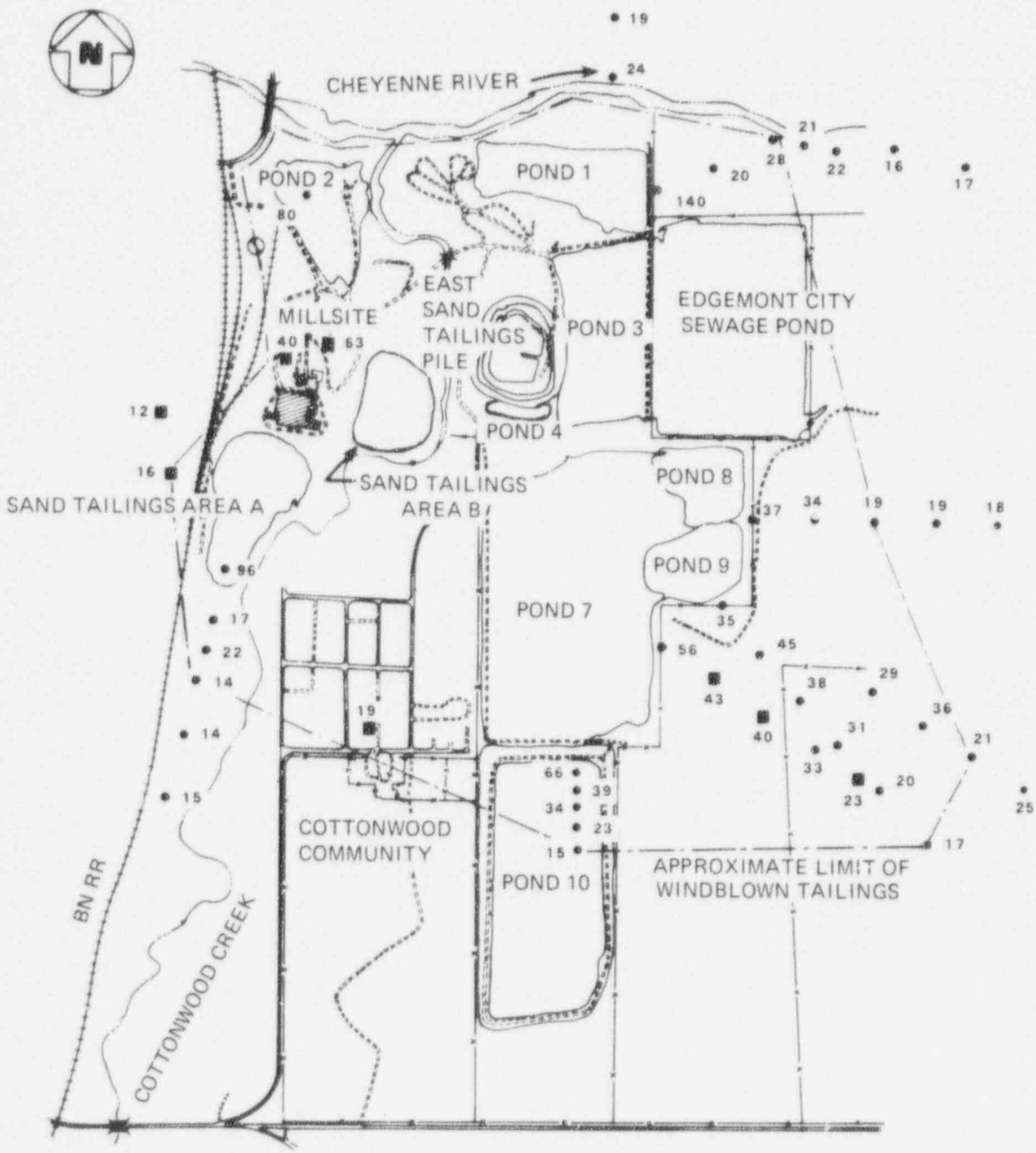


LEGEND

■ PRESSURIZED ION CHAMBER

• GM PROBE

NOTE:

NUMBERS SHOWN ARE GROSS GAMMA RATES IN μR/HR, 3 FT ABOVE SURFACE

0 500 1000 FT

FIGURE 3-9. GAMMA LEVELS IN VICINITY

211-00

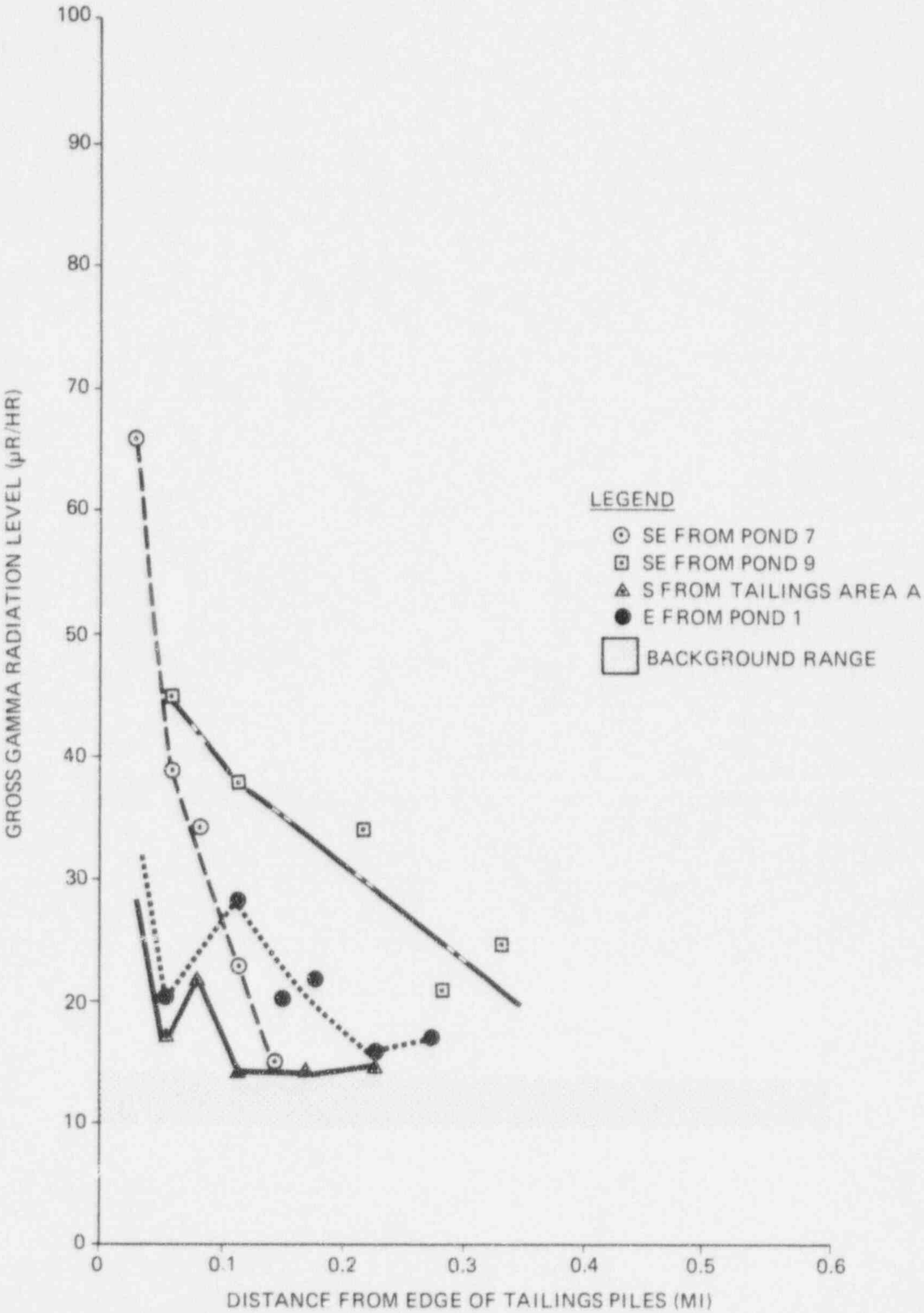
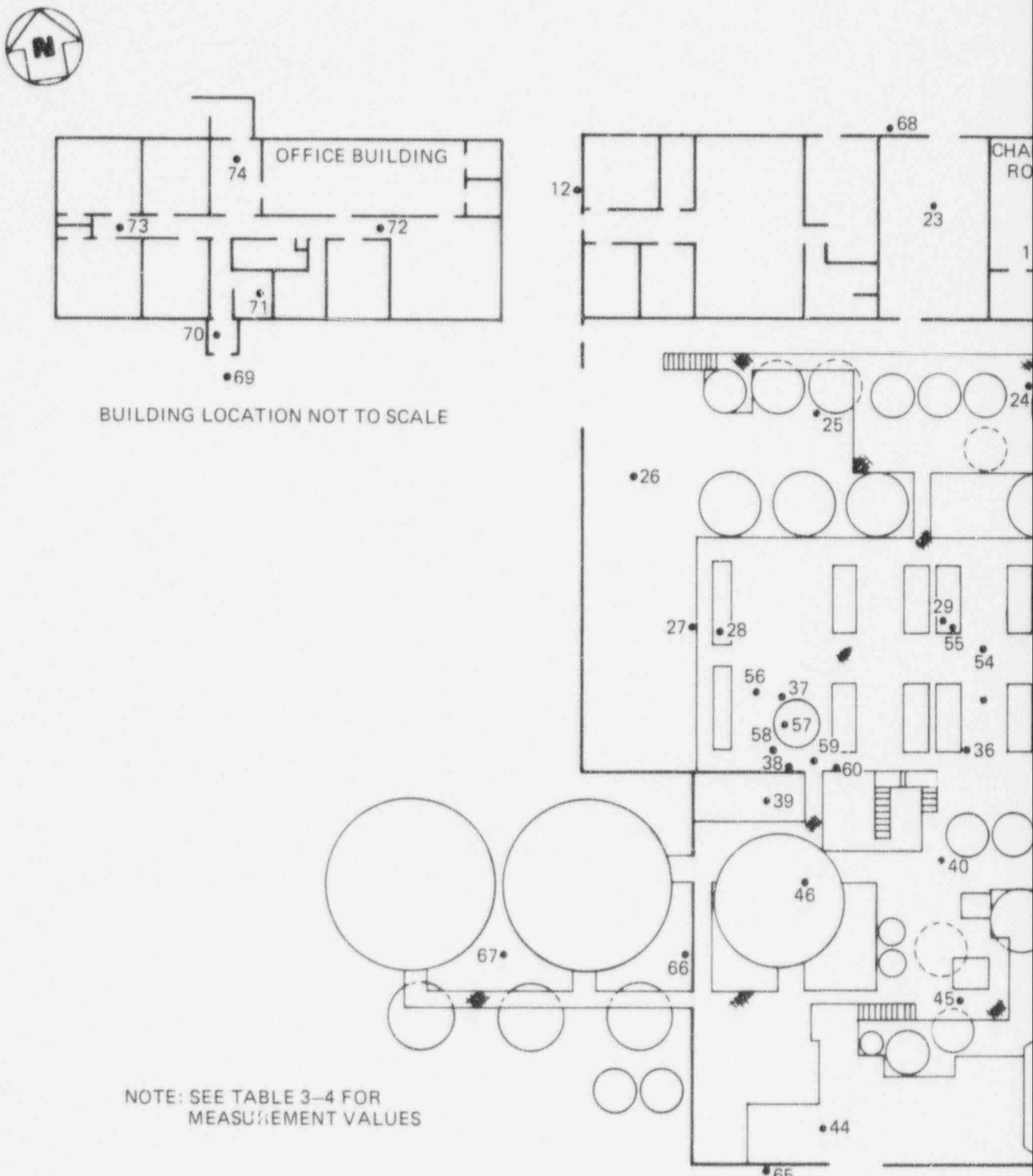


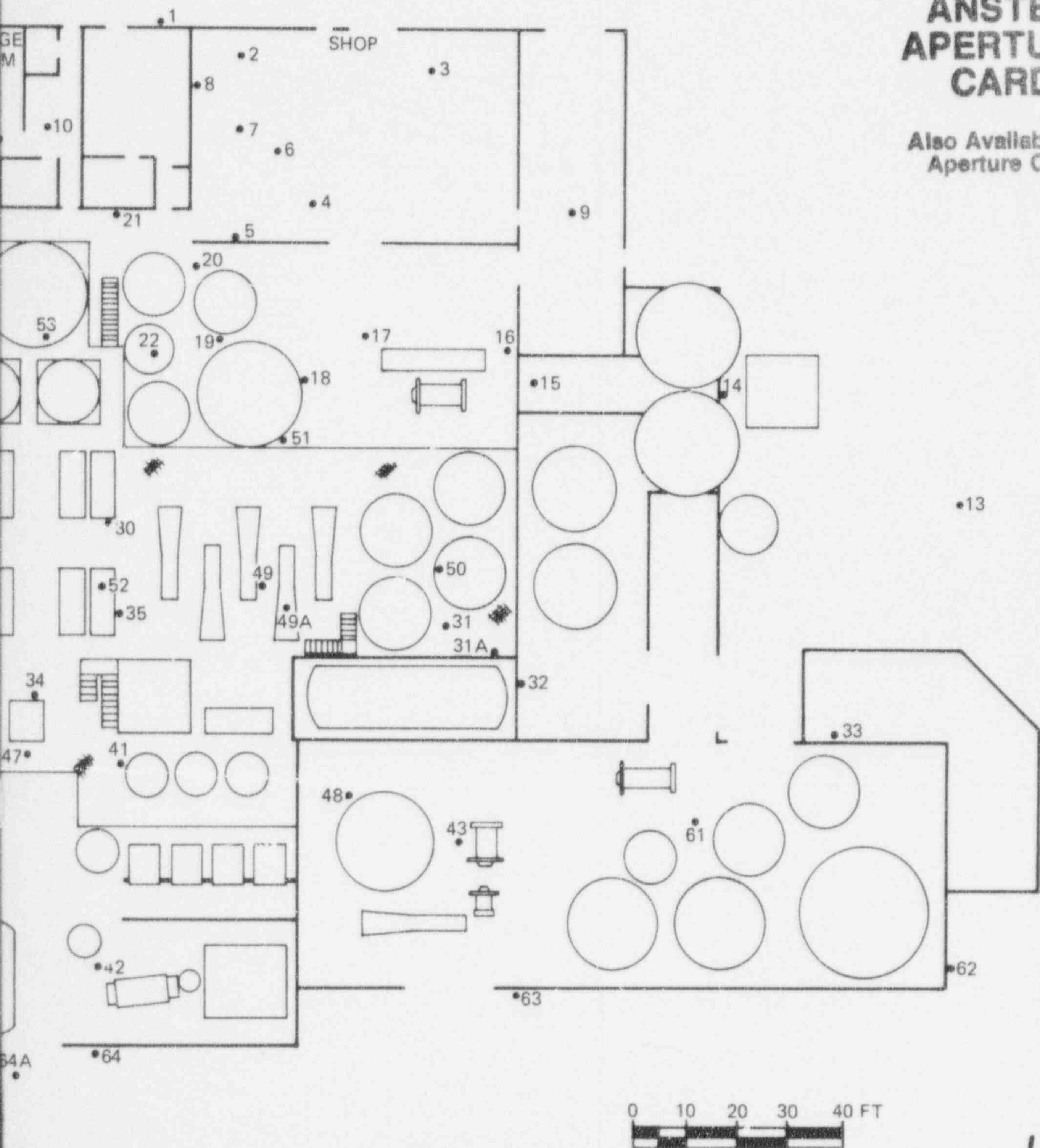
FIGURE 3-10. REDUCTION OF EXTERNAL GAMMA RADIATION LEVELS WITH DISTANCE FROM THE TAILINGS PILES

211-00



NOTE: SEE TABLE 3–4 FOR MEASUREMENT VALUES

FIGURE 3-11. MEASUREMENT LOCATIONS IN MILL AND OFFICE BUILDINGS



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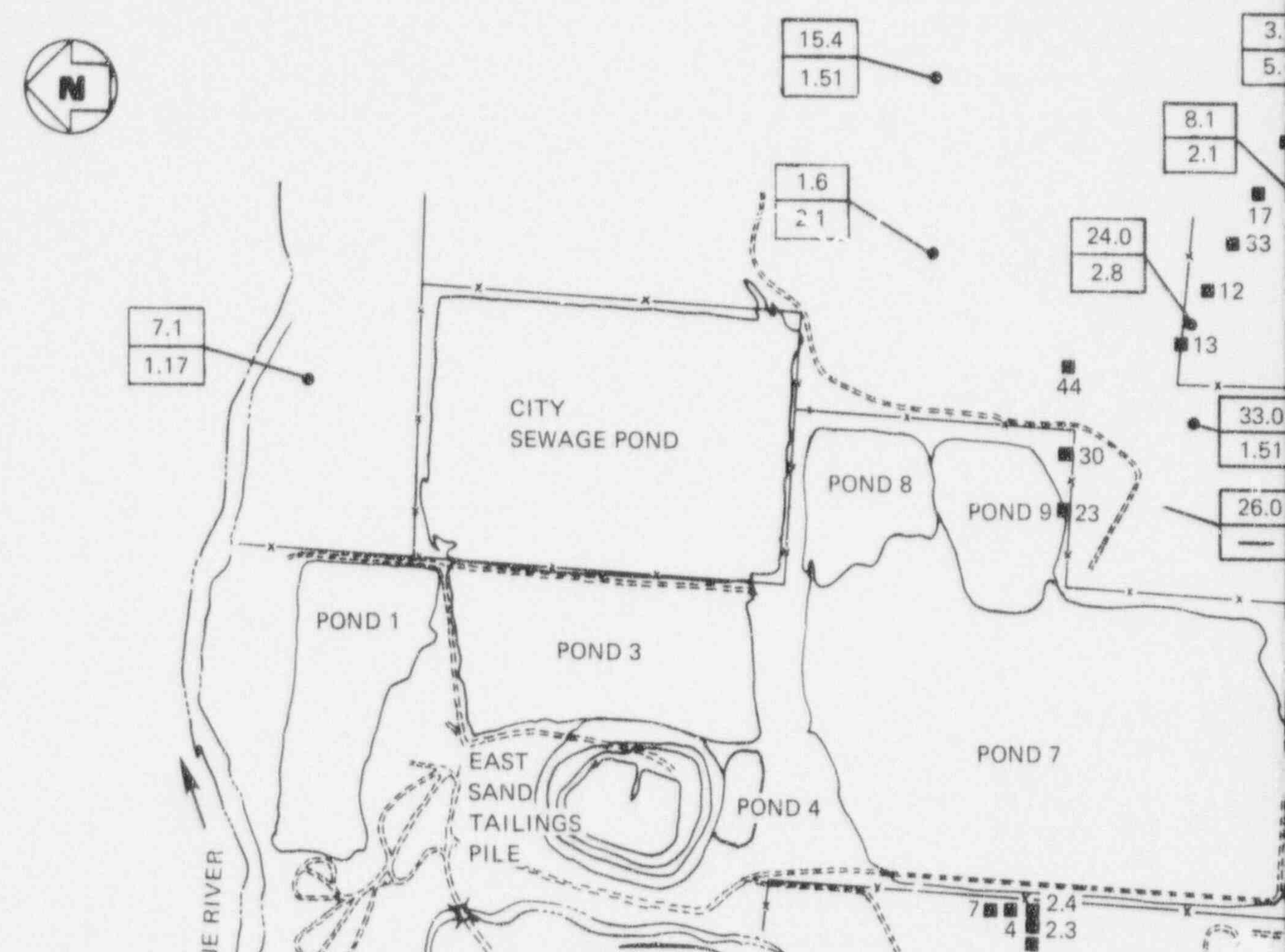
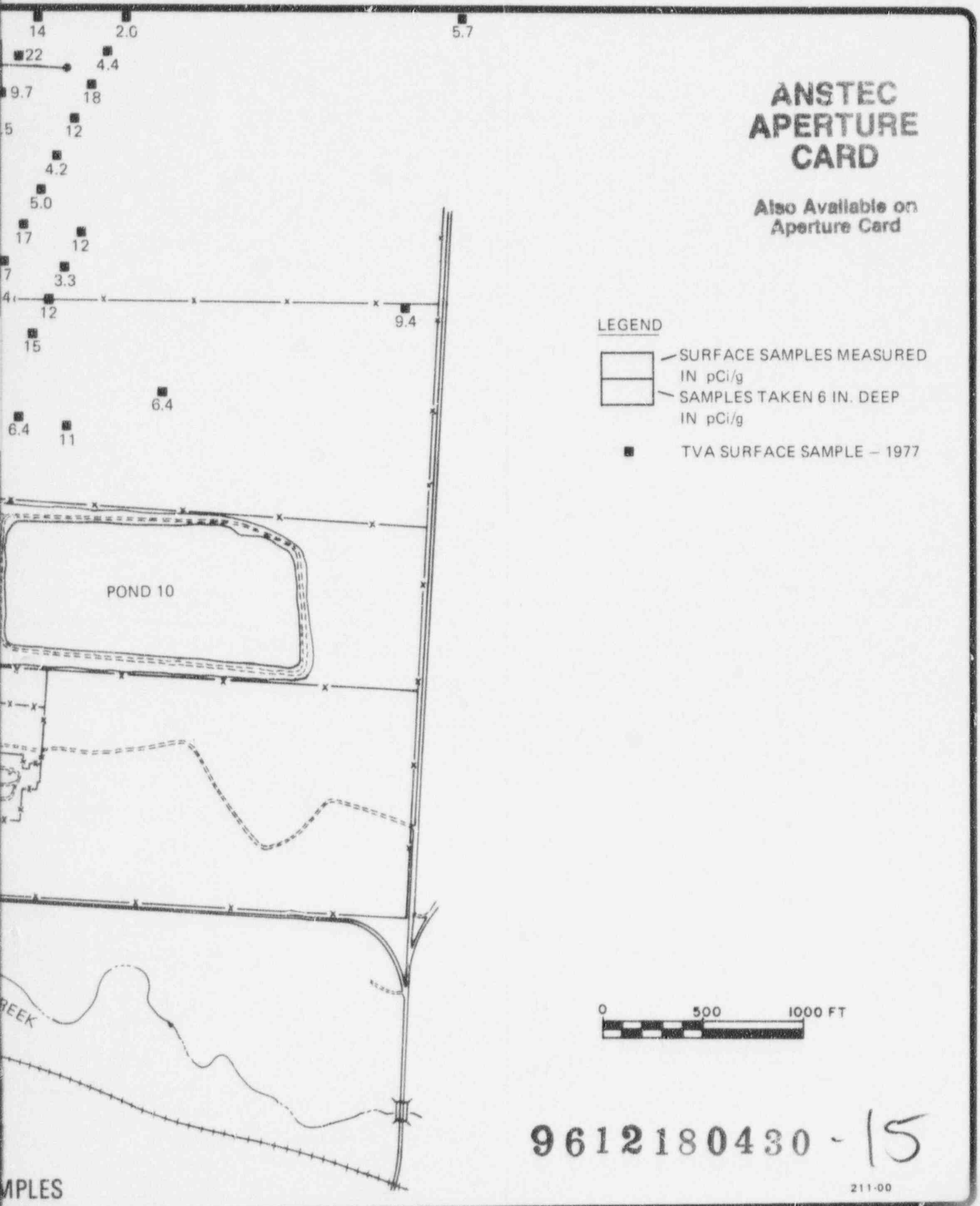


FIGURE 3-12. SURFACE AND SUBSURFACE RADIUM CONCENTRATION IN SOIL SA



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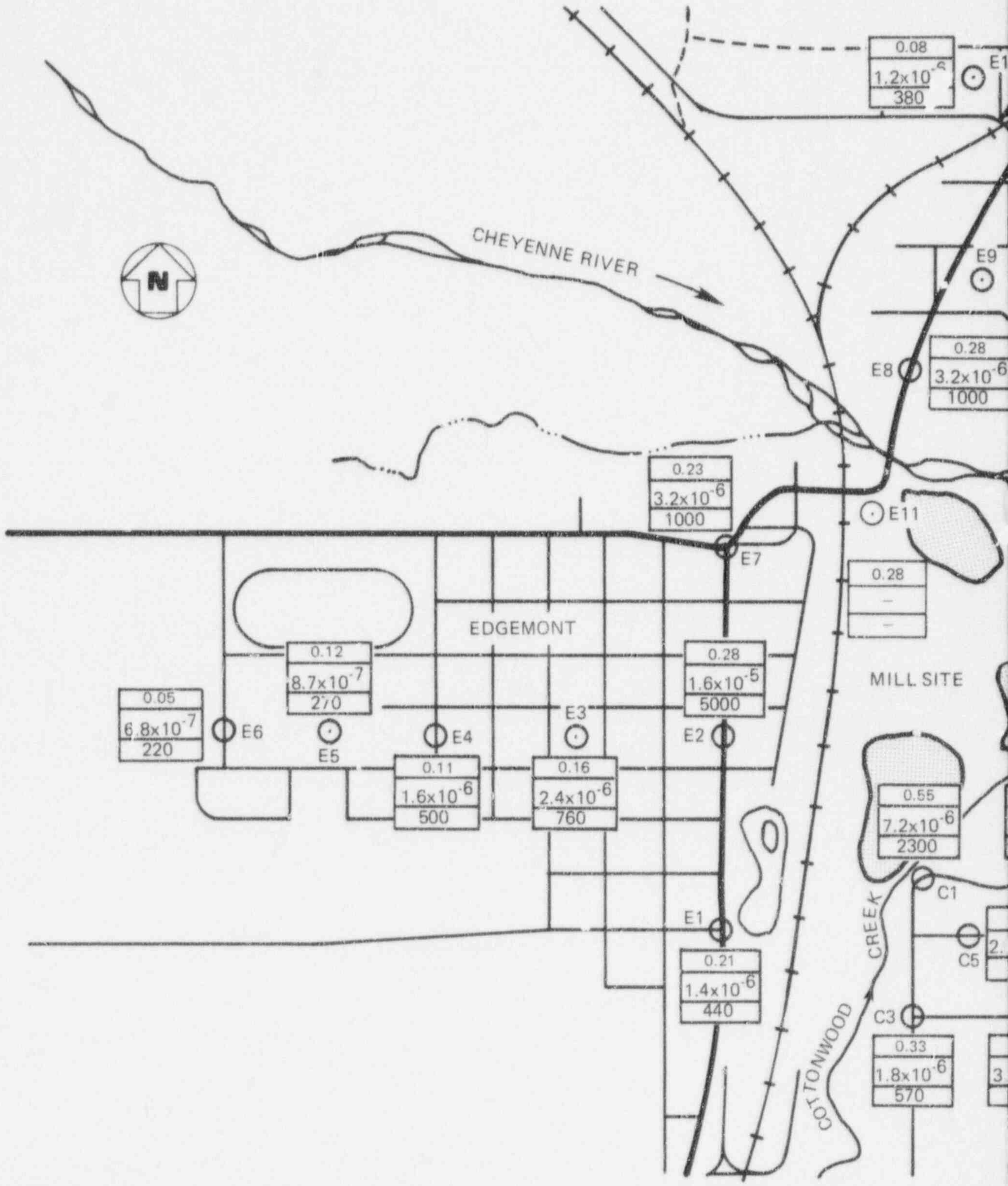
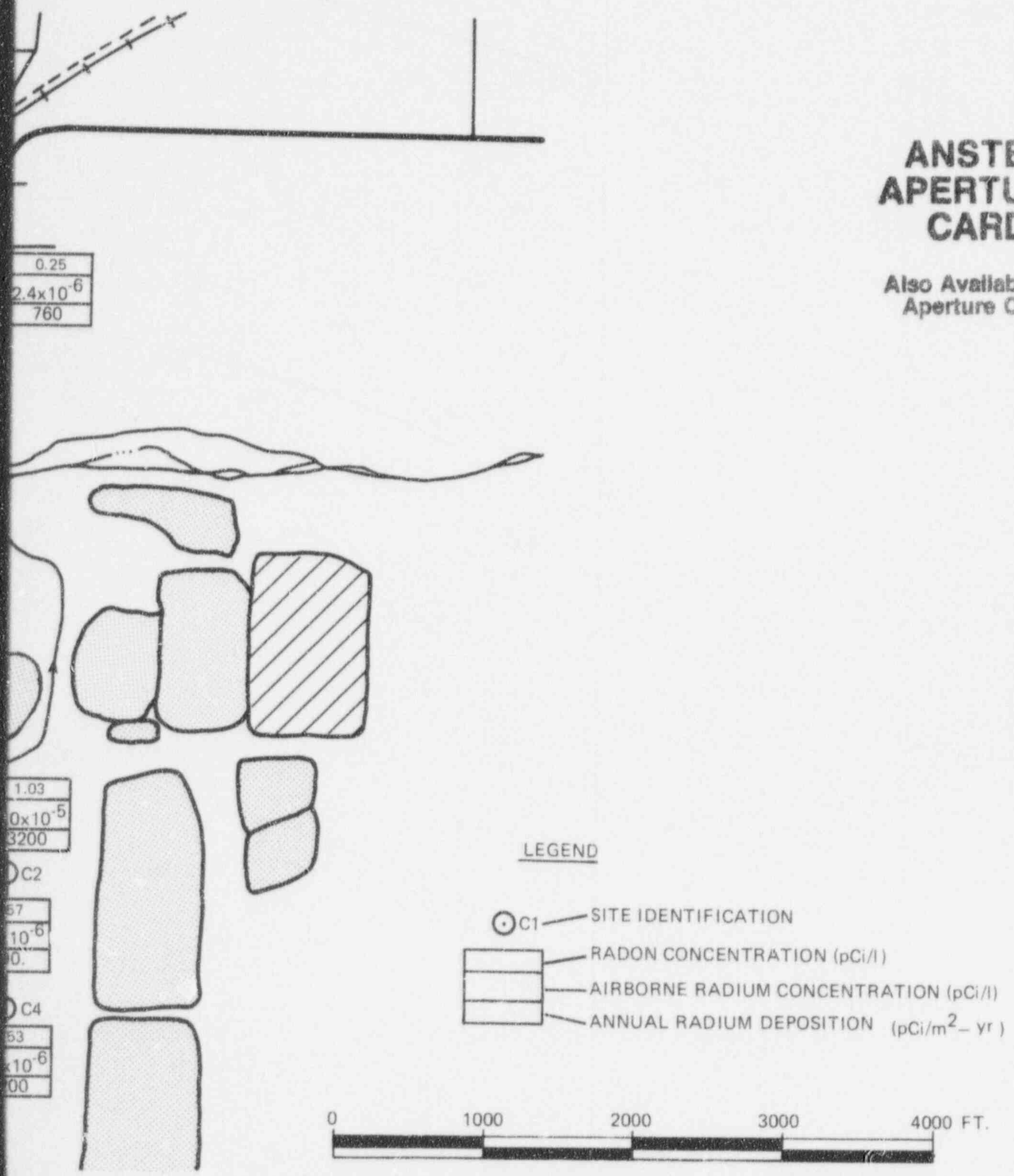


FIGURE 3-13. CALCULATIONS OF RADON AND AIR PARTICULATE CONCENTRAT



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ONS ABOVE BACKGROUND

211-00

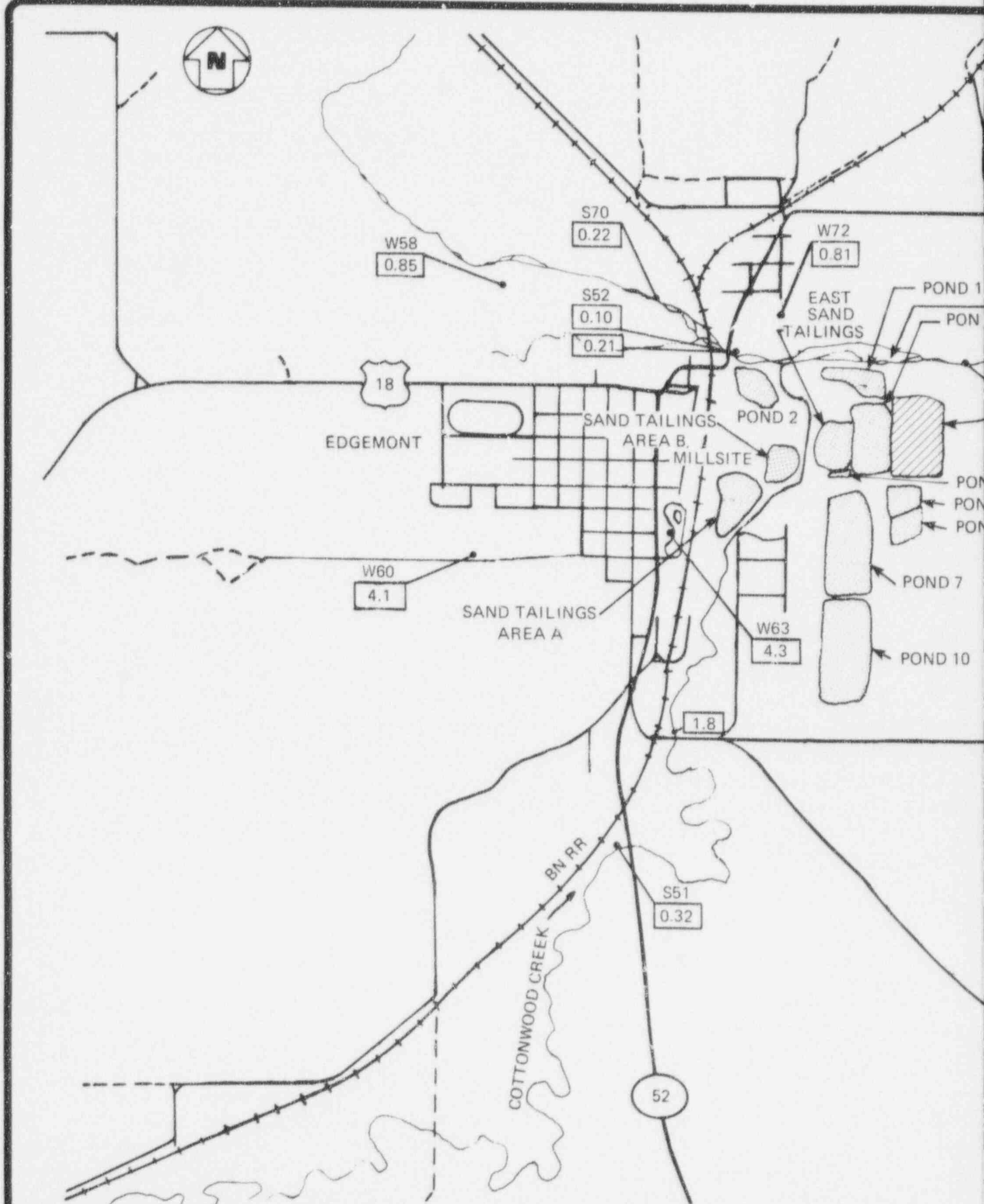
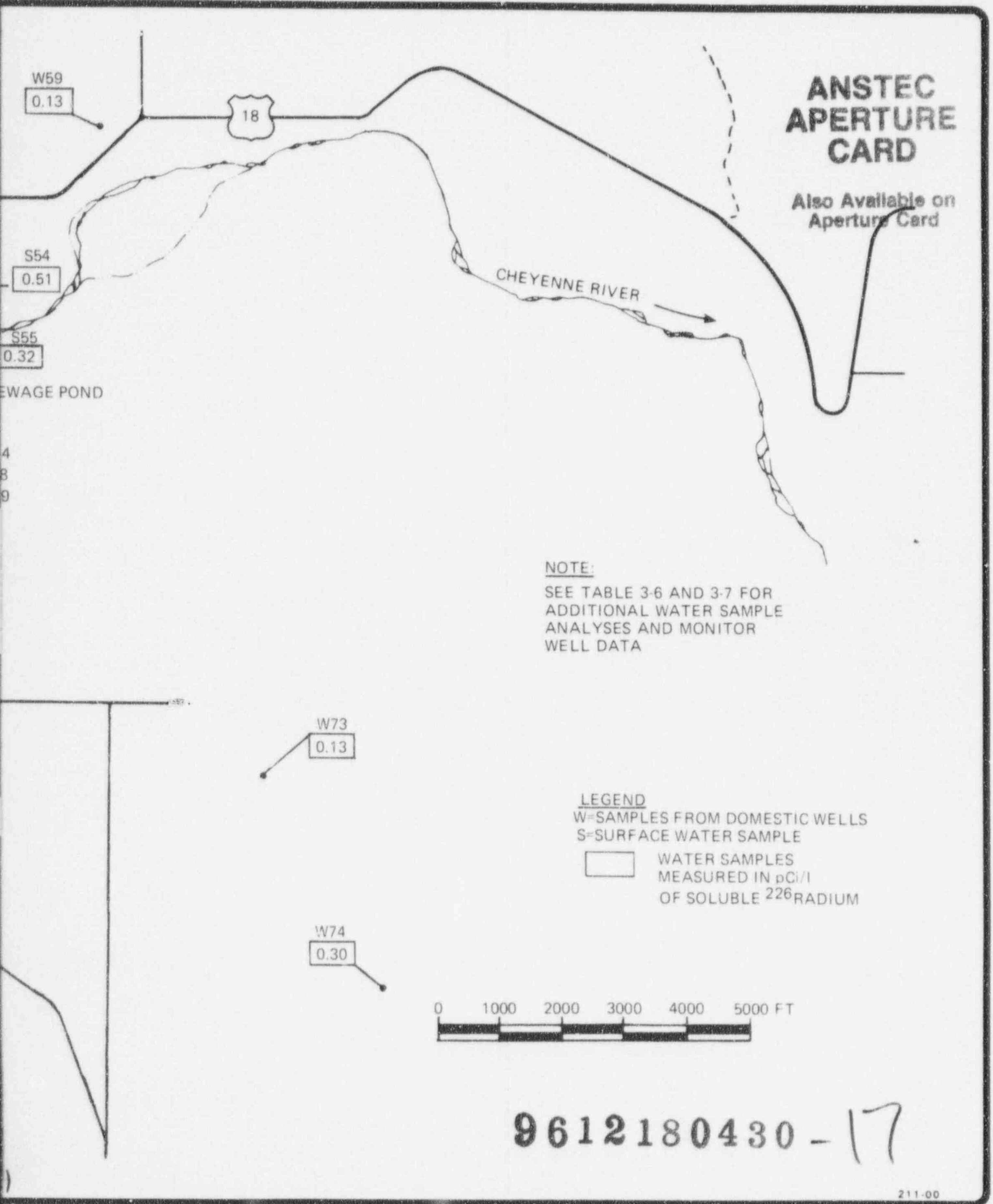


FIGURE 3-14. SURFACE AND GROUND WATER RADIUM CONCENTRATIONS (OFF SI


W59
0.13
18
S54
0.51
S55
0.32
EWAGE POND
CHEYENNE RIVER
NOTE:
SEE TABLE 3-6 AND 3-7 FOR ADDITIONAL WATER SAMPLE ANALYSES AND MONITOR WELL DATA
W73
0.13
LEGEND
W=SAMPLES FROM DOMESTIC WELLS
S=SURFACE WATER SAMPLE
WATER SAMPLES MEASURED IN pCi/l OF SOLUBLE 226RADIUM
W74
0.30
0 1000 2000 3000 4000 5000 FT
211-00

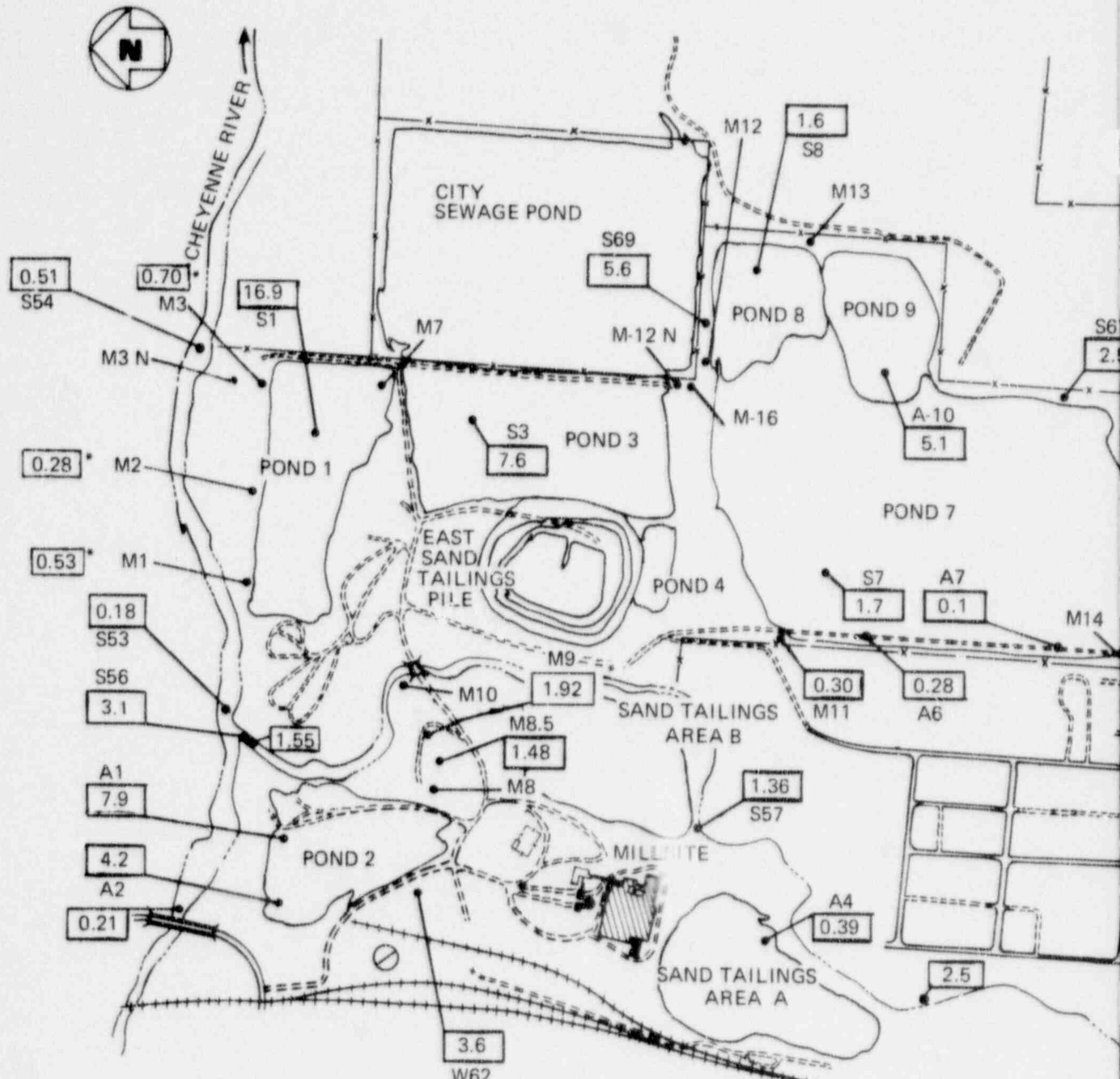
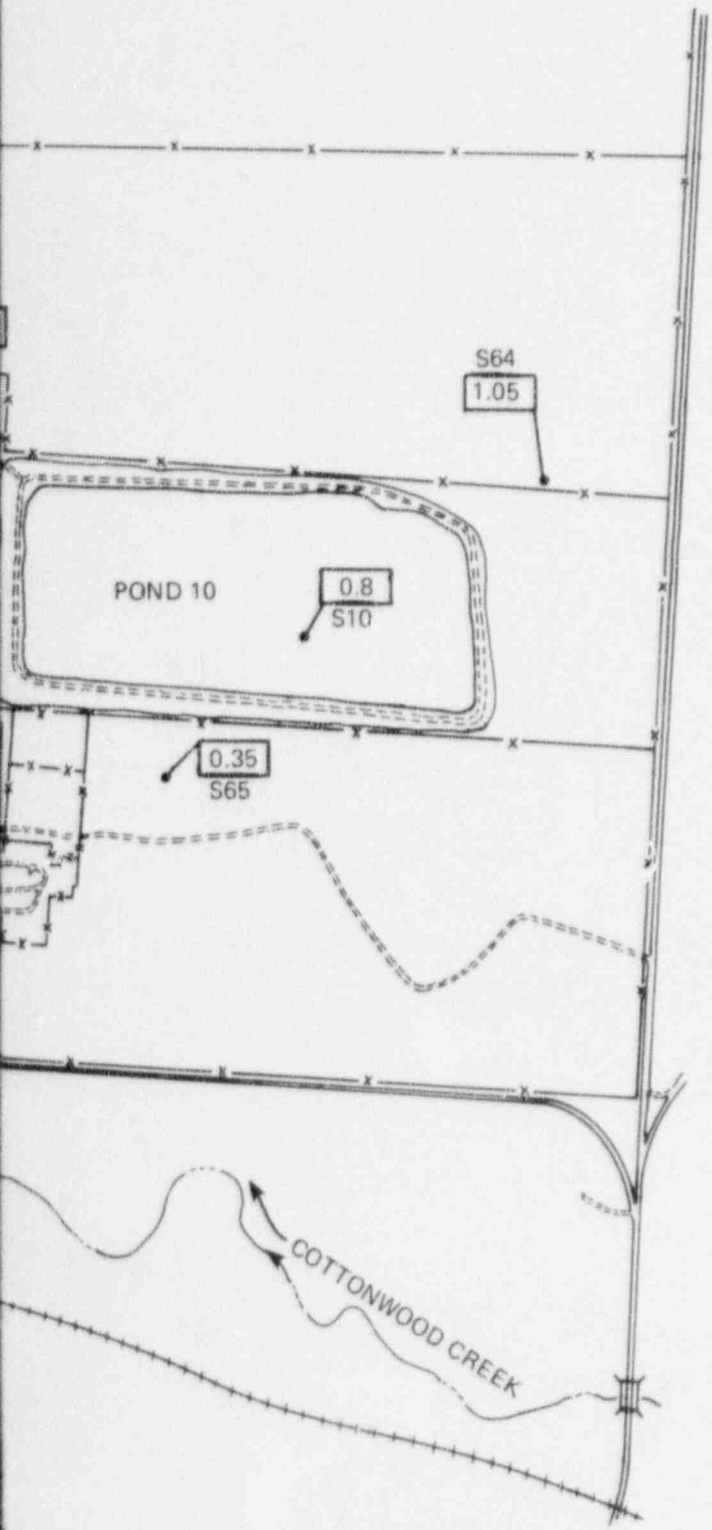


FIGURE 3-15. SURFACE AND GROUND WATER RADIUM CONCENTRATIONS (ON



NOTE:
SEE TABLE 3-6 AND 3-7 FOR ADDITIONAL WATER SAMPLE ANALYSES AND MONITOR WELL DATA

LEGEND

W=SAMPLES FROM DOMESTIC WELLS
M=SAMPLE FROM EXISTING MONITOR WELL
A=SAMPLE FROM FB&DU AUGER HOLE
S=SURFACE WATER SAMPLE
▭ WATER SAMPLES MEASURED IN pCi/l OF SOLUBLE ^{226}RADIUM
• TVA SAMPLES - AVERAGE OF SAMPLES FROM 11/76 TO 4/77

SITE)

211-00

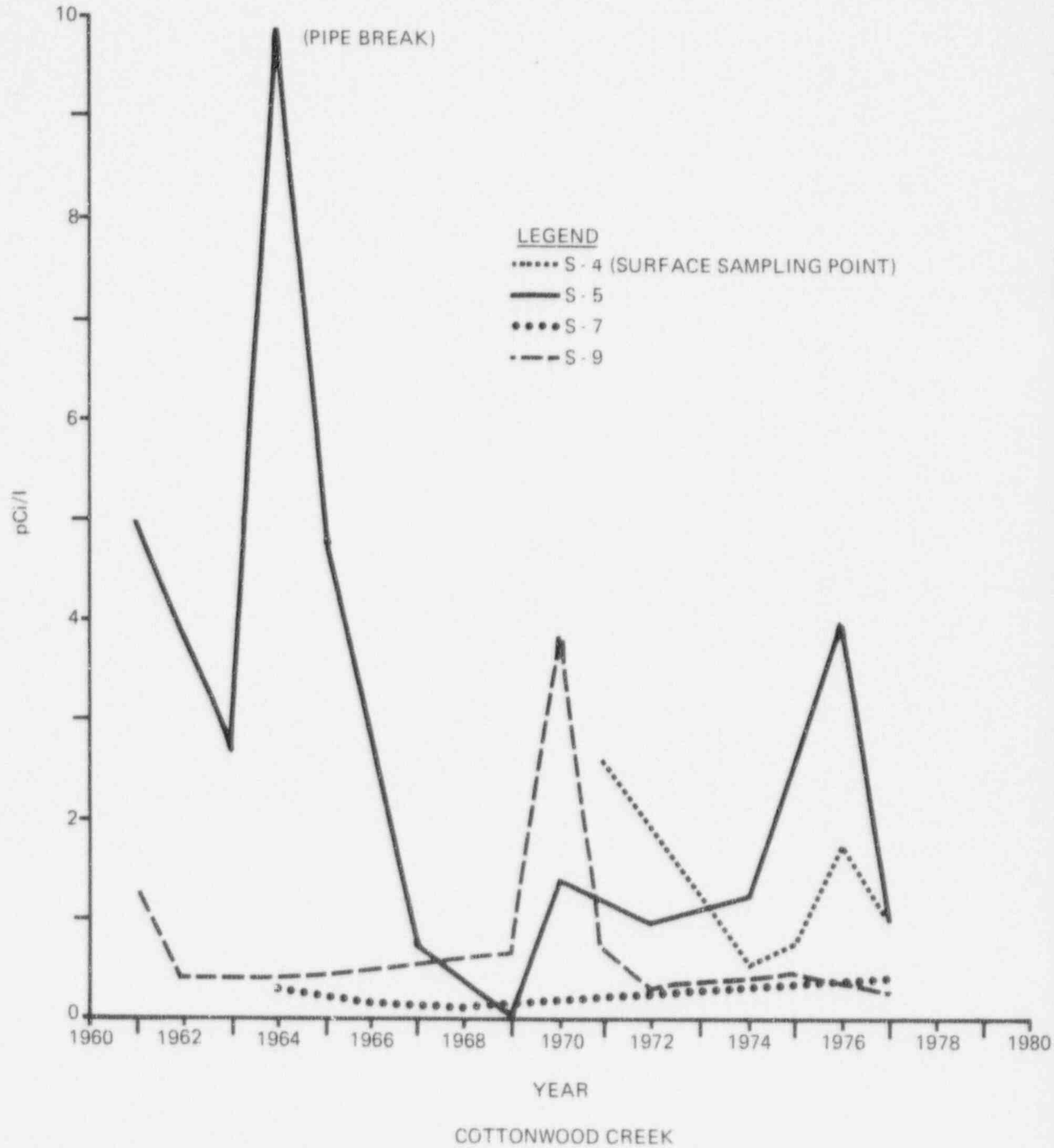
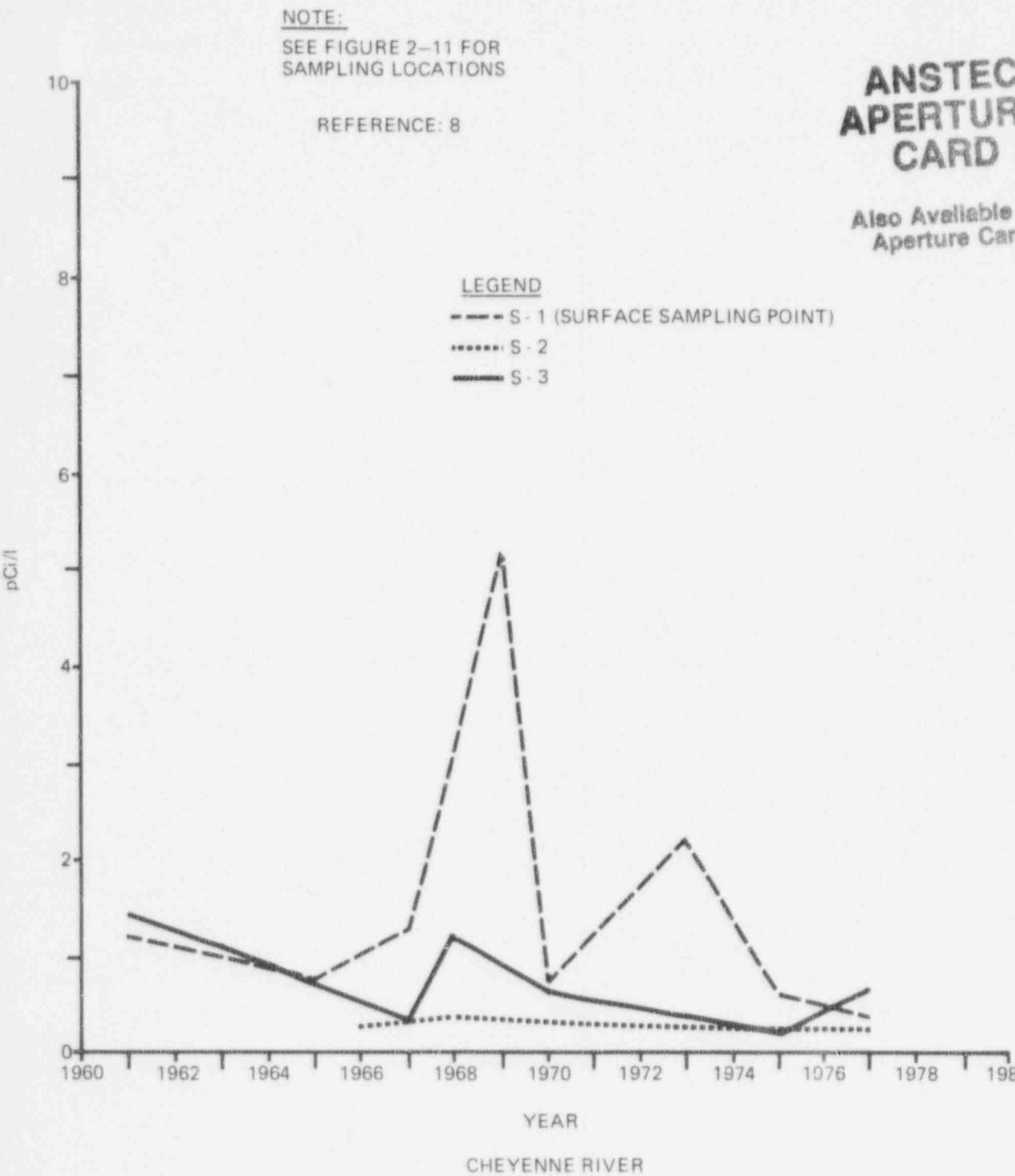


FIGURE 3-16. RADIUM CONCENTRATION TRENDS ALONG COTTONWOOD CREEK



AND CHEYENNE RIVER

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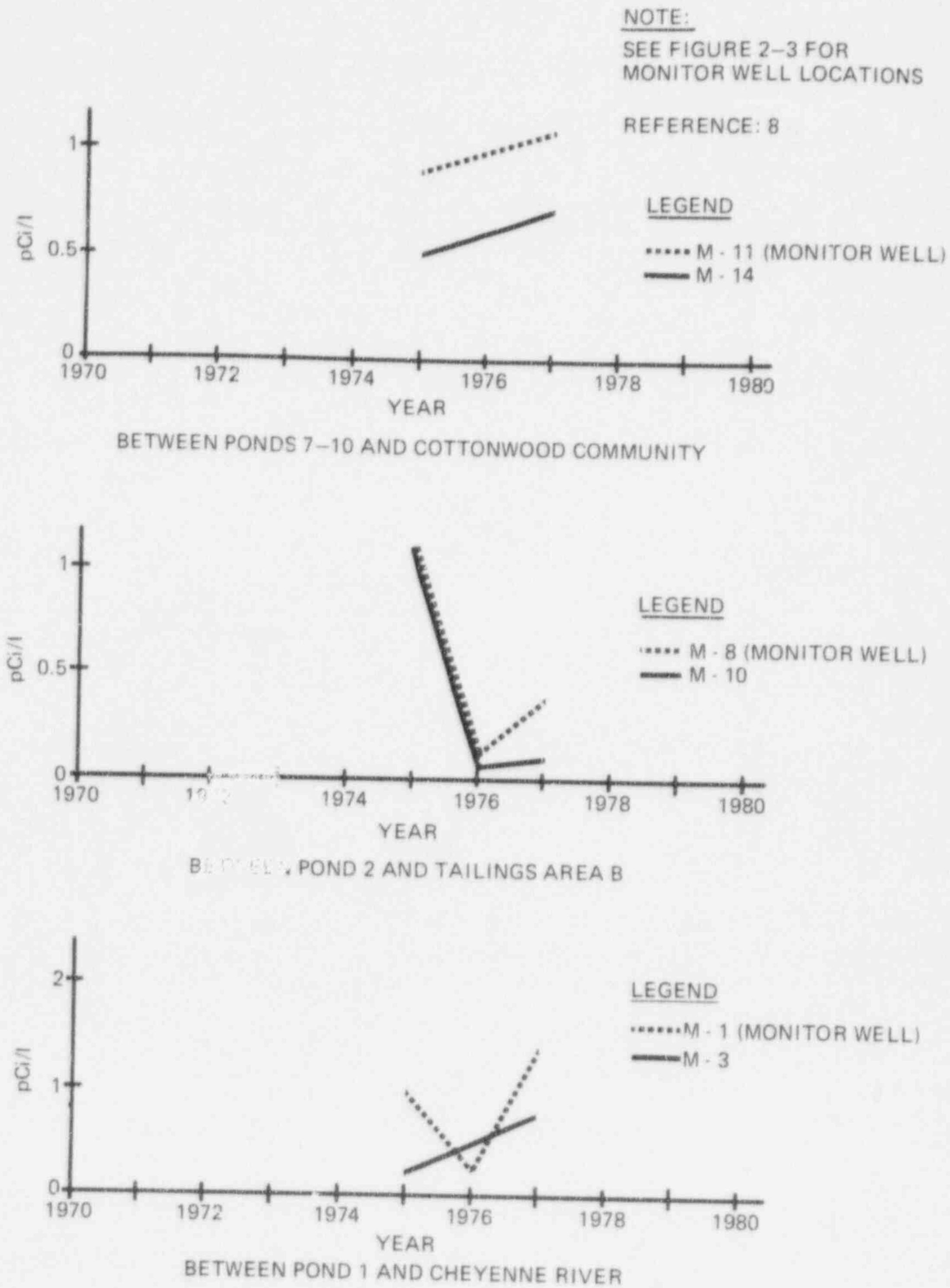

FIGURE 3-17. RADIUM CONCENTRATIONS IN GROUND WATER

211-00

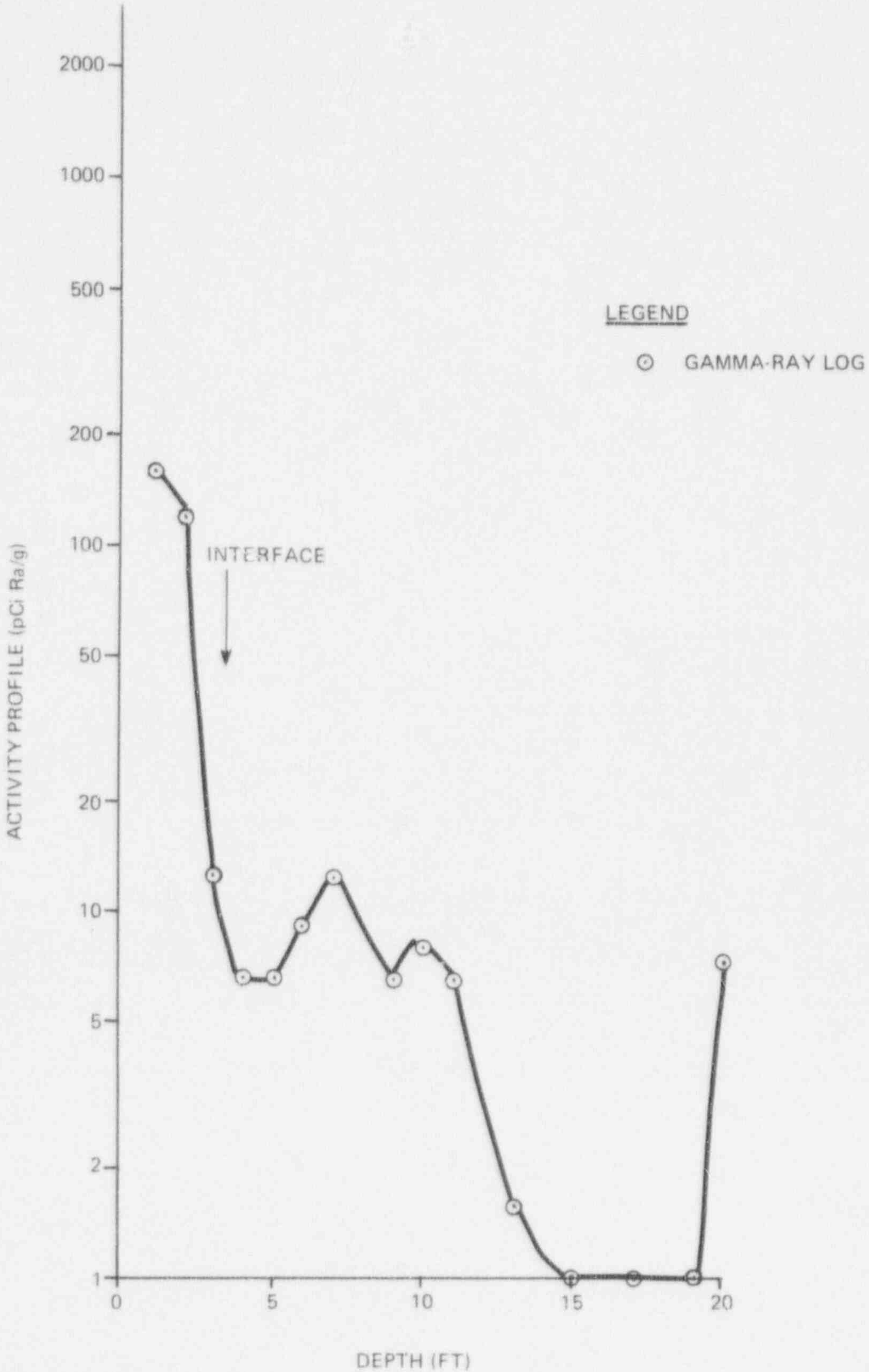

FIGURE 3-18. RADIOMETRIC PROFILE AT DRILL HOLE ESD-4, PILE A

211-00

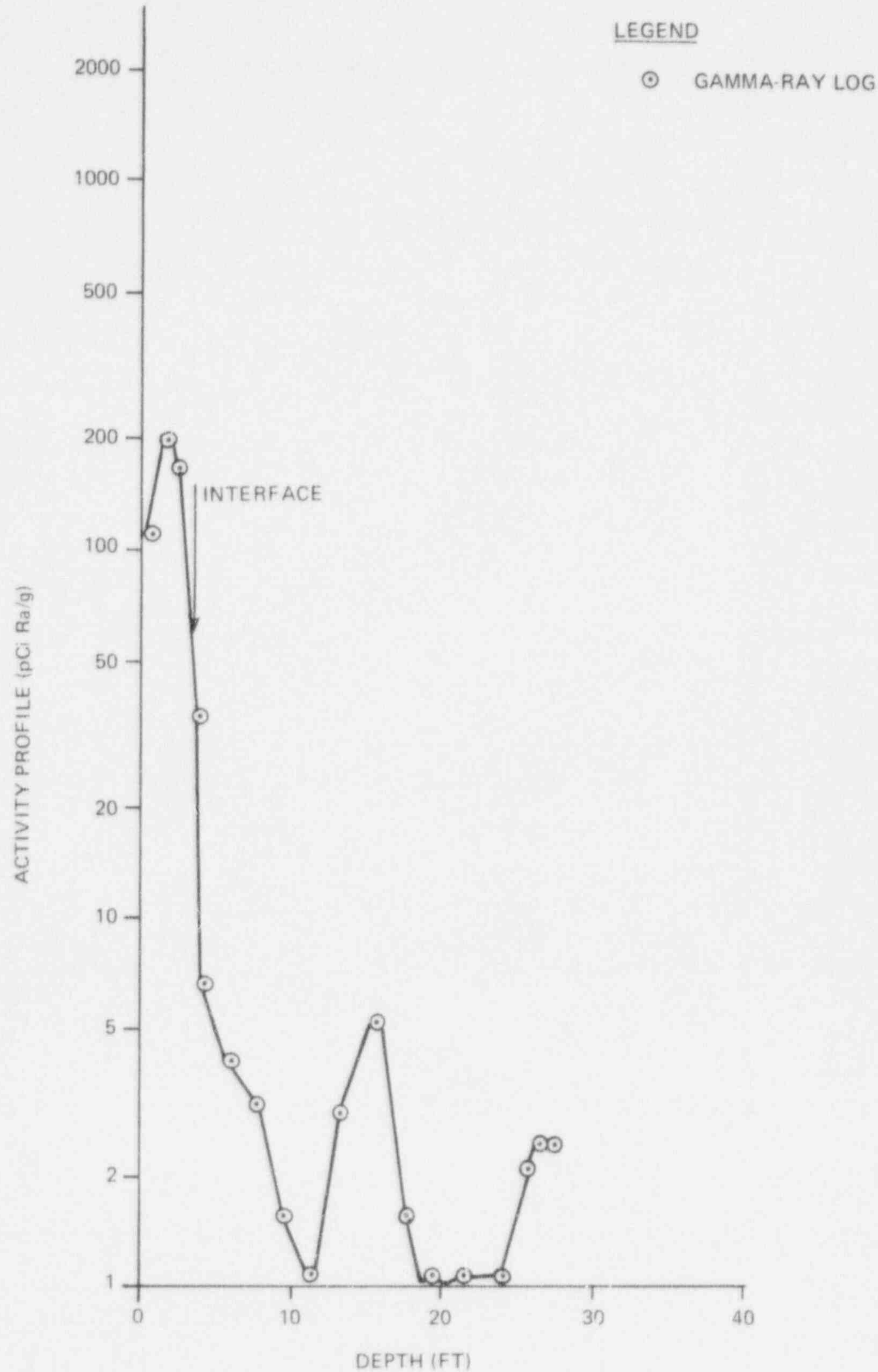

FIGURE 3-19. RADIOMETRIC PROFILE AT DRILL HOLE ESD-1, PILE 2

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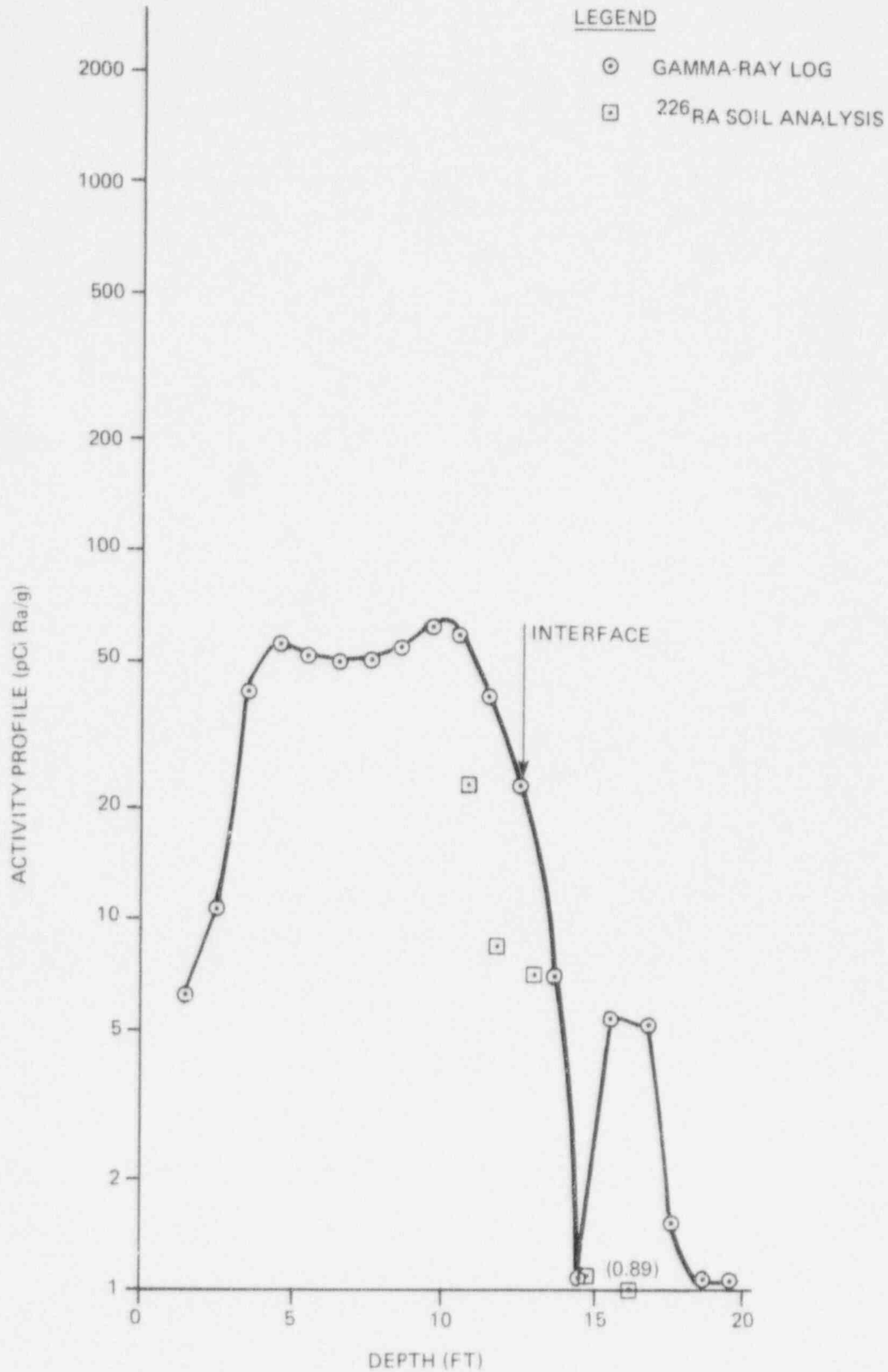


FIGURE 3-20. RADIOMETRIC PROFILE AT DRILL HOLE ESD-10, PILE 9

211-00

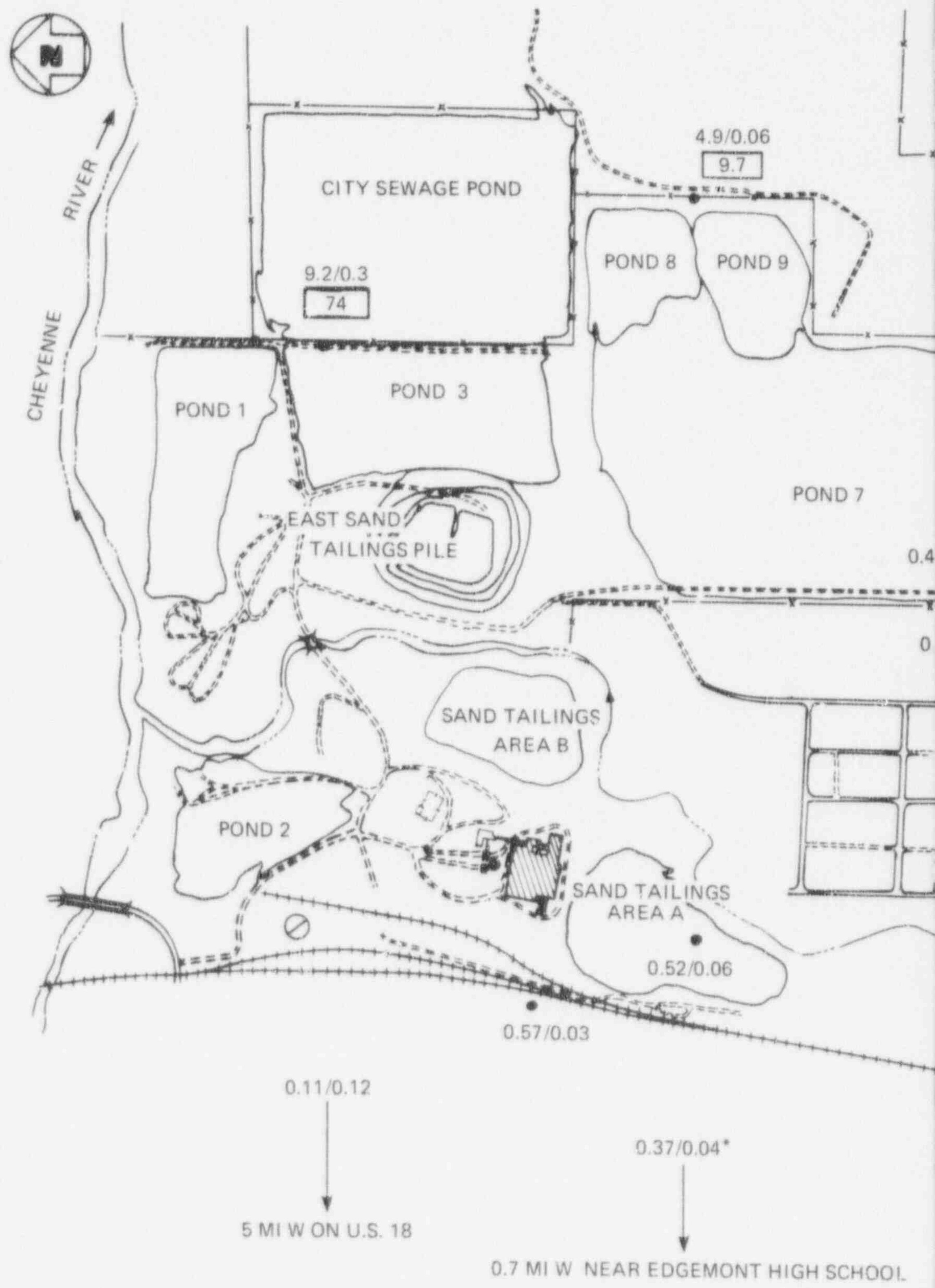
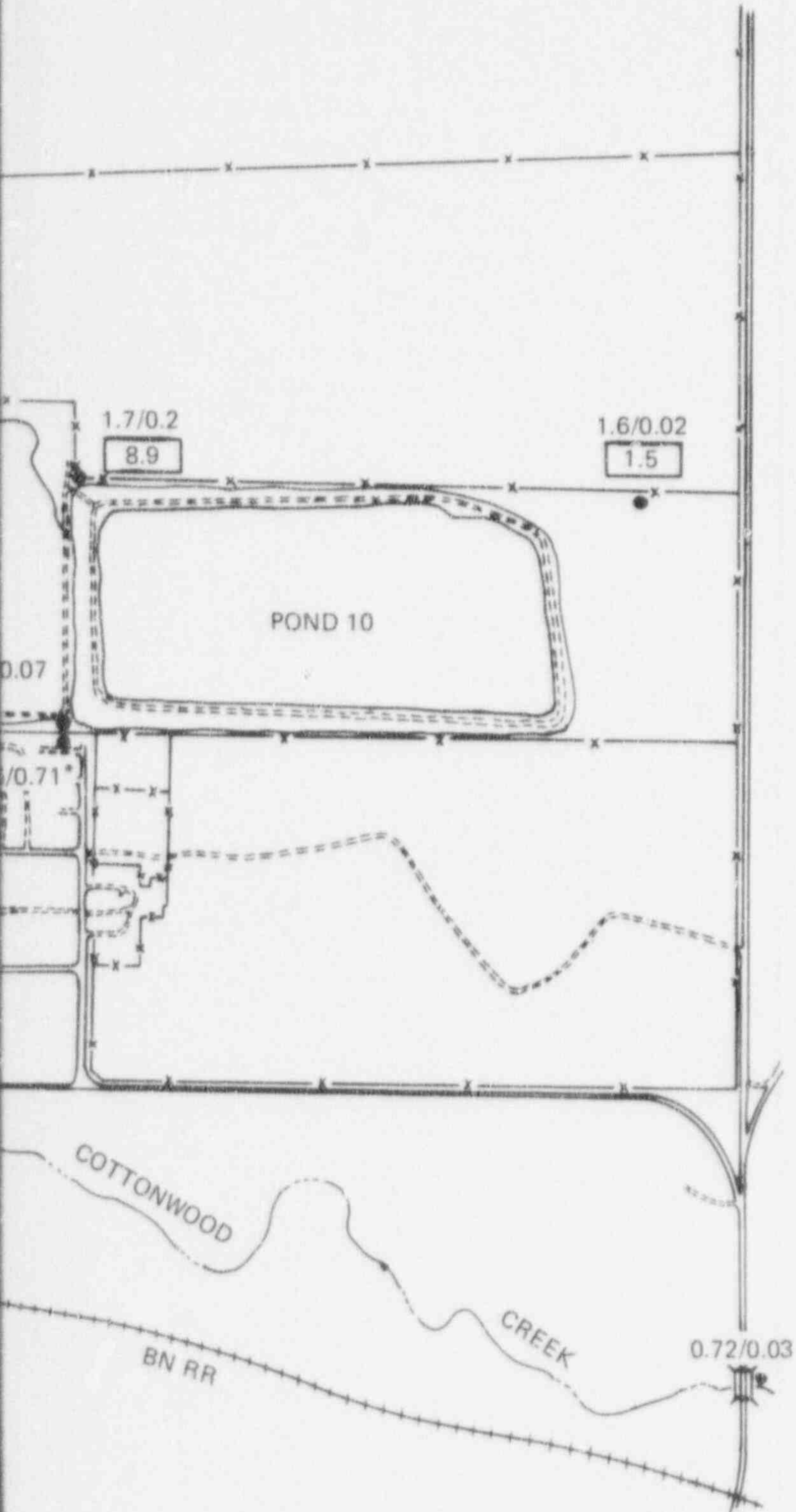


FIGURE 3-21. RADIUM CONCENTRATION IN VEGETATION SAMPLES



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NOTES:

a/b — a IS ^{226}Ra CONCENTRATION IN DRY PLANT MATERIAL pCi/g

b IS ^{226}Ra CONCENTRATION WASHED FROM PLANT MATERIAL pCi/g OF DRY PLANT MATERIAL

[box] — ^{226}Ra CONCENTRATION IN SOIL - pCi/g

* — TOMATO PLANTS, ALL OTHER SAMPLES ARE PASTURE GRASSES

0 — 500 — 1000 FT

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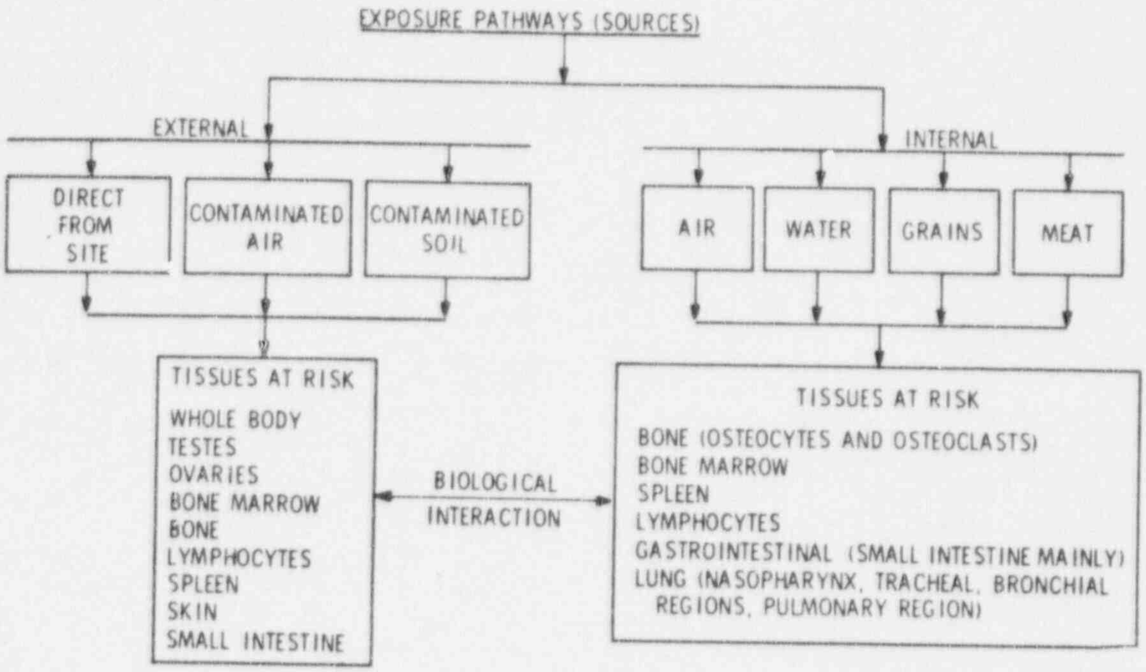

FIGURE 3-22. EXPOSURE PATHWAYS

211-00

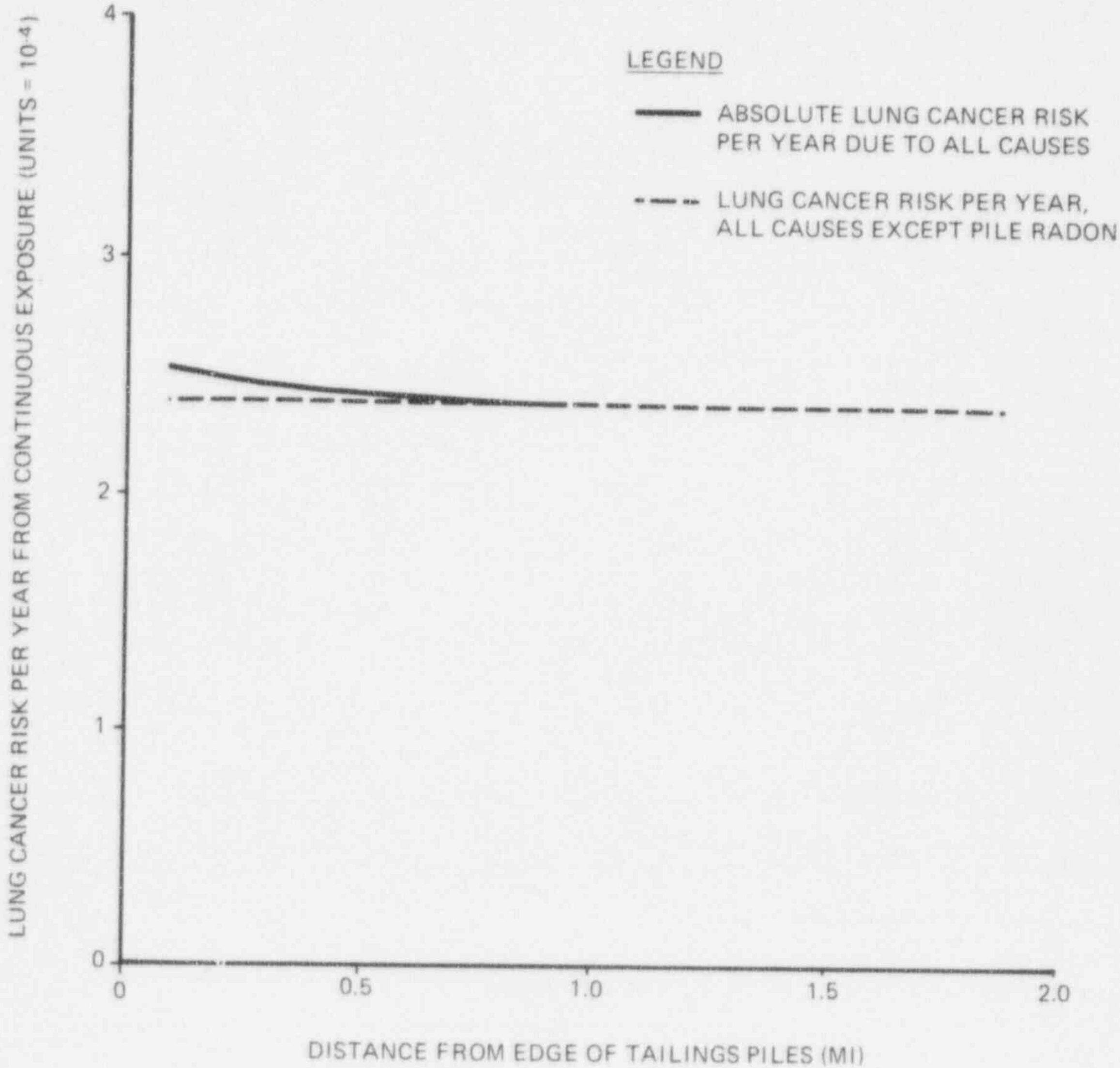

FIGURE 3-23. LUNG CANCER RISK FROM CONTINUOUS EXPOSURE TO RADON DIFFUSION

211-00

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).
One Working Level Month (WLM)	- WLM-Exposure to air containing a RDC of 1 WL for a duration of 170 hr.
Roentgen (R)	- that quantity of gamma radiation which yields a charge deposition of 2.58 x 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 x 10^{-6} erg.
Rem	- unit of energy deposition in man. 1 rem = 1 rad x quality factor. The quality factor = 20 for alpha particles.

TABLE 3-2

BACKGROUND RADIATION SOURCES IN SOIL IN VICINITY OF EDGEMONT

Sample Location[a]		^{226}Ra (pCi/g)	^{230}Th (pCi/g)	^{210}Pb (pCi/g)
Canister C1 Surface		0.66 ± 0.03	1.02 ± 0.05	3.3 ± 0.2
Canister C1 6-in. deep		0.50 ± 0.02[b]	1.35 ± 0.08[b]	1.82 ± 0.09[b]
Canister C2 Surface[c]		5.6 ± 0.3	5.2 ± 0.3	5.6 ± 0.3
Canister C2 6-in. deep		1.38 ± 0.07[b]	2.4 ± 0.1[b]	1.80 ± 0.09[b]
Canister C3 Surface		1.76 ± 0.09	1.23 ± 0.09	2.1 ± 0.1
Canister C3 6-in. deep		1.39 ± 0.07[b]	0.92 ± 0.05[b]	1.82 ± 0.09[b]
Site 2 E Sec 14 EDG	Surface	0.94 ± 0.07[b]	1.61 ± 0.09[b]	0.15 ± 0.07[b]
	Shale	3.02 ± 0.20[b]	1.54 ± 0.08[b]	3.30 ± 0.20[b]
Site 6 N Sec 14 EDG	Surface	0.64 ± 0.08[b]	0.25 ± 0.02[b]	1.87 ± 0.12[b]
	Shale Subsurface	1.43 ± 0.22[b]	0.96 ± 0.08[b]	0.88 ± 0.10[b]
		1.33 ± 0.84	1.29 ± 0.67	2.63 ± 1.75

[a] See Figure 3-2

[b] Used for average background concentrations

[c] Canister location near a road

TABLE 3-3

RADON EXHALATION FLUX FROM THE EDGEMONT TAILINGS

Sample[a]	Location	Radon Flux (pCi/m^2-s)
ESD-2	Background NNE of site C2[b] Red Canyon Site - 4 mi	2.7
ESD-3	Background, 4 mi NW of site C3[b]	3.5
ESD-4	Background, 4 mi SW of site C4[b]	2.2
ESD-7	Pond 1 - west side[c]	260
ESD-8	Pond 1 - central, near water	61
ESD-24	Pond 1 - near center	400
ESD-25	Pond 1 - near center	490
ESD-26	Pond 1 - near center	300
ESD-27	Pond 1 - near center	220
EUM-1	Pond 1 - central, near water	72
ESD-5	Pond 2 - west side	290
ESD-6	Pond 2 - east side	130
EUM-2	Pond 2 - center	40
ESD-9	Pond 3 - north end near water	6.7
ESD-10	Pond 3 - south end	970
ESD-13	Pond 4	6.8
ESD-18	Pond 7 - south central area	17
ESD-17	Pond 7 - east side on dirt cover	6.8
EUM-7	Pond 7 - northwest corner	18
ESD-23	Near Pond 7 - 10 yd from southeast corner	43
ESD-14	Pond 8 - center	4.9
ESD-15	Pond 9 - north end	2.8

TABLE 3-3 (Cont)

Sample[a]	Location	Radon Flux (pCi/m^2-s)
ESD-16	Pond 9 - south end	6.2
EUM-9	Pond 9 - center	13
ESD-19	Pond 10 - center, near water	3.6
ESD-20	Pond 10 - south end	4.7
ESD-21	Sand Tailings Area A Pile - northeast side	57
ESD-22	Sand Tailings Area A Pile - southwest side	52
ESD-11	East Sand Tailings Pile - near top on west side	46
ESD-12	East Sand Tailings Pile - near top on east side	66

[a] EUM: 3-hr samples taken Jun 22, 1977
ESD: 24-hr samples taken Aug 17-18, 1977

[b] Background flux locations shown in Figure 3-2

[c] Remainder of flux measurement locations shown in Figure 3-4.

TABLE 3-4

SURVEY OF MILL BUILDINGS

LOCATION NO.[a]	α Surface (dpm) per 100 cm^2	α Smear (dpm) per 100 cm^2	β + γ @ 3 ft above Surface/@ Surface (mR/hr)	Remarks
1	350	≤ MDA	0.06/0.05	surface unchanged
2	700	--	0.08/0.05	--
3	700	--	0.08/0.05	--
4	875	--	0.05/0.07	--
5	1,050	70	0.07/0.1	after smear α surface = 350
6 grinder floor	700-1,400	≤ MDA	--	--
7 drillpress floor	700	≤ MDA	--	--
8 bench top	525	≤ MDA	--	--
2-7 composite of floor smear	--	35-70	--	--
9	1,225	50	0.08/0.06	--
10	350	50	0.06/0.05	--
11	700	70	--	--
12	350	--	0.07/0.05	--
13	--	--	0.3 /0.3	--
14	700	--	0.3 /0.4	--
15	350	35	--	--
16	2,450	50	--	--
17	700	--	0.5 /0.14	large accumulation of dust
18	1,750	35	0.1 /0.45	--
19	1,400	--	- /0.1	--
20	700	--	- /0.11	--
21	700	70	- /0.09	--
22	10,500	2,100	0.08/0.75	after smear α surface=700
23	525	--	0.04/0.07	after smear α surface=9,000
24	4,200	140	0.15/1.0	--
25	2,800	--	0.07/0.03	--
26 floor	1,050	35	0.05/1.0	--

TABLE 3-4 (Cont)

LOCATION NO.[a]	α Surface (dpm) per 100 cm^2	α Smear (dpm) per 100 cm^2	β + γ @ 3 ft above Surface/@ Surface (mR/hr)	Remarks
26 interior walls	2,100	210	--	--
27	1,750	--	0.2 /0.45	--
28 bottom of map item No. 42	14,000	700	0.15/10.0	β+γ smear ∿0.06 mR/hr/100cm^2 ∿3,300 dpm/100cm^2
28 bottom of map item No. 42	--	β+γ smear 3,000	-- --	-- --
29 floor	2,450	--	0.8 /2.0	--
30 floor	1,750	--	0.25/1.0	--
31 under vats	--	--	0.5 /0.6	--
31A wall	700	--	--	--
32 wall	175	--	0.17/0.17	--
33 exterior wall	525	--	0.08/0.08	--
34 floor	1,400	--	0.15/0.1	--
35 floor	1,400	--	0.8 /0.4	--
36 floor	2,100	--	0.8 /0.8	--
37 floor	8,400	1,750	0.6 /1.5	--
38 dose-rate	--	--	1.0 / -	--
39 floor	7,000	--	0.1 /1.0	--
40 floor	700	--	0.1 /0.15	--
41 floor	1,050	--	0.08/0.05	--
42 floor	1,400	--	0.05/0.1	--
43 floor	350	--	0.07/0.07	--
44 floor	1,050	≤ MDA	0.15/0.15	--
45 mezz floor	700	--	0.05/0.1	--
46 mezz floor	1,050	70	0.15/0.2	--
47 mezz	700	--	0.05/0.07	--
48 mezz	700	--	0.1 /0.05	--
49 mezz	1,050	35	0.15/0.35	--
49A auger No. 33	2,800	105	- /1.5	on edge of auger
50 mezz	1,400	--	0.5 / -	--

TABLE 3-4 (Cont)

LOCATION NO.[a]	α Surface (dpm) per 100 cm^2	α Smear (dpm) per 100 cm^2	$\beta + \gamma$ @ 3 ft above Surface/@ Surface (mR/hr)	Remarks
51 mezz	1,050	90	--	--
52 mezz	3,150	--	0.5 /0.7	resin basket
53 mezz	3,150	--	0.4 /0.4	--
54 mezz	3,500	--	0.6 /0.6	--
55 mezz	490,000	700	- /15.0	resin basket
56 concrete floor	7,000	--	0.5 /0.8	--
57 in item No. 44	--	--	- /1.5γ - /∿150$\beta+\gamma$	in yellowcake dryer
58 near item No. 44	315,000	70,000	8-10/50.0	floor behind yellowcake dryer
59 3rd floor	21,000	7,000	--	duct to scrubber dryer
60 wall	700-210,000	70	--	wall near scrubber dryer
61 mezz	175	≤ MDA	0.05/0.06	--
62 exterior wall	525	--	0.1 /0.14	∿4 ft off ground
63 exterior wall	700	--	0.15/0.07	--
64 exterior wall	350	--	0.08/0.08	--
64A cement pad	525	≤ MDA	--	--
65 building exterior	1,050	≤ MDA	0.1 /0.25	on concrete (vertical)
65 building exterior	175	≤ MDA	--	on building metal
66 building exterior	350	--	0.07/0.08	--
67 building exterior	--	--	0.03/0.03	dose-rate
68 concrete walkway	350	≤ MDA	--	--
69	350	--	0.05/0.05	--
70	525	≤ MDA	0.02/0.02	--
71	≤ 350	≤ MDA	0.02/0.02	--
72	≤ 350	--	0.03/0.03	--
73	175	≤ MDA	0.03/0.03	--
74	≤ 350	≤ MDA	0.02/0.03	--
75 FeV building	700	--	--	--
Oil storage shed	≤ 350	≤ MDA	--	--

TABLE 3-4 (Cont)

LOCATION NO.[a]	α Surface (dpm) per 100 cm^2	α Smear (dpm) per 100 cm^2	β + γ @ 3 ft above Surface/@ Surface (mR/hr)	Remarks
Garage	≤ 700	--	--	--
Conveyor outside	350-700	∿35-70	--	--
Conveyor No. 2 inside	175	∿30	--	--
Crusher area	350-1,050	≤105	--	--
Air scrubber	2,800	700	--	--
Filter conveyor	∿ 250	--	--	after smear α surface = 250

Miscellaneous

1 beam (vertical) 1,400 - 2,100 dpm/100 cm^2 @ surface

Wood beams (loose on floor) 21,000 dpm/100 cm^2 @ surface; smear = 700 dpm/100 cm^2

[a]Location numbers are shown in Figure 3-11.

TABLE 3-5

OFF-SITE SOIL SAMPLE ANALYSES

Sample Location[a]	^{226}Ra pCi/g ± σ[b]	^{230}Th pCi/g ± σ[b]	^{210}Pb pCi/g ± σ[b]
200 yd ENE of pond 1 surface to 1.5 in.	7.1 ± 0.4	6.1 ± 0.3	7.9 ± 0.4
200 yd ENE of pond 1 at 6 in.	1.17 ± 0.06	1.08 ± 0.08	0.80 ± 0.05
200 yd east of well M-13 surface	1.60 ± 0.08	4.0 ± 0.3	3.4 ± 0.2
200 yd east of well M-13 at 6 in.	2.1 ± 0.1	1.4 ± 0.1	1.44 ± 0.08
400 yd east of well M-13 surface	15.4 ± 0.8	8.6 ± 0.4	19 ± 1
400 yd east of well M-13 at 6 in.	1.51 ± 0.08	1.6 ± 0.1	3.6 ± 0.2
200 yd SE of pile 9 surface to 1 in.	24 ± 1	12.8 ± 0.6	75 ± 4
200 yd SE of pile 9 at 6 in.	2.8 ± 0.1	1.74 ± 0.09	3.2 ± 0.2
400 yd at 130° SE of pile 9 surface to 1 in.	8.1 ± 0.4	5.4 ± 0.4	1.80 ± 0.9
400 yd at 130° SE of pile 9 at 6 in.	2.1 ± 0.1	1.5 ± 0.2	1.3 ± 0.1
600 yd at 130° SE of pile 9 surface to 1 in.	3.7 ± 0.2	2.8 ± 0.2	3.3 ± 0.2
600 yd at 130° SE of pile 9 at 6 in.	5.2 ± 0.3	2.4 ± 0.2	4.2 ± 0.2
100 yd north of Cheyenne River surface	1.68 ± 0.08	1.8 ± 0.1	2.2 ± 0.1
100 yd north of Cheyenne River at 6 in.	0.84 ± 0.04	1.17 ± 0.06	2.6 ± 0.1
100 yd SE of pond 7 east fence surface	26 ± 1	10.8 ± 0.5	51 ± 2
200 yd SE of pond 7 east fence surface	33 ± 2	7.7 ± 0.5	44 ± 2
200 yd SE of pond 7 east fence at 6 in.	1.51 ± 0.08	1.7 ± 0.1	2.6 ± 0.3

[a]Sample locations are shown in Figure 3-12.

[b]One standard deviation due to counting statistics.

TABLE 3-6

RADIONUCLIDE ANALYSES OF WATER SAMPLES

Designation of Sample on Figures 3-14 & 3-15	Designation by FB&DU for Lab Analysis	Location	Dissolved Concentrations ^{226}Ra (pCi/l)	^{230}Th (pCi/l)	Total Uranium (pCi/l)
A 1	ESD -1	NE portion of pond 2, hole 1	7.9	0.4	130
A 2	ESD -2	NW portion of pond 2, hole 2	4.2	0.3	36
A 6	ESD -6	NW on dike of pond 7, hole 6	0.28	0.2	330
A 7	ESD -7	SW on dike of pond 7, hole 7	0.08	<0.1	220
A 10	ESD -10	S center of pile 9, hole 10	5.1	1.5	2.4×10^3
M 9	M-9	By Cottonwood Creek on W side	1.48	<0.1	26
M 11	M-11	NW corner of pond 7 outside dike, inside fence 200 ft E of sewage pumping station	0.30	0.4	214
A 4	ESD W-4	Center of E road on sand tailings area A, hole 4	0.39	<0.2	21
A 100	ESD W-51	N of pile 2 by Cheyenne River	0.21	0.6	27
S 51	ESD W-51	Cottonwood Creek upstream	0.32	<0.1	14
S 52	ESD W-52	Cheyenne River upstream at bridge	0.10	<0.1	9
S 53	ESD W-53	Cheyenne River below confluence with Cottonwood Creek	0.18	<0.1	7
S 54	ESD W-54	Cheyenne River downstream	0.51	<0.1	8
S 55	ESD W-55	Cheyenne River downstream	0.32	<0.1	6
S 56	ESD W-56	Cottonwood Creek, mouth of Cottonwood Creek	3.1	0.3	22
S 57	ESD W-57	Cottonwood Creek above E sand tailings	1.36	<0.1	25
S 64	ESD W-64	Standing water SE of pond 10	1.05	2.8	< 4
S 65	ESD W-65	Standing water W of pond 10	0.35	<0.1	6
S 67	ESD W-67	Standing water E of pond 7	2.5	1.26×10^3	1.16×10^3
S 69	ESD W-69	Seep N of pond 8	5.5	3.3	20
S 70	ESD W-78	Cheyenne River upstream from bridge	0.22	12.1	6

TABLE 3-6 (Cont)

Designation of Sample on Figures 3-14 & 3-15	Designation by FB&DU for Lab Analysis	Location	Dissolved Concentrations ^{226}Ra (pCi/l)	^{230}Th (pCi/l)	Total Uranium (pCi/l)
W 58	ESD W-58	Well N of fairgrounds in ESD, S of river	0.85	0.3	5
W 59	ESD W-59	Domestic well off Highway 3424 NE of Dudley	0.13	0.3	5
W 60	ESD W-60	Edgemont water supply from well	4.1	9	6
W 62	ESD W-62	Burlington well, E of RR roundhouse near site office	3.6	1.5	< 3
W 63	ESD W-63	Well flowing into pond in ESD city park	4.3	1.7	< 3
W 72	ESD W-72	Domestic well, campground N of Cheyenne River	0.81	0.6	6
W 73	ESD W-73	Well, 2 mi SE of tailings	0.13	19	8
W 74	ESD W-74	Well, 2.8 mi SE of tailings	0.30	3.8	5
S 1	Pond 1	Pond 1	16.9	3.2×10^4	8.4×10^3
S 3	Pond 3	Pond 3	7.6	4.7×10^3	8.8×10^3
S 7	Pond 7	Pond 7	1.7	2.6×10^4	1.85×10^4
S 8	Pond 8	Pond 8	1.6	1.53×10^3	2.3×10^3
S 10	Pond 10	Pond 10	0.8	3.1×10^3	5.8×10^3
MONITOR WELL DATA TAKEN BY TVA*					
M 1	--	↑	1.35	0.17	28.2
M 2	--		0.69	0.23	117
M 3	--		0.59	0.56	12.5
M 7	--		0.62	0.41	74.3
M 8	--		0.10	0.74	19.4
M 9	--		1.92	0.64	18.7
M 10	--	See Figure 3-15 for monitor well locations	0.29	0.63	768
M 11	--		1.19	0.76	78.3
M 12	--		1.11	1.39	25.0
M 13	--		1.24	1.43	1.13
M 14	--	↓	0.88	0.38	118
RT	--	Control, R. Toman farm	0.41	0.14	12

*Average of sample data in Reference 6

TABLE 3-7

CHEMICAL ANALYSES OF WATER SAMPLES

Sample No.[a]	Mercury	Copper	Iron	Lead	Manganese
MCL[b]	0.002	--	--	0.05	--
ESD 1-2[c]	<0.0002	0.013	0.148	0.071	0.587
ESD -1	0.0080	0.035	0.099	0.189	1.074
ESD -2	<0.0002	0.020	52.100	0.091	17.680
ESD -6	<0.0002	0.046	0.249	0.182	1.045
ESD -10	0.0060	0.037	0.111	0.163	0.030
ESD W-100	<0.0002	0.019	0.119	0.109	1.307
ESD M-1	<0.0002	0.027	0.185	0.163	3.149
ESD M-2	<0.0002	0.029	0.159	0.163	2.742
ESD M-3	<0.0002	0.017	94.900	0.123	9.080
ESD M-3N	<0.0002	0.018	41.900	0.143	3.260
ESD M-7	<0.0002	0.038	0.142	0.207	0.045
ESD M-8	<0.0002	0.009	0.078	0.047	0.862
ESD M-12[d]	<0.0002	0.017	6.170	0.087	0.117
ESD M-12[e]	<0.0002	0.012	6.310	0.088	3.200
ESD M-12[f]	<0.0002	0.013	0.079	0.091	0.722
ESD M-13	<0.0002	0.019	1.95	0.104	6.70
ESD M-14	<0.0002	0.991	240.00	0.121	14.13
ESD W-4	<0.0002	0.016	0.132	0.089	0.806
ESD W-51	0.0009	0.011	0.075	0.082	0.189
ESD W-52	<0.0002	0.008	0.073	0.052	0.009
ESD W-53	<0.0002	0.008	0.057	0.058	0.006
ESD W-54	<0.0002	0.040	0.076	0.056	0.002
ESD W-55	<0.0002	0.010	0.084	0.061	0.004
ESD W-56	<0.0002	0.009	0.201	0.061	0.163
ESD W-57	<0.0002	0.012	0.111	0.077	1.265
ESD W-58	<0.0002	0.006	0.087	0.051	0.081
ESD W-59	<0.0002	0.009	24.400	0.033	0.029
ESD W-60	<0.0002	0.007	3.52	<0.001	0.024
ESD W-62	<0.0002	0.006	0.048	0.027	0.003
ESD W-63	<0.0002	0.005	0.072	0.031	0.002
ESD W-64	<0.0002	0.006	1.426	<0.001	0.036
ESD W-65	<0.0002	0.005	0.187	0.011	0.124
ESD W-67	0.0440	0.154	67.500	0.030	5.450
ESD W-69	0.0002	0.042	46.000	0.110	12.880
ESD W-72	<0.0002	0.007	0.102	0.048	0.091
ESD W-73	<0.0002	0.009	0.071	0.034	0.003
ESD W-74	<0.0002	0.008	4.540	0.039	1.421
ESD W-78[g]	<0.0002	0.010	0.062	0.046	0.004
M-9	<0.0002	0.019	0.048	0.075	0.067
M-11	<0.0002	0.033	0.075	0.173	0.025
Pond 1	0.0125	5.420	60.300	0.148	150.200
Pond 3	0.0012	3.500	399.000	0.120	103.900
Pond 7	0.0165	13.330	5,450.000	0.153	222.800
Pond 8	0.0015	3.540	422.000	0.088	78.600
Pond 10	0.0048	95.600	7,510.000	0.137	303.400

TABLE 3-7 (Cont)

Sample No.[a]	Nickel	Titanium	Vanadium	Zinc	Cadmium
MCL[b]	--	--	--	--	0.010
ESD 1-2[c]	0.059	<0.001	0.014	0.062	0.006
ESD -1	0.161	<0.001	0.023	0.060	0.010
ESD -2	1.774	<0.001	0.115	0.083	0.006
ESD -6	1.450	<0.001	0.160	0.158	0.018
ESD -10	0.145	<0.001	0.050	0.039	0.004
ESD W-100	0.166	<0.001	0.008	0.024	0.005
ESD M-1	0.395	<0.001	0.009	0.071	0.024
ESD M-2	0.202	<0.001	0.030	0.025	0.004
ESD M-3	2.520	<0.001	0.007	0.047	0.005
ESD M-3N	1.608	<0.001	0.009	0.031	0.009
ESD M-7	0.174	<0.001	0.022	0.056	0.010
ESD M-8	0.058	<0.001	0.042	0.022	0.004
ESD M-12[d]	0.078	<0.001	0.010	0.014	<0.001
ESD M-12[e]	0.145	<0.001	0.021	0.054	0.004
ESD M-12[f]	0.160	<0.001	0.030	0.079	0.006
ESD M-13	0.457	0.008	0.011	0.644	0.010
ESD M-14	18.600	0.015	0.013	3.100	0.027
ESD W-4	0.356	<0.001	0.011	0.128	0.005
ESD W-51	0.018	<0.001	0.010	0.019	<0.001
ESD W-52	0.006	<0.001	<0.001	0.013	<0.001
ESD W-53	0.003	<0.001	<0.001	0.015	0.009
ESD W-54	<0.001	<0.001	0.006	0.050	0.024
ESD W-55	<0.001	<0.001	0.003	0.026	<0.001
ESD W-56	<0.001	<0.001	0.008	0.046	<0.001
ESD W-57	0.011	<0.001	0.009	0.053	<0.001
ESD W-58	0.006	<0.001	0.007	0.162	0.004
ESD W-59	0.015	<0.001	0.005	0.097	0.007
ESD W-60	0.055	<0.001	0.007	0.011	0.003
ESD W-62	0.014	<0.001	0.015	0.044	<0.001
ESD W-63	0.012	<0.001	0.010	0.009	<0.001
ESD W-64	<0.001	<0.001	0.004	0.013	<0.001
ESD W-65	<0.001	<0.001	0.006	0.025	<0.001
ESD W-67	1.860	<0.001	0.091	0.857	0.039
ESD W-69	6.830	<0.001	0.055	0.422	0.006
ESD W-72	0.033	<0.001	0.009	0.132	0.004
ESD W-73	0.029	<0.001	0.008	0.022	<0.001
ESD W-74	0.053	<0.001	0.007	0.055	0.024
ESD W-78[g]	0.025	<0.001	0.006	0.013	<0.001
M-9	0.053	<0.001	0.014	0.133	0.007
M-11	0.153	<0.001	0.007	0.027	0.009
Pond 1	15.660	<0.001	0.550	6.100	3.850
Pond 3	52.700	<0.001	161.000	6.920	0.036
Pond 7	286.000	<0.001	120.000	29.400	0.400
Pond 8	101.800	<0.001	43.000	3.630	0.030
Pond 10	510.000	<0.001	110.000	30.100	0.107

TABLE 3-7 (Cont)

Sample No.[a]	Arsenic	Chromium	Barium	Selenium	Silver
MCL[b]	0.05	0.05	1.	0.01	0.05
ESD 1-2[c]	<0.001	0.014	0.016	<0.001	0.010
ESD -1	<0.001	0.020	0.027	<0.001	0.032
ESD -2	0.020	0.051	0.026	<0.001	0.009
ESD -6	<0.001	0.027	0.029	<0.001	0.026
ESD -10	0.024	0.009	0.042	<0.001	0.025
ESD W-100	<0.001	0.015	0.044	<0.001	0.013
ESD M-1	<0.001	0.024	0.024	<0.001	0.026
ESD M-2	0.001	0.026	0.024	<0.001	0.027
ESD M-3	<0.001	0.046	0.028	<0.001	0.014
ESD M-3N	<0.001	0.045	0.018	<0.001	0.018
ESD M-7	<0.001	0.034	0.020	<0.001	0.032
ESD M-8	<0.001	0.020	0.040	<0.001	0.005
ESD M-12[d]	<0.001	0.015	0.005	<0.001	0.008
ESD M-12[e]	<0.001	0.014	0.003	<0.001	0.007
ESD M-12[f]	<0.001	0.015	<0.001	<0.001	0.008
ESD M-13	<0.001	0.039	<0.001	<0.001	<0.001
ESD M-14	<0.001	0.138	0.021	<0.001	0.014
ESD W-4	<0.001	0.013	0.005	<0.001	0.009
ESD W-51	<0.001	<0.001	0.045	<0.001	0.013
ESD W-52	<0.001	<0.001	0.064	<0.001	0.007
ESD W-53	<0.001	<0.001	0.044	<0.001	0.009
ESD W-54	<0.001	<0.001	0.059	<0.001	0.008
ESD W-55	<0.001	<0.001	0.053	<0.001	0.006
ESD W-56	<0.001	<0.001	0.028	<0.001	0.004
ESD W-57	<0.001	0.010	0.042	<0.001	0.008
ESD W-58	<0.001	0.005	0.025	<0.001	0.004
ESD W-59	<0.001	0.022	0.009	<0.001	0.008
ESD W-60	<0.001	0.005	<0.001	<0.001	0.003
ESD W-62	0.004	0.006	0.036	<0.001	0.002
ESD W-63	0.007	0.005	0.031	<0.001	0.002
ESD W-64	<0.001	<0.001	<0.001	<0.001	<0.001
ESD W-65	<0.001	<0.001	0.007	<0.001	<0.001
ESD W-67	<0.001	0.526	0.022	<0.001	<0.001
ESD W-69	0.009	0.029	0.007	<0.001	0.017
ESD W-72	<0.001	0.008	<0.001	<0.001	<0.001
ESD W-73	<0.001	0.007	0.012	<0.001	<0.001
ESD W-74	<0.001	0.009	0.011	<0.001	<0.001
ESD W-78[g]	<0.001	0.008	0.020	<0.001	<0.001
M-9	<0.001	0.009	0.015	<0.001	0.007
M-11	<0.001	0.024	0.034	<0.001	0.029
Pond 1	4.600	3.630	0.024	0.932	0.024
Pond 3	4.200	10.960	0.014	0.255	0.019
Pond 7	2.750	3.000	0.020	0.456	0.026
Pond 8	0.006	10.540	0.017	<0.001	0.020
Pond 10	0.004	6.850	0.021	0.087	0.027

TABLE 3-7 (Cont)

Sample No.[a]	Molybdenum	pH Units	Nitrate	Sulfate	Chloride
MCL[b]	--	--	10.	--	--
ESD 1-2[c]	0.021	7.65	1.90	4,000.0	216.0
ESD -1	0.018	7.00	0.48	13,400.0	400.0
ESD -2	--	--	--	--	--
ESD -6	--	--	--	--	--
ESD -10	0.725	7.91	0.05	14,000.0	370.0
ESD W-100	--	--	--	--	--
ESD M-1	<0.001	7.30	175.00	12,200.0	810.0
ESD M-2	0.010	7.90	39.00	12,400.0	860.0
ESD M-3	0.011	6.90	10.10	10,000.0	940.0
ESD M-3N	0.013	7.32	0.05	10,800.0	900.0
ESD M-7	0.009	7.79	2.10	14,000.0	1,130.0
ESD M-8	0.011	7.54	8.50	3,800.0	180.0
ESD M-12[d]	<0.001	8.11	1.32	3,800.0	440.0
ESD M-12[e]	0.022	8.17	1.14	3,600.0	340.0
ESD M-12[f]	0.011	8.15	0.84	3,600.0	390.0
ESD M-13	<0.001	7.05	0.28	3,400.0	780.0
ESD M-14	<0.001	3.15	3.90	8,800.0	300.0
ESD W-4	--	--	--	--	--
ESD W-51	0.023	7.34	0.03	2,720.0	290.0
ESD W-52	0.019	7.95	0.05	1,280.0	312.0
ESD W-53	0.008	7.50	0.19	1,180.0	314.0
ESD W-54	0.012	7.25	0.52	1,140.0	308.0
ESD W-55	0.018	7.45	0.40	1,140.0	312.0
ESD W-56	0.011	7.20	0.08	900.0	254.0
ESD W-57	0.011	7.67	<0.01	980.0	252.0
ESD W-58	<0.001	8.05	<0.01	1,680.0	24.0
ESD W-59	0.005	7.77	0.02	440.0	84.0
ESD W-60	0.007	7.77	0.07	300.0	230.0
ESD W-62	0.013	7.81	0.10	202.0	124.0
ESD W-63	0.010	7.34	<0.01	312.0	228.0
ESD W-64	<0.001	7.32	0.03	1,920.0	< 1.0
ESD W-65	<0.001	7.42	0.08	20.0	4.0
ESD W-67	0.010	2.74	0.06	900.0	< 1.0
ESD W-69	--	--	--	--	--
ESD W-72	0.012	7.45	1.62	1,640.0	16.0
ESD W-73	0.004	7.78	2.20	1,600.0	30.0
ESD W-74	0.012	6.92	0.07	3,000.0	14.0
ESD W-78[g]	0.010	7.95	0.09	1,220.0	308.0
M-9	<0.001	7.20	3.80	2,040.0	180.0
M-11	0.016	7.59	0.08	18,600.0	480.0
Pond 1	--	--	--	--	--
Pond 3	--	--	--	--	--
Pond 7	0.230	2.01	0.14	40,000.0	200.0
Pond 8	--	--	--	--	--
Pond 10	--	--	--	--	--

TABLE 3-7 (Cont)

Sample No.[a]	Carbonate	Bicarbonate	Total Dissolved Solids
ESD 1-2[c]	<0.01	622.2	15,575.0
ESD -1	<0.01	2,049.6	22,717.0
ESD -2	--	--	--
ESD -6	--	--	--
ESD -10	<0.01	488.0	21,418.0
ESD W-100	--	--	--
ESD M-1	<0.01	805.2	20,940.0
ESD M-2	<0.01	1,903.2	21,796.0
ESD M-3	<0.01	427.0	15,437.0
ESD M-3N	<0.01	1,695.0	17,171.0
ESD M-7	<0.01	3,538.0	26,028.0
ESD M-8	<0.01	305.0	13,907.0
ESD M-12[d]	<0.01	353.8	7,098.0
ESD M-12[e]	<0.01	366.0	6,000.0
ESD M-12[f]	<0.01	317.2	6,303.0
ESD M-13	<0.01	85.4	6,514.0
ESD M-14	<0.01	< 0.01	14,545.0
ESD W-4	--	--	--
ESD W-51	<0.01	253.8	3,904.0
ESD W-52	<0.01	185.4	2,473.0
ESD W-53	<0.01	183.0	2,457.0
ESD W-54	<0.01	180.6	2,377.0
ESD W-55	<0.01	185.4	2,547.0
ESD W-56	<0.01	326.9	2,020.0
ESD W-57	<0.01	224.5	2,130.0
ESD W-58	<0.01	261.1	2,526.0
ESD W-59	<0.01	348.9	1,069.0
ESD W-60	<0.01	190.3	1,032.0
ESD W-62	<0.01	222.0	738.0
ESD W-63	<0.01	217.0	1,072.0
ESD W-64	<0.01	46.4	591.0
ESD W-65	<0.01	214.7	308.0
ESD W-67	<0.01	< 0.1	1,422.0
ESD W-69	--	--	--
ESD W-72	<0.01	246.4	2,498.0
ESD W-73	<0.01	158.6	2,387.0
ESD W-74	<0.01	63.4	4,649.0
ESD W-78[g]	<0.01	165.9	2,380.0
M-9	<0.01	458.7	4,024.0
M-11	<0.01	3,294.0	30,532.0
Pond 1	--	--	--
Pond 3	--	--	--
Pond 7	<0.01	< 0.01	64,732.0
Pond 8	--	--	--
Pond 10	--	--	--

TABLE 3-7 (Cont)

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[a]ESD - water samples from drill holes
ESD-W - surface and ground water samples
ESD-M - water samples from monitor wells

[b]MCL - maximum contaminant levels from National Interim Primary Drinking Water Regulations, Federal Register, Dec 24, 1975.

[d]ESD M-12 - sampled after pumping test

Original Designation	Corrected Designation*
[c]ESD 1-2	M-10
[e]ESD M-12, 1st north	M-16
[f]ESD M-12, northmost	M-12N
[g]ESD W-78	ESD W-70

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*Original maps contained several incorrect well designations. Correct designations are as indicated.

Notes: 1. For samples locations, see Figures 3-14 and 3-15.
2. All measurements are in mg/l unless listed otherwise

TABLE 3-8A

RADIONUCLIDE CONCENTRATIONS IN TAILINGS PONDS/PILES

Pond/Pile	Depth (ft)	Vertical Composite Samples (pCi/g)[a]		
		^{226}Ra	^{230}Th	^{210}Pb
1	0 - 5	202 ± 10	32 ± 2	1070 ± 50
2	0 - 24	25 ± 1	109 ± 5	195 ± 9
3	0 - 3	18.4 ± 0.9	47 ± 2	16.3 ± 0.8
South of 3	0 - 6	7.7 ± 0.4	12.7 ± 0.6	63 ± 3
7	0 - 5.5	480 ± 20	74 ± 4	1900 ± 100
8	0 - 4	3.1 ± 0.2	19 ± 1	20 ± 1
9	0 - 20	17.3 ± 0.9	5.4 ± 0.3	31 ± 2
10	0 - 2.5	2.2 ± 0.1	51 ± 2	118 ± 6
Tailings area A	0 - 27	17.6 ± 0.9	78 ± 4	182 ± 9

[a]Gamma logs were run in same holes from which vertical composite samples were taken

[b]Pond 10 has no uranium tailings

Note: The results of analyses of samples from tailings area B are not available. A gamma log maximum indicating 225 pCi/g of ^{226}Ra was logged at a 3.5 ft depth.

TABLE 3-8B

RADIONUCLIDE CONCENTRATIONS IN TAILINGS PONDS/PILES[a]

Pond/Pile	Depth (ft)	^{226}Ra (pCi/g)	^{230}Th pCi/g)	Total Uranium (pCi/g)
1 slimes	Surface	238	270	13
1 slimes	0 - 8	692	822	26
2 sand	Surface	60	12	4
3 slimes	Surface	293	273	22
3 slimes	0 - 5	335	249	20
4-7 sand	Surface	48	9	6
7 sand	Surface	52	20	3
7 slimes	Surface	810	497	66
7 slimes	0 - 7	586	596	80
8 slimes	Surface	66	67	10
8 slimes	0 - 7	99	141	17
East sand tailings		124	37	4.8
Tailings area B	(No information available)			

[a]TVA data - average for all samples reported

TABLE 3-9

ANNUAL DOSE COMMITMENTS TO INDIVIDUALS
FROM RADIOACTIVE RELEASES FROM THE EDGEMONT SITE
AND FROM BACKGROUND

		Dose (mrem/yr)				Background Dose (mrem/yr)			
Location	Exposure Pathway	Whole Body	Lung[b]	Bone	Bronchial Epithelium	Whole Body	Lung	Bone	Bronchial Epithelium
Nearest Permanent Resident (NE Corner of Cottonwood Community)	Inhalation[a]	18	236	116	1,030	1	2	1	1,200
	Ingestion	3	--	39	--	11	--	110	--
	External	220	220	220	--	114	114	114	--
	Total	240	460	375	1,030	126	116	225	1,200
Rancher Consuming Beef Cattle That Graze SE of Site	Ingestion	25	--	250	--	--	--	--	--

[a]Doses to whole body, lung, and bone are those resulting from inhalation of particulates of U-238, U-234, Th-230, Ra-226, and Pb-210.

[b]Does not include dose to bronchial epithelium from radon and radon daughters, which is listed separately.

TABLE 3-10

ANNUAL POPULATION DOSE COMMITMENTS
TO POPULATION OF EDGEMONT (manrem)

Receptor Organ	Millsite Source	Natural Background
Whole Body	20	250
Lung	120	250[a]
Bone	70	450
Bronchial epithelium	321	2,400

[a]Does not include dose to bronchial epithelium from radon and radon daughters, which is listed separately.

TABLE 3-11

ESTIMATED HEALTH IMPACT FROM EDGEMONT TAILINGS FOR AN AREA 0-1 MILE FROM TAILINGS EDGE

Time Period	Population (Persons)	Total Pile-Induced RDC Health Effects/yr	Background RDC Health Effects/yr
1975	2,000	0.01	0.11
2000 (Static)	2,000	0.01	0.11
2000 (Declining growth[a])	4,097	0.03	0.22

25-yr Cumulative Effect	Pile-Induced RDC	Background-Induced RDC
Static population	0.36	2.7
Declining growth rate[a]	0.65	4.9

[a]The population doubles in 10 yr and grows at a 0.16% rate for 15 yr.

Note:

The total cummulative pile-induced RDC health effects are projected here through the year 2000 to illustrate possible trends. This projection is not made past the year 2000 due to difficulties in estimating population growth and does not imply that the hazard would diminish after that time.

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CHAPTER 4

SOCIOECONOMIC AND LAND USE IMPACTS

CHAPTER 4

SOCIOECONOMIC AND LAND USE IMPACTS

The Edgemont tailings and millsite are located immediately east of the railroad tracks that border the town of Edgemont, South Dakota. Edgemont is a relatively small town in Fall River County in rural southwestern South Dakota. The political jurisdictions of Fall River County are shown in Figure 4-1. The county seat, Hot Springs, is located 27 mi to the northeast along U.S. Highway 18.

4.1 SOCIOECONOMIC BACKGROUND

Shortly after the Civil War, gold was discovered in the Black Hills, land settlements were made with the Sioux Indians, and entire areas of South Dakota including Fall River County were opened to homesteading. For decades, Fall River County's economy was based on ranching, mining, farming, and the railroad. Edgemont was founded as a railroad town and the town's economy fluctuates greatly with the fortunes of the Burlington Northern. Areas near Edgemont were known for sheep raising, but more recently, ranchers have been reducing their herds of sheep and raising cattle instead. Lignite was mined near Edgemont until the 1930's, and in the 1950's the uranium boom resulted in significant population increases associated with the mill and mining efforts.

The future demographic and economic conditions of Edgemont can be projected by extrapolating statistical data contained in census reports and from planning documents for the area.[1-10] The populations of the town of Edgemont, Fall River County and the State of South Dakota have vacillated greatly over time. For many years the out-migration from the agricultural communities has exceeded the in-state increase in urban opportunities. Edgemont's population is quite small and reacts substantially to changes in economic opportunities. In the last 5 yr the population has virtually doubled, but during the preceeding 10 yr the population shrank by almost one third. As might be expected, the population of Edgemont decreased in the 1930's, increased during the 1940's, and increased dramatically during the 1950's with a major decrease in the 1960's due to long-term regional out-migration of younger working age people. Of all the political entities in Fall River County, only Edgemont and Hot Springs experienced a net increase in population growth from 1930 to 1970.

Educational attainment in the Edgemont vicinity is above the median education attainment level for both the state as a whole and for the United States. The population is virtually 50% men and 50% women and considerably older than the state's median. Employment composition in the areas has changed with time reflecting the national trend in which people have migrated from rural areas to central marketing centers such as Rapid City. Government

jobs account for about 40% of county employment. Edgemont had a 1970 work force of 783 persons of which the largest employment categories were professional services, transportation/public utilities, wholesale/retail trade, and agriculture. Mining has accounted for approximately 5% of county employment and the railroad has provided about 33% of the jobs in recent years. Today, Edgemont is a community with an economy that remains highly dependent on the railroad, on resource extraction, and on agriculture for its prosperity.

4.2 POPULATION ESTIMATES

The 1970 census figures list 1,174 town residents and 7,505 county residents. Fractions of the populations of two nearby townships, Dudley and Cottonwood, have been added to the Edgemont population in order to estimate the number of residents within 1/4, 1/2, and 1 mi of the perimeter of the site. Residential concentrations are west of the site and north across the Cheyenne River. Residents nearest the site live in the Cottonwood community directly west of pond 7. Population distribution around the millsite is shown in Figure 2-4, Chapter 2. For the purposes of this report the following population estimates are used:

	1970	1975
Edgemont	1,174	1,775
"Greater Edgemont" (includes 80% of Dudley and Cottonwood townships)	1,870	2,000
Population within 1/4 mi of the site	935	1,000
Population within 1/2 mi of the site	1,770	1,900
Population within 1 mi of the site	1,870	2,000

Several factors must be considered in determining population projections and future growth patterns for Edgemont. South Dakota's geographic location isolates it from major consumer and industrial markets. Transportation networks, and a lack of water will limit long-term growth. However, the area is rich in natural resources and the development of energy resources along the Burlington Northern rail route (such as Wyoming's Powder River Basin) and in Fall River County (such as the uranium deposits) will be major stimulants to growth. The out-migration from agricultural areas appears to have stabilized, timber contracts have expanded, manufacturing employment looks promising in nearby cities, and growth in wholesale, retail, transportation, communications, public utilities, financial institutions, insurance companies and real estate firms will parallel regional growth. Two major employment sectors, tourism and government, are difficult to predict. Other developments may depend on such water projects as the Missouri River Pipeline or the Oahe Pipeline. Still others

may be heavily influenced by energy shortages which tend to stimulate energy development, but depress tourism and agriculture. On balance, planners predict a bright future for western South Dakota and for Edgemont in particular.

Considering these factors, four rates of growth were calculated. The highest rate assumes a continuation of the past 5-yr trend of annual growth at 1.83%. The second rate assumes a 0.66% annual growth rate which is the second highest regional growth projected by the Department of Rural Sociology, South Dakota State University. The third rate is 0.39% annual growth which assumes the conservative growth rate projected by the South Dakota State University study. The lowest rate, 0.16% annual growth, assumes a growth rate similar to that which Edgemont experienced from 1930 to 1970. These projected growth curves are illustrated in Figure 4-2.

Assumptions of a steady rate of growth may be highly unrealistic. For the reasons given above, the rate of growth could decline and approach zero by some future date. This is referred to as a "declining rate of growth". A more likely growth rate would be a doubling of population by 1985 followed by a slow rate of growth. These rates are depicted in Figure 4-2. The following population projections and growth factors indicate the range of growth expected at Edgemont:

Annual Growth	Population 1975	Population 2000	Factor	Population 2025	Factor
Steady 1.83%	2,000	3,147	1.57	4,952	2.48
Declining 0.16%	2,000	2,048	1.02	2,051	1.03
No Growth	2,000	2,000	1.00	2,000	1.00
Double by 1985 followed by steady 0.16%	2,000	4,132	2.06	4,109	2.09

The present population distribution with respect to the Edgemont site is discussed in paragraph 2.6, Chapter 2.

4.3 IMPACT OF THE TAILINGS ON LAND USE

At the present time, neither Fall River County nor Edgemont has zoning ordinances or a comprehensive zoning plan. The largest single factor that affects the area's land use is federal and state management of land. Most government land is grazed or used for recreational purposes. In total, two-thirds of the county's land is used for range or pasture (irrigated), with only scattered housing. The land east and south of the site is grazed and some of the land west of the site is pasture land. Figure 4-3 depicts the area's land use and Figure 4-4 indicates ownership of land bordering the site.

The railroad forms an extensive industrial land use running north-south along the western edge of the site and separating the site and the town. Residential areas are to the west and north of the site across the Cheyenne River. This north area is known as "Dudley", where about 60 people live. The recent sudden expansion in the town's population has strained the housing resources of the area. New housing complexes are under construction including a senior citizen's unit, rental units brought in from Igloo, 8 mi south of Edgemont, and new housing developments southwest of town near the airport. Space for trailers has been rented in vacant lots and driveways. The school has been able to accommodate the increase of students, but will become seriously overcrowded if the town's population were to double in the next 10 yr. Presently, the sewage and water systems are undergoing considerable remodeling.

The presence of the mill and tailings area has not restricted the use of land in the town of Edgemont to the west of the railroad. Residential growth presently is southwestward toward the airport and commercial development is along Highway 18 west of town, both unaffected by the millsite. Vacant land for additional commercial development is located along Highway 18, northeast of Edgemont. This area is north of the millsite and is separated from the site by the Cheyenne River. The millsite should have little effect on land use in this area.

The location of the mill and tailings piles prohibits access to Cottonwood Community (population about 75) from the north and inhibits development of that area. If the mill and tailings were removed from the site, it is unlikely that significant expansion of Cottonwood Community would occur toward the north since Cottonwood Creek bounds it on the north and the railroad switchyard would be adjacent to any northward expansion. The presence of the sewage pond would also limit expansion to the northeast for residential use. Growth to the south is feasible and could take place if demand for additional housing continues and if the tailings were removed. Thus, it is not expected that pressures will develop for expanding residential use into the mill and tailings area.

The millsite is not well suited for commercial use because of limited access from the highway. Other more desirable property exists along the highway. If the entire area were available for unrestricted use, it would probably be best suited for industrial use. However, there must be a demand for such use and other suitable property exists west of the town. The railroad switchyard could conveniently expand into the western portion of the site if additional capacity was needed. The area probably would revert to pasture land if the land remained vacant.

4.4 IMPACT OF THE TAILINGS ON LAND VALUES

The area of the mill and tailings (±213 acres) is almost as large as the occupied areas of Edgemont, but their presence has

been a minor factor in land values in the town of Edgemont. The railroad which separates the town from the tailings and mill area reduces the tailings impact on land use and values in Edgemont. The presence of Cottonwood Creek and the Cheyenne River, and their relationships to the tailings is another factor which tends to isolate the tailings and mill areas from town life, population centers, land usage, and consequently land values. The only exception would be the Cottonwood residential area which is located between the creek and the tailings. This area reflects the presence of the tailings more than does any other location in the Edgemont area, and development has been inhibited. Land values in Cottonwood would normally be less than those in Edgemont because the location is separated from Edgemont; access to the area is only from the south and the area is adjacent to mill tailings piles. Bare land close to town is valued at approximately $2,000/acre and bare lots in town, without utilities, are available for about $1,500, or approximately $8,700/acre. Lots with utilities have a market value of up to $5,000.

The presence of the Edgemont city sewage effluent pond just east of the tailings also has some bearing on land values. No one lives within about 1/4 mi of this installation. Were the tailings not in the area, it is probable that this pond would have been built in approximately the same location, and thus it is a low land value area. The railroad and highway locations have as great an impact on land values as do the tailings.

The average cost per acre of the mill and tailings area, when purchased, was about $140/acre. The market value at present would be difficult to determine. If the site were left in a condition suitable for unrestricted use, the total site area would have an average estimated market value of approximately $1,500/acre as undeveloped land.(11)

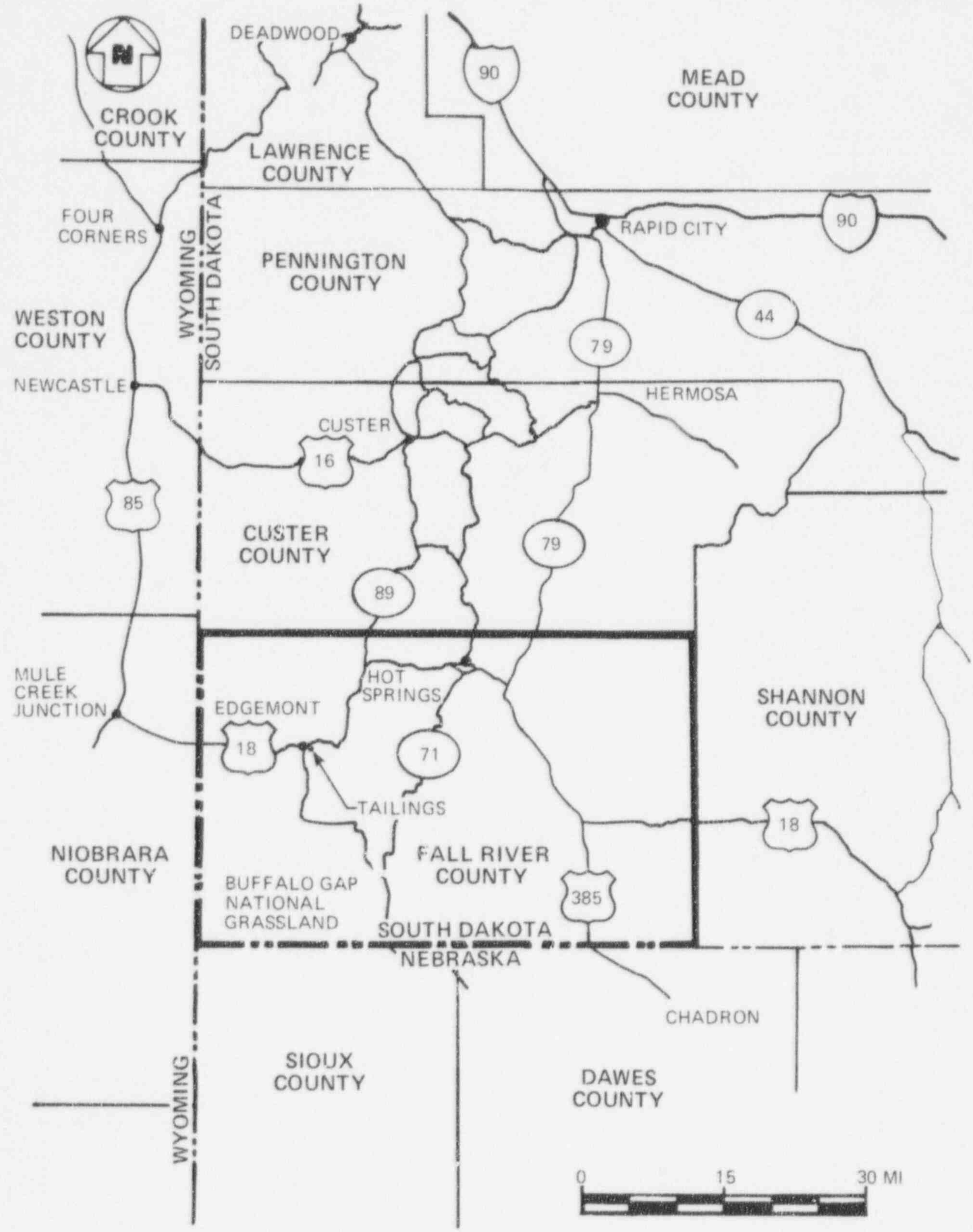

FIGURE 4-1. MAP OF FALL RIVER COUNTY BOUNDARIES

211-00

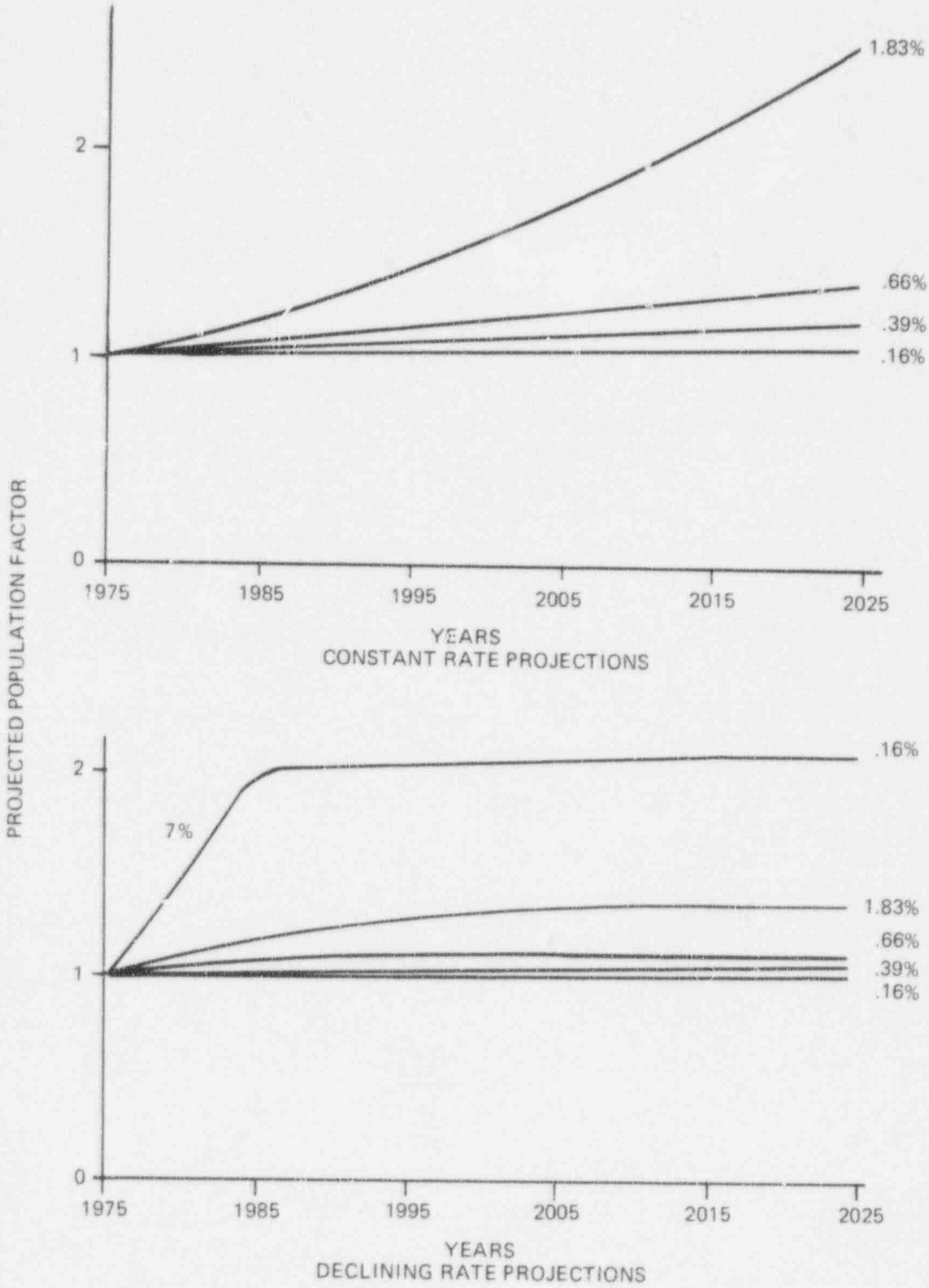

FIGURE 4-2. POPULATION PROJECTIONS

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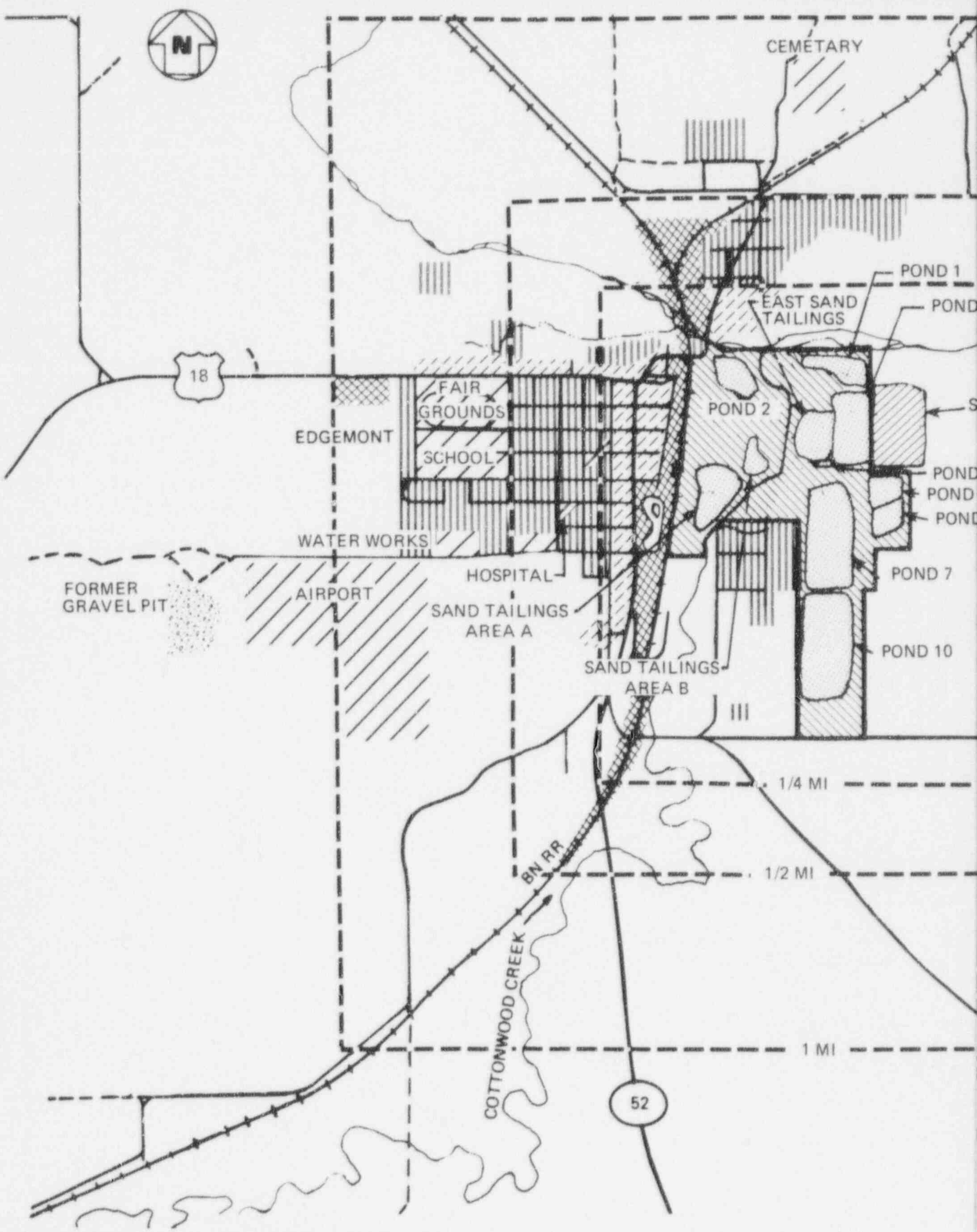
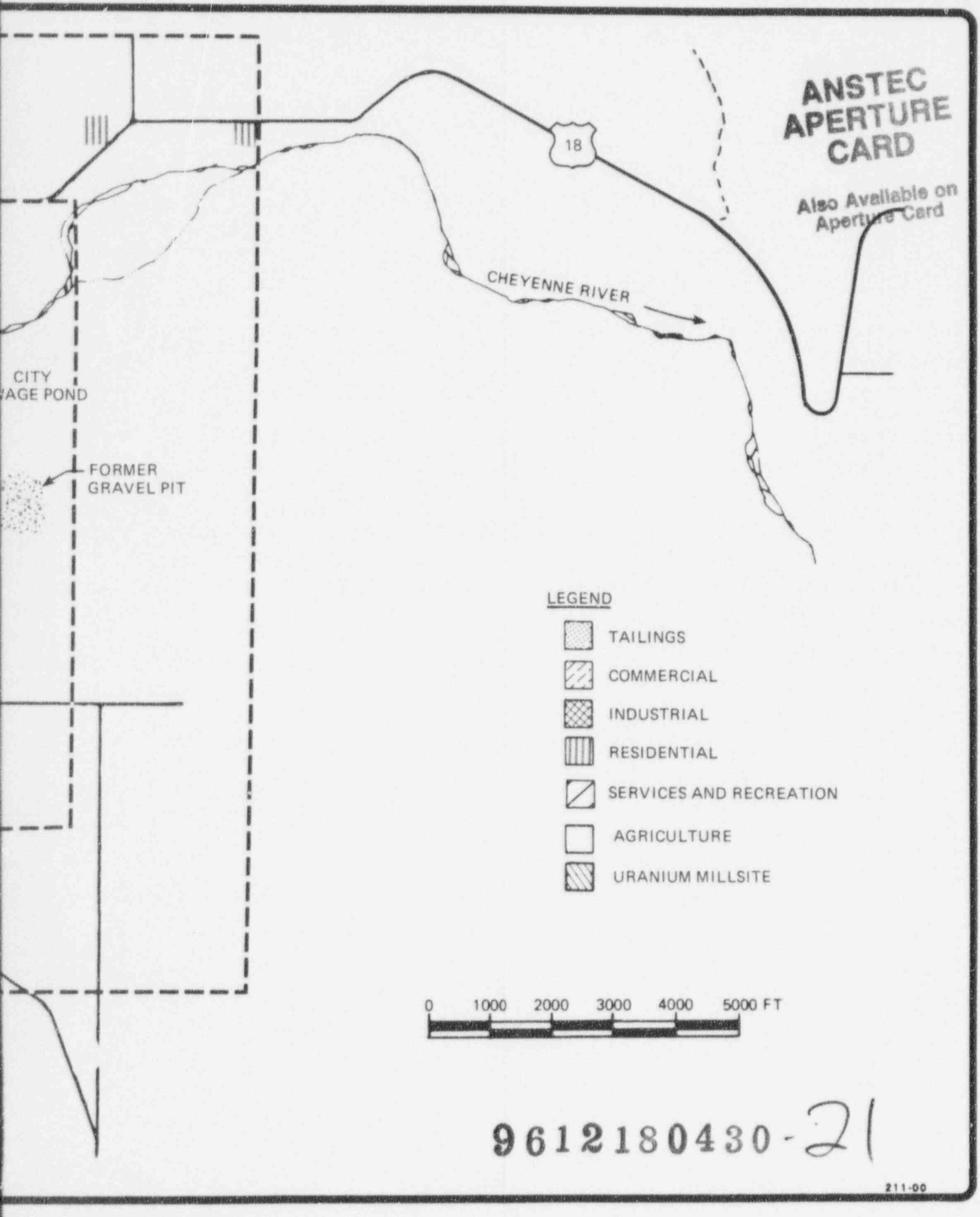


FIGURE 4-3. VICINITY LAND USE



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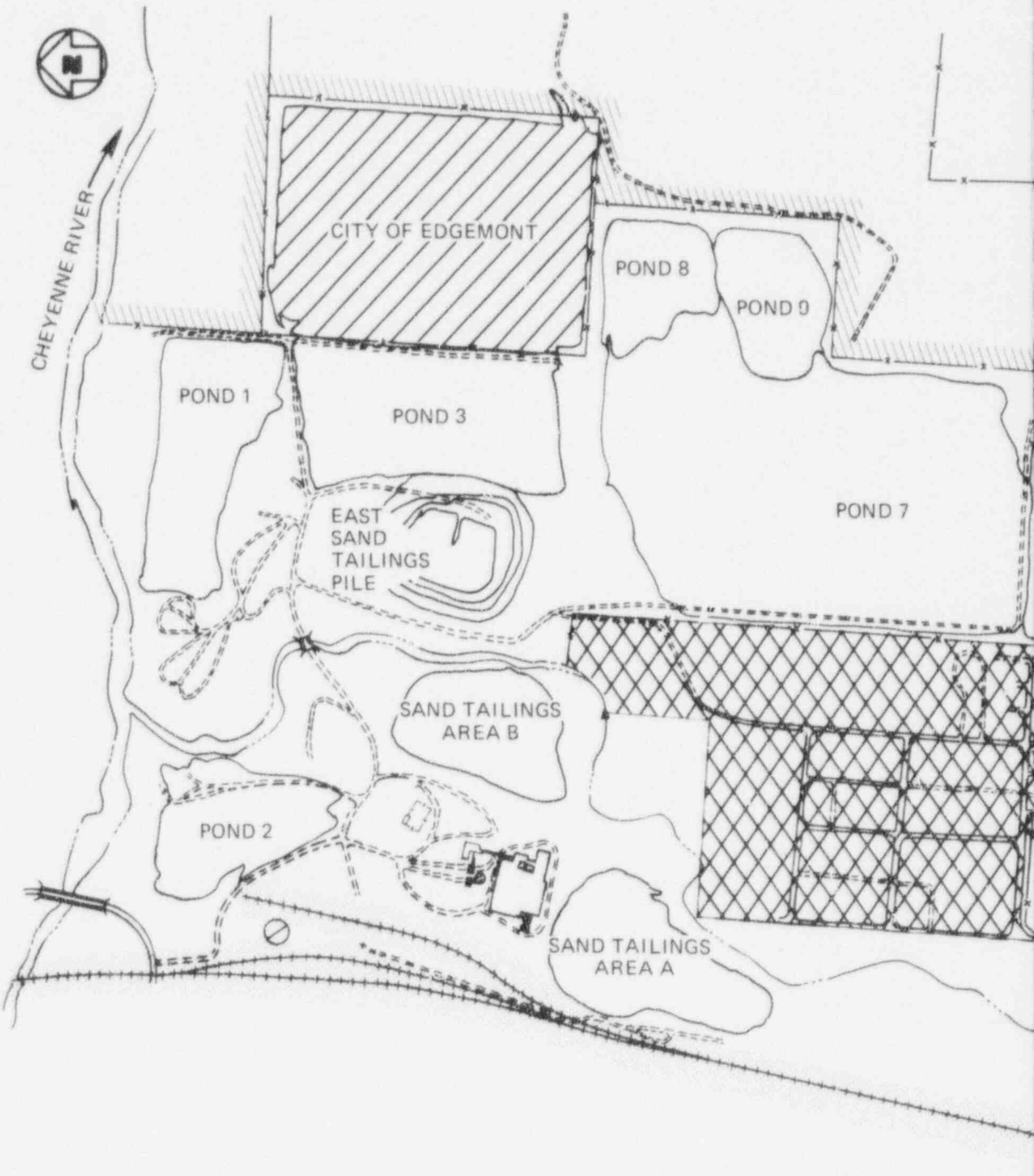
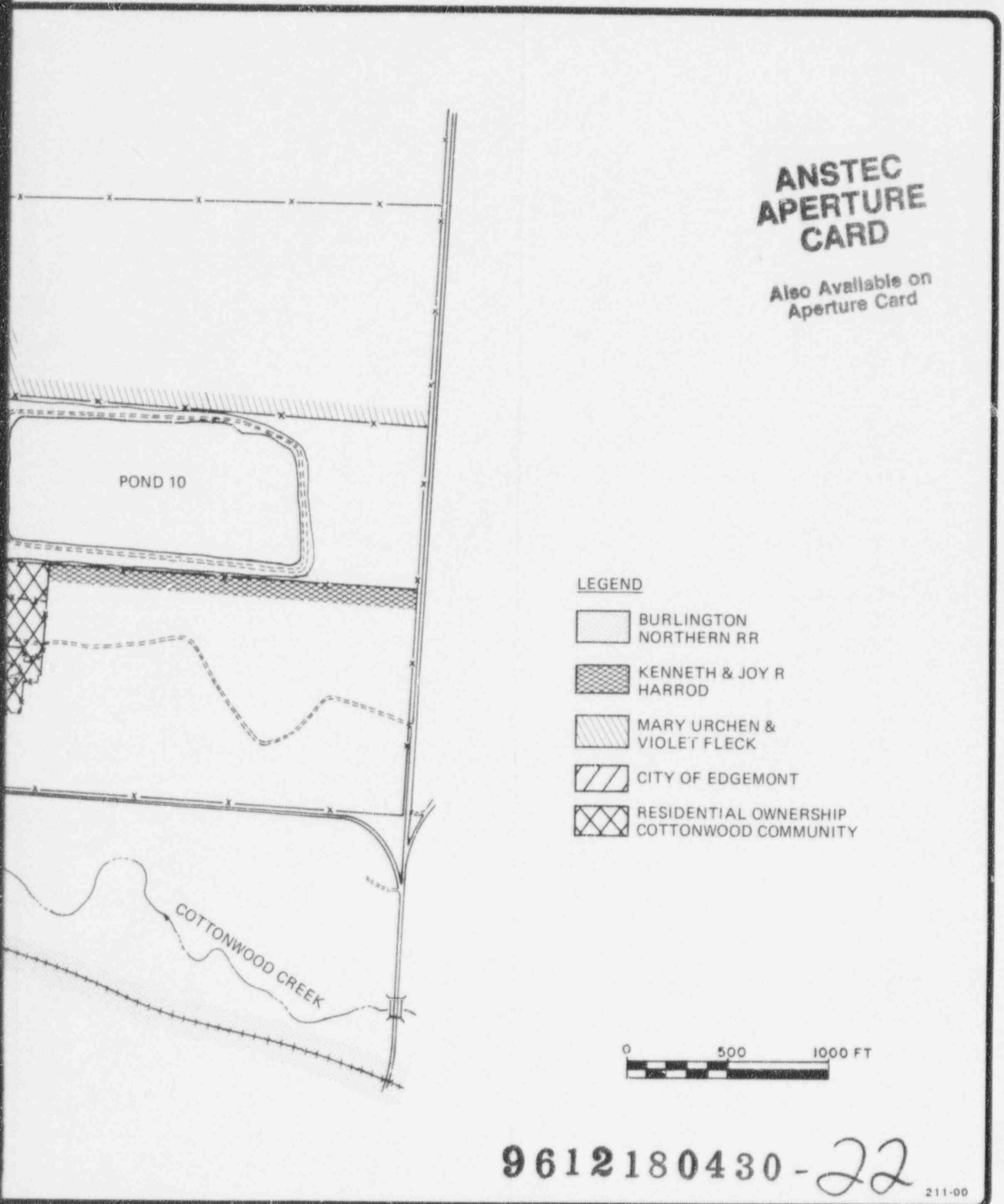


FIGURE 4-4. MAP OF LAND OWNERSHIP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MARY URCHEN & VIOLET FLECK
CITY OF EDGEMONT
RESIDENTIAL OWNERSHIP COTTONWOOD COMMUNITY
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CHAPTER 5

RECOVERY OF RESIDUAL VALUES

CHAPTER 5

RECOVERY OF RESIDUAL VALUES

The principal purpose of this chapter is to address questions such as:

(1) Do the tailings represent a future uranium resource?

(2) Should the tailings be reprocessed before stabilization?

(3) Is there any likelihood that once stabilized the tailings would be disturbed again?

The feasibility of economic recovery at each millsite is a function of:

(1) Total mineral recovery

(2) Reprocessing costs

(3) Market price

5.1 PROCESS ALTERNATIVES

Two alternative methods of treating uranium tailings to recover uranium are: (a) placing the tailings on a prepared pad and heap leaching, and (b) treating in a conventional mill at some remote site.

5.1.1 Heap Leaching

In heap leaching, the mill tailings are placed on an impermeable pad for leaching with appropriate reagents. The pregnant solution is collected in the pad drainage system and processed for uranium recovery.

It is difficult to obtain optimum conditions for metal extraction in heap leaching, the uranium recovery using the heap leach method is only about 56% of a conventional mill operation, as shown in Figure 5-1.[1] However, the construction costs of a heap leaching facility are only about 60% of the costs for a conventional mill. The operating costs for a heap leach plant are also lower than for a conventional mill for plants of the size considered--500 to 5,000 tons/day.

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[1] See end of chapter for references.

The heap leaching site must be an acceptable tailings disposal site that can be readily stabilized and maintained, as discussed in Chapter 8, or must be adjacent to the tailings disposal site. A heap leach site of about 10 acres of relatively flat ground would be required if the 436,000 tons of tailings from pond 7 were to be leached and stabilized in place. The reprocessing site also would require water and power.

5.1.2 Treating in a New Mill at a Remote Site

For future milling of ore, TVA is presently evaluating several potential uranium millsites, one of which is at Burdock about 15 mi northwest of the present site.

The capital cost of a new ore processing mill would be borne by the new ore being processed. The cost of retreating the tailings would include reclaiming, transporting, mill operating, and tailings disposal costs.

The advantage of the remote site would be the reduced environmental impact of the mill and tailings piles. The disadvantages of the new millsite would be increased mill capital cost at an undeveloped site, and increased cost of transporting the tailings to the new mill.

5.2 EDGEMONT RECOVERY ECONOMICS

The parameters discussed in this paragraph determine the economic viability of reprocessing Edgemont uranium mill tailings to recover residual mineral values. The major factor in evaluating recovery economics is the mineral content of the tailings, which is calculated from the tonnage and composition of the tailings. The tailings tonnage and composition are presented in Table 5-1.(2) From the data in Table 5-1, it can be seen that pond 7 has the second highest quantity of uranium and the highest quantity of vanadium. Calculations of contained mineral values indicate that the tailings in pond 7 would be the most economically feasible for reprocessing; consequently, for the remainder of the reprocessing economic evaluation, pond 7 data will be used and the Phase II-Title I approach to recovery potential will be followed.

5.2.1 Recovery

The Edgemont tailings pond 7 consists of 270,000 dry tons or 436,000 wet tons of tailings containing 38.1% moisture.(2) The tailings in pond 7 contain 0.087 lb of insoluble U_3O_8/ton and 2.25 lb of insoluble V_2O_5/ton of wet solids, and 0.077 lb of solubilized U_3O_8/ton and 1.06 lb of solubilized V_2O_5/ton of wet solids, as determined from TVA analyses. Further sampling would be necessary to verify these estimates. Additional sampling and analyses of pond 7 tailings are being performed under the direction of TVA. If the tailings are treated in a conventional mill it is conservatively estimated that 95% of the soluble, and 40% of the insoluble U_3O_8 would be recovered. In addition, approximately 65% of the

soluble, and 15% of the insoluble V_2O_5 would be recovered. Amenability tests performed for TVA support recovery of these levels for both uranium and vanadium.(2) Heap leach recovery is estimated at 56% of conventional mill recovery as discussed in paragraph 5.1.1.

5.2.2 Reprocessing Costs

A range of operating costs for both heap leaching and conventional uranium mills as a function of plant capacity are shown in Figures 5-2 and 5-3.(1) Operating costs of a heap leach plant range from \$3.55 to \$2.80/ton of feed for a 500- to 5,000-ton/day uranium mill, while operating costs for a conventional mill range from \$7.00 to \$3.30/ton of feed for a 500- to 5,000-ton/day uranium mill. Additional reagents and facilities would be required to recover vanadium, increasing the operating cost by 50% and the construction cost by 25% for both heap leach and conventional mills. The construction costs of a heap leach facility are obtained from the lower range of Figure 5-4.

5.3 ASSESSMENT OF EDGEMONT MINERAL RECOVERY POTENTIAL

Using Figures 5-2 through 5-5 and the estimated mineral recovery, as discussed in paragraph 5.2.1, the breakdown of costs of uranium recovery for the Edgemont tailings can be calculated as follows:

	U_3O_8 Recoverable (lb)	Operating Costs (\$M)	Construction Costs (\$M)	Total Cost (\$M)	Cost/lb (\$)
Heap Leach	26,400	1.5[a]	2.7[a]	4.2	159
Mill at Remote Site	47,100	1.9[b]	1.8[c]	3.7	79

	V_2O_5 Recoverable (lb)	Additional Operating Costs (\$M)	Additional Construction Costs (\$M)	Total Cost (\$M)	Cost/lb (\$)
Heap Leach	210,000	0.75[d]	1.06[e]	1.8	9
Conventional	447,000	0.95[d]	--	0.95	2

[a]For a 500-ton/day facility
[b]For a 2,000-ton/day facility
[c]Reclaiming costs plus transportation costs of \$0.10/ton/mi for 15 mi
[d]50% of U_3O_8 costs
[e]25% of U_3O_8 costs

Using the Phase II approach for the economic evaluation of reprocessing Edgemont tailings, it can be seen that none of the two proposed options are presently economically feasible even when the reprocessing of only pond 7 is considered. The lowest cost for reprocessing appears to be \$79/lb of U_3O_8 in the remote site approach. This value is based on current dollars and includes no interest costs, inflation costs, nor allowance for profit. If vanadium were recovered, the reprocessing cost would be further reduced to an equivalent of \$68/lb of U_3O_8. While it is always possible that the uranium price may increase or technological improvements may be developed to decrease the reprocessing costs, the present Phase II-type estimation indicates that it is not economically feasible to reprocess the tailings at this time.

TVA is currently assessing the possibility of reprocessing the Edgemont tailings using a more detailed approach. With the Phase II-Title I method of evaluation, cost-per-pound is marginally uneconomic. A more detailed evaluation might indicate that the tailings can be reprocessed economically.[2]

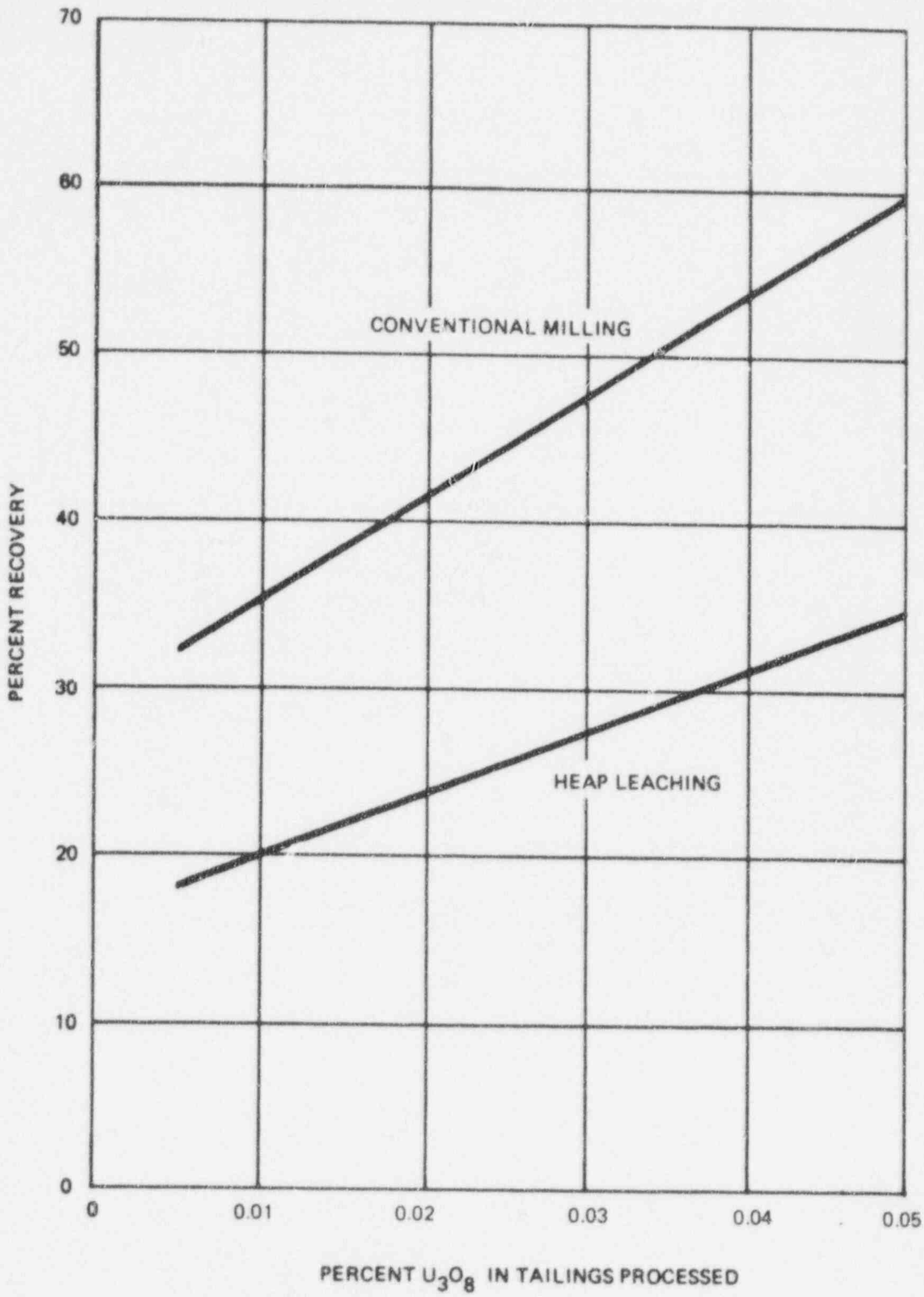

FIGURE 5-1. URANIUM RECOVERY FROM MILL TAILINGS AS A FUNCTION OF U_3O_8 CONTENT IN TAILINGS

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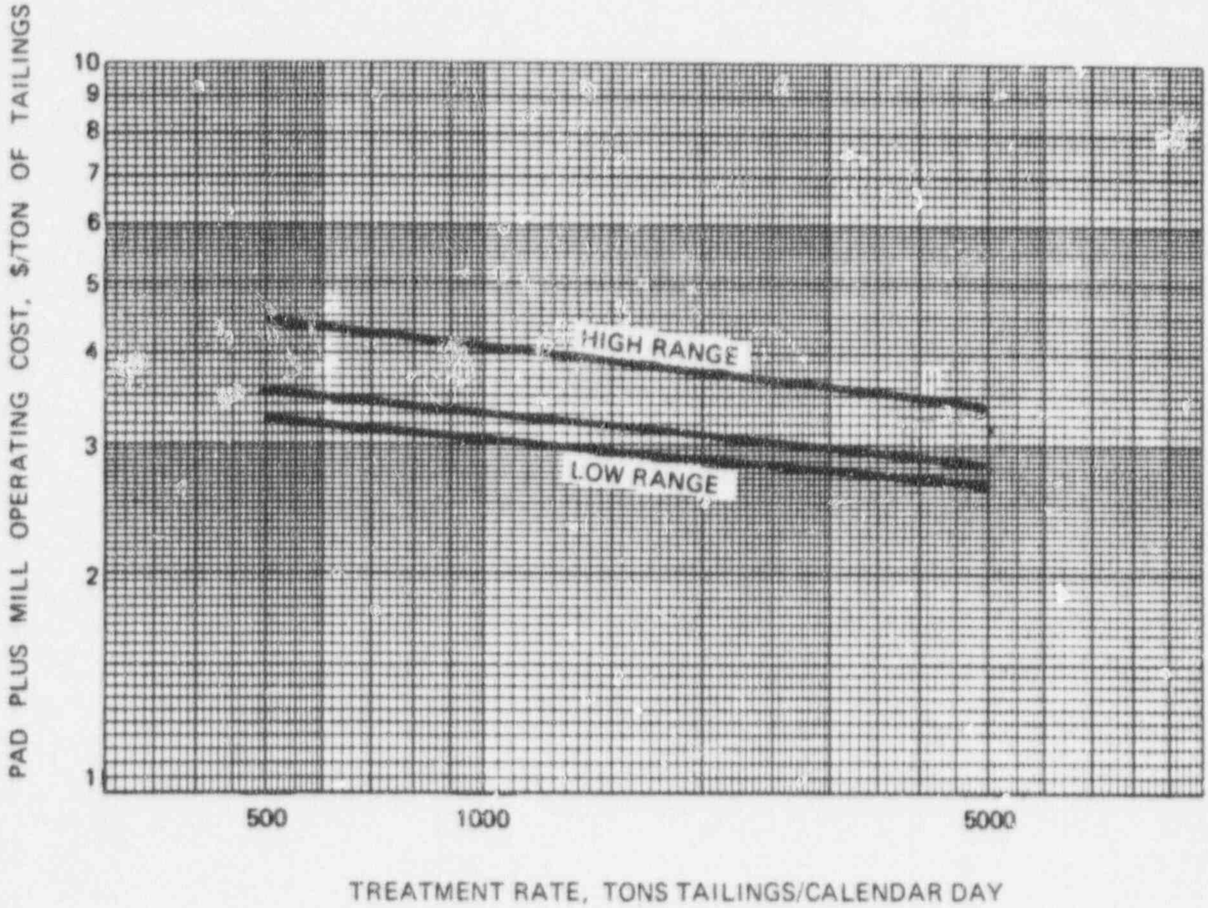

FIGURE 5-2. OPERATING COSTS OF HEAP LEACHING OF URANIUM MILL TAILINGS CONTAINING 0.01 TO 0.05% U_3O_8 WITH URANIUM RECOVERY RANGING FROM 20 TO 35% (COST ADJUSTED TO JANUARY 1977)

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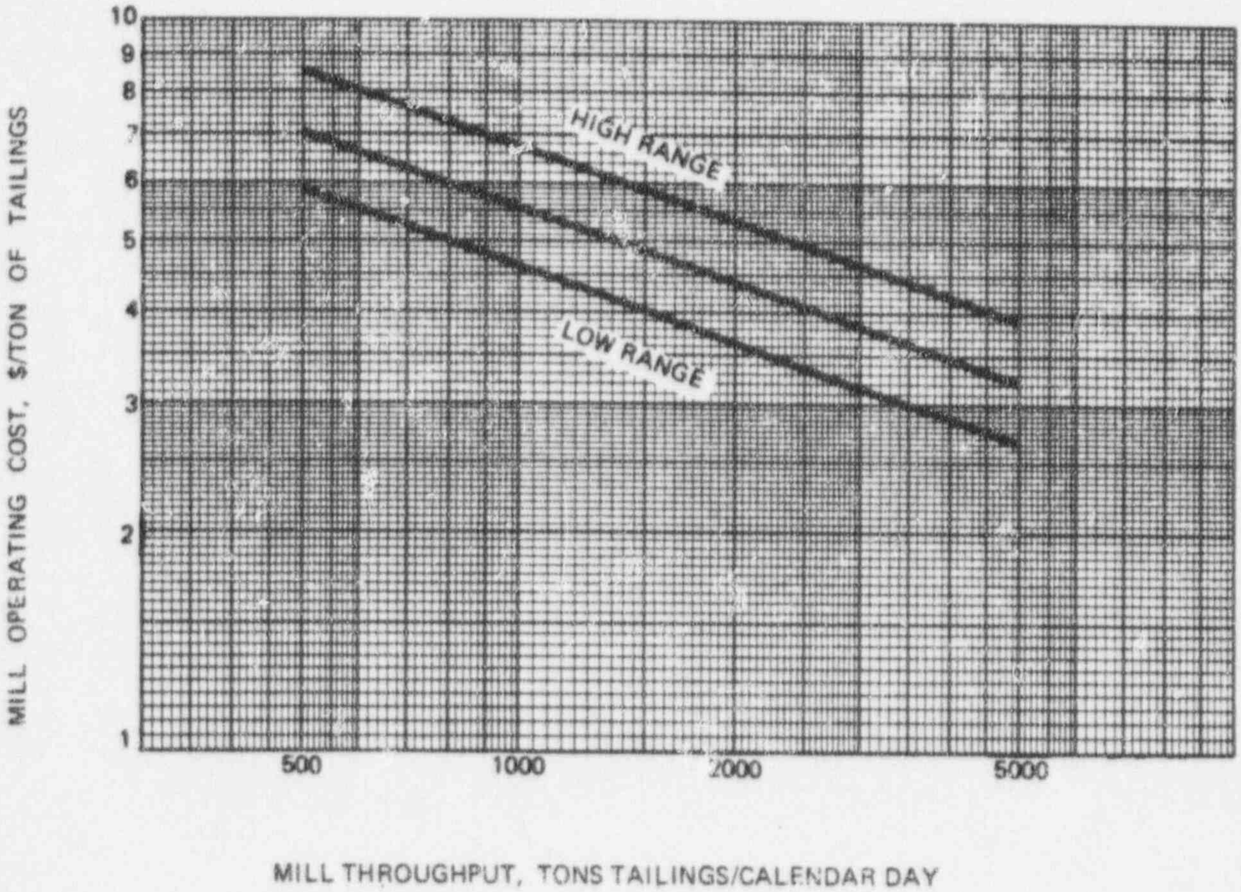

FIGURE 5-3. OPERATING COSTS OF CONVENTIONAL MILLING W/O CRUSHING AND GRINDING FACILITIES TO REPROCESS TAILINGS CONTAINING 0.01 TO 0.05% U_3O_8 WITH URANIUM RECOVERY RANGING FROM 35 TO 60% (COST ADJUSTED TO JANUARY 1977)

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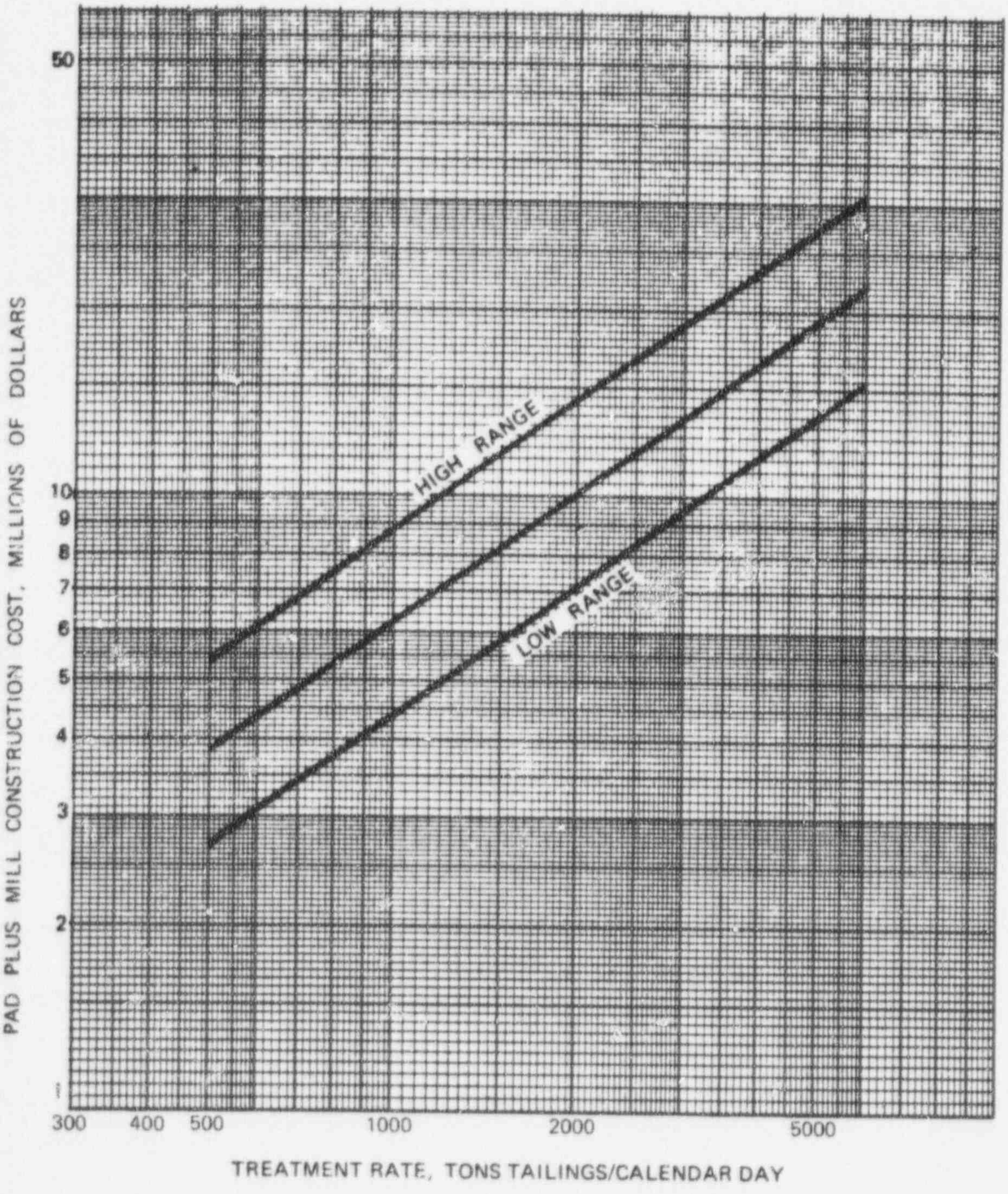

FIGURE 5-4.
CONSTRUCTION COSTS OF HEAP LEACHING PLANT TO REPROCESS URANIUM MILL TAILINGS CONTAINING 0.01 TO 0.05% U_3O_8 WITH URANIUM RECOVERY 20 TO 35% (COST ADJUSTED TO JANUARY 1977)

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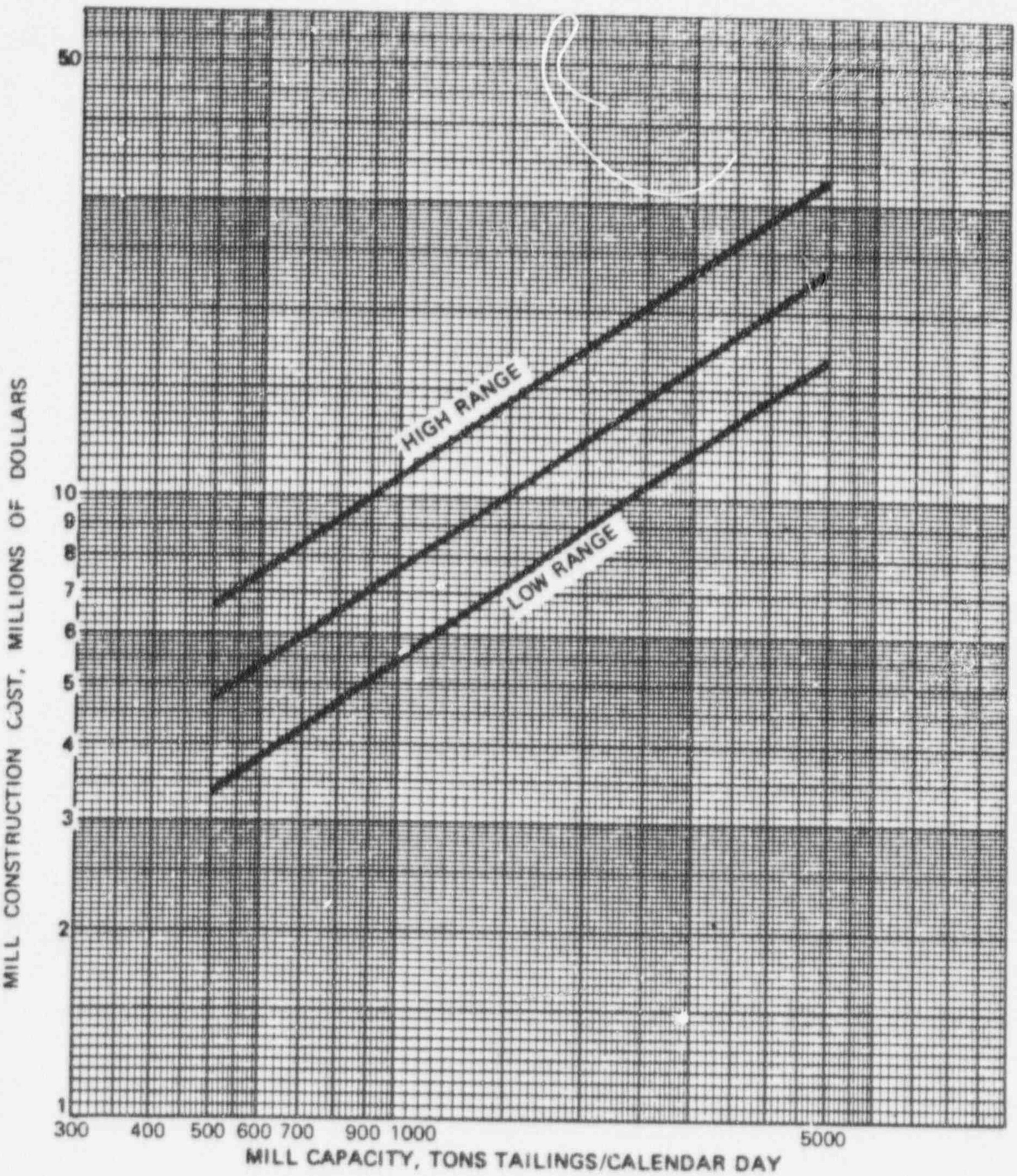

FIGURE 5-5. CONSTRUCTION COSTS OF A CONVENTIONAL URANIUM MILL W/O CRUSHING AND GRINDING FACILITIES TO REPROCESS TAILINGS CONTAINING 0.01 TO 0.05% U_3O_8 WITH URANIUM RECOVERY RANGING FROM 35 TO 60% (COST ADJUSTED TO JANUARY 1977)

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TABLE 5-1

MINERAL CONTENT BY TAILINGS POND/PILE

Pond	Dry Tonnage[1] (tons)	Mineral Composition[2] $\%U_3O_8$	$\%V_2O_5$	Mineral Content U_3O_8 (lb)	V_2O_5 (lb)
1	91,800	0.009	0.170	16,500	312,000
2	398,300	0.010	0.062	79,700	494,000
3	101,300	0.010[3]	0.374[3]	20,300	758,000
4	0	--	--	--	--
between 4 & 7	52,700	0.003	0.025	3,200	26,000
7	270,000	0.013	0.216	70,200	891,000
8	109,400	0.003	0.180	6,600	394,000
9	75,000	0.001	0.029	1,500	43,500
10	0	--	--	--	--
Area A	275,000	0.007	0.022	38,500	121,000

[1]Estimated from volume estimates using average density of 100 lb/ft^3.

[2]Obtained from a composite of grab samples unless noted.

CHAPTER 5 REFERENCES

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CHAPTER 6

MILL TAILINGS RECLAMATION

CHAPTER 6

MILL TAILINGS RECLAMATION

Remedial actions involve long-term storage of tailings, and require an adequate reclamation program to prevent the spread of radioactive materials into the environment. Of the NRC performance objectives for tailings management, only those listed below are applicable to the Edgemont site. Objectives (5), (6), and (7) below could be met by physical stabilization at the present site. If the tailings and other contaminated materials were moved to a new location, objectives (1) through (7) could be met.

(1) Locate the tailings isolation area, remote from people, so that population exposures will be reduced to the maximum extent reasonably achievable.

(2) Locate the tailings isolation area so that disruption and dispersion by natural forces are eliminated or reduced to the maximum extent reasonably achievable.

(3) Design the isolation area so that seepage of toxic materials into the ground water system will be eliminated or reduced to the maximum extent reasonably achievable.

(5) Reduce direct gamma radiation from the impoundment area to essentially background.

(6) Reduce the radon exhalation rate from the impoundment area to about twice the exhalation rate in the the surrounding environs.

(7) Eliminate the need for ongoing monitoring and maintenance program following successful reclamation.

6.1 PREVENTION OF WIND AND WATER EROSION

Wind and water erosion of the tailings can be prevented by physical stabilization with various types of cover materials. Vegetative stabilization aids in preventing erosion of the cover materials.

6.1.1 Chemical Stabilization of the Surface

This process involves applying chemicals to the surface of the tailings to form a water- and wind-resistant crust. Chemical 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. Chemical surface stabilizers, however, are susceptible to physical breakup and gradual degradation and will not meet the long-term requirements for stabilizing the Edgemont tailings piles.

Other complications also can arise in achieving satisfactory chemical stabilization in that the surfaces of tailings piles seldom are homogeneous, and variables such as particle size and moisture content affect the bonding characteristics of the chemical stabilizers.[1]

Tests were conducted by the Bureau of Mines[1] 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 to achieve surface stabilization and to reduce wind erosion. The attempt was unsuccessful because the material decomposed and the tailings were exposed within 2 to 3 yr.

Since no chemical sealant has been used successfully to stabilize uranium tailings for more than a few years, this method has not been considered in the various stabilization alternatives presented in Chapter 9.

6.1.2 Complete Chemical Stabilization

This process, which has been used in other mineral industry operations, involves the addition of chemicals in sufficient quantities to a slurry to produce a chemical reaction which solidifies the slurry. Chemicals may be added in two ways: to a slurry pipeline, and in situ. The in situ method of stabilization is relatively new and extensive research is required in each individual situation to define the optimum chemical addition to produce the desired results.

One of the features claimed for this stabilization method is that all pollutant chemicals are locked in the solidified slurry and chemicals cannot be leached from the solid.

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[1] See end of chapter for references.

The cost of this stabilization method is expensive for the chemicals alone. A cover material, such as gravel, would be required to protect the solidified slurry from wind and water erosion. It is not known whether vegetation can be established after topsoil and other soil cover have been spread over the solidified slurry. This probably would be a function of the specific chemical makeup of the solidified slurry and would require research to identify the conditions under which vegetation could thrive.

6.1.3 Physical Stabilization

Physical stabilization consists of isolating the contained material from wind and water erosion by covering the radioactive materials with some type of resistant material (e.g. rock, soil, smelter slag, broken concrete, asphalt, etc.). A stabilization cover should also reduce radon exhalation flux and gamma radiation, and prevent leaching of radioactive materials from the tailings due to precipitation on the pile. Thin covers of concrete or asphaltic materials have been shown to break down over relatively short periods of time; and starting within a few years after application, continuing maintenance is required. A concrete covering sufficiently thick and properly reinforced would be relatively permanent and maintenance-free, but the cost would be prohibitive for large areas.

In some arid regions, where the potential for successful vegetation stabilization is slight, physical stabilization using combinations of pit-run sand and gravel, soil, and riprap has been successful in preventing wind and water erosion of uranium tailings. An important component of physical stabilization is the proper treatment of the finished surface by such means as contour-grading and the terracing to reduce water erosion. Such treatments can reduce greatly long-term maintenance costs.

At the time of the Edgemont field survey, cover material was being taken from an area south of pond 10 and placed on pond 4, on an area between pond 4 and 7, and on the east edge of pond 7 to a depth of about 3 ft. Pond 9 was stabilized in 1976 and is discussed further in paragraph 6.1.4.

6.1.4 Vegetative Stabilization

This method involves the establishment of vegetative cover on the tailings or on a growing medium placed over the tailings.

There are species of plants which are self-regenerating and require little or no maintenance after growth becomes established. Vegetation can survive providing that:

(a) Evapotranspiration is not excessive

(b) Landscapes are properly shaped

(c) Nontoxic soil mediums capable of holding moisture are provided

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

(e) Proper selection of plants conducive to self-regeneration under conditions anticipated over a long time

Generally, establishing the growth of vegetation at sites receiving less than 10 in. of annual precipitation and with high evapotranspiration rates requires irrigation and fertilization. At Edgemont, precipitation averages about 14 in. annually and appears capable of supporting vegetation.

Pond 9 at Edgemont was stabilized with 3 ft of weathered shale in 1976. Since that time a good vegetative cover has been established. The soil cover has reduced gamma radiation to near background rates and has reduced radon exhalation by an estimated 50%.

One potential problem in the use of vegetative stabilization is the possibility of pickup of radioactive elements by the plants. The effect of this mechanism is addressed in Chapter 3.

6.2 PREVENTION OF LEACHING

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

(a) Employ chemical stabilization to prevent leaching into underground aquifers.

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

(c) Contour the tailings surface, then employ appropriate chemicals to seal the surface, thus preventing water from penetration and destabilizing the tailings.

(d) For a new site, line the storage area with an impermeable membrane (bentonitic clays and various plastic materials commonly are used for this purpose). Placement of dry tailings above the water table and below a cover layer, which prevents collection of runoff, may obviate the need for a lining in the storage area.

The current NRC performance objectives for tailings management address the prevention of leaching. Recent uranium mill

licenses have included provisions for an impermeable barrier beneath new tailings ponds, most commonly, a compacted clay liner. This approach is applicable to the Edgemont tailings if they are moved to a new site.

6.3 REDUCTION OF RADON EXHALATION

The NRC performance objectives for uranium tailings management include a provision for reducing the radon exhalation rate in the tailings impoundment area to about twice the exhalation rate in the surrounding environs in the post-operational period. At present, little experimental data on the effective diffusion coefficients for radon in various types of cover material of practical interest are available. However, for the purposes of this assessment effective diffusion coefficients have been estimated, and are used consistently in the alternatives, facilitating intercomparison.

Radon exhalation from uranium tailings may be reduced by covering the tailings with an impermeable cover, by increasing the diffusion path with ordinary soils such that the radon decays to a nongaseous state before reaching the surface, or by using dense materials with smaller diffusion coefficients to reduce the thickness of cover material required. Reducing the amount of radium in the tailings also would reduce radon exhalation, but this poses additional technological problems in radium recovery and radioactive waste disposal.

From simplified diffusion theory estimates, about 13 ft of dry soil (2,3) are needed to reduce radon flux by 95%, but only a few feet of soil are needed if a high moisture content is maintained in the cover material. Effective diffusion coefficients recently employed(4) for radon diffusion in dry soil commonly available for stabilization cover and in moist clay are 1.2×10^{-2} and 6.6×10^{-4} cm^2/s, respectively. Where clay is expensive because of low availablilty in the vicinity, it is possible to use combinations of materials such as layers of clay and soil. Economic tradeoffs can be calculated to determine the optimum thicknesses of the cover layers necessary to achieve the desired radon flux reduction at the least overall cost for materials and earthmoving operations.

6.4 REDUCTION OF GAMMA RADIATION

A few feet of cover material are sufficient to reduce gamma radiation to acceptable levels. Three feet of cover reduce the gamma radiation from the tailings by nearly three orders of magnitude.(5,6) Therefore, the 3 ft of average cover thickness now being placed on some of the tailings areas by the TVA should be sufficient to reduce even the highest gamma radiation levels on site to near background levels.

6.5 ASSESSMENT OF APPLICABILITY

None of the methods used thus far to stabilize uranium tailings sites has been a totally satisfactory solution to uranium tailings radiation problems. It is believed that recently authorized stabilization methods will result in acceptable tailings management programs. These methods involve such techniques as encapsulation of the tailings in compacted clay liners and caps plus addition of soil cover. The objective would be to reduce gamma radiation to background, reduce radon exhalation to twice the background flux, and reduce or eliminate seepage of toxic materials from the tailings.

The alternative remedial actions in Chapter 9 that include long-term storage of the tailings at the Edgemont site also include provision for covering the tailings with a compacted clay cap plus additional soil cover to meet the NRC performance objectives with regard to reduction of gamma radiation and radon flux from the tailings. The tailings are now located on relatively low permeability shale, and downward seepage is small as confirmed by the hydrological slug injection tests in wells around the tailings ponds and piles. Additional remedial action will be necessary along the west side of pond 7. The tailings might be located elsewhere on the site or replaced in the same location after chemical fixation and/or within improved diking. Also, diking improvements will be required for protection of some of the other tailings areas from erosion.

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5. K. J. Schiager; "Analysis of Radiation Exposures on or Near Uranium Mill Tailings Piles"; Radiation Data and Reports; EPA; Vol 15; Jul 1974.

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CHAPTER 7

OFF-SITE REMEDIAL ACTION

CHAPTER 7

OFF-SITE REMEDIAL ACTION

Another objective of this engineering assessment is to estimate the costs of appropriate remedial action at those structures and land areas off site where tailings are located, based upon the Surgeon General's guidelines.

Some tailings have been transported off the site by individuals, others by wind and water erosion.

7.1 DATA SOURCES

A mobile scanning unit, operated by the AEC under interagency agreement for the EPA, conducted a scanning survey in the Edgemont, South Dakota area in 1971. In 1972, field survey teams, consisting of personnel from the EPA and the State of South Dakota, performed gamma-screeming surveys of locations suspected of contamination[1] reported in the 1971 scanning survey. Fifty-six locations were surveyed by the field teams.

The gamma survey and soil analyses were the data sources used for consideration of the remedial action for open land areas.

7.2 REMEDIAL ACTION FOR STRUCTURES

Uranium tailings were found under or within 10 ft of structures at 25 locations in Edgemont and at 1 location in Provo. At 18 other locations in the two communities, tailings were found more than 10 ft from structures or on vacant land. Possible tailings use locations are included herein, although the radioactive materials were not identified as tailings.

An extended series of measurements, such as required in the full application of the Grand Junction remedial action criteria, might modify the actual number of locations included in the remedial action. The locations at which tailings are on vacant lands or are greater than 10 ft from structures could constitute a problem in the future. Remedial action costs for this category are not included in this assessment because they are not covered under the Grand Junction remedial action criteria.

The presence of ore was identified at several locations, but these locations were not given further consideration in this study.

The average cost of remedial action at off-site structures in Grand Junction where tailings were found under or within 10 ft

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[1] See end of chapter for references.

of the structures is about $13,000. This figure is considered to be higher than the eventual overall average because the locations with tailings under the structures or with extensive use of tailings were remedied early in the program to reduce exposure to the occupants. In the Phase II - Title I DOE program, an average of $8,000 per location was used where a relatively large number of structures was involved covering a range of tailings use. If only a few locations were involved, this average was adjusted based upon review of the individual radiological survey results. Also, not all locations will qualify for remedial action after the required series of measurements are made.

For the 26 locations identified in Edgement and Provo, a cost of $200,000 has been estimated for remedial action. This cost is not included in the costs of the remedial action alternatives in Chapter 9.

7.3 REMEDIAL ACTION FOR OPEN LANDS

The extent of windblown tailings is indicated by data in Figure 3-9, Chapter 3. Decontamination of windblown tailings consists of removing the contaminated soil and returning it to the tailings piles. The Phase II criteria state that the area for windblown soil removal is determined by residual radium concentration in the soil of no more than twice background radium concentration in the vicinity. All areas could be decontaminated by moving an average of 4 in. of soil, gravel roads, etc. After decontamination, the affected areas would be restored with additional clean material and vegetation would be reestablished.

The estimated cost for off-pile decontamination of open lands for the Edgemont site is $50,000 without engineering costs and contingency. These costs are not included in the remedial action costs in Chapter 9.

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CHAPTER 8

TAILINGS DISPOSAL SITE ALTERNATIVES

CHAPTER 8

TAILINGS DISPOSAL SITE ALTERNATIVES

In several of the alternative remedial actions considered in this assessment, the tailings would be moved to an alternate site isolated from the populace. For convenience, alternate storage sites for tailings are referred to in this report as disposal sites.

8.1 CRITERIA FOR TAILINGS DISPOSAL

Possible alternative sites for disposal of tailings were sought and identified that could meet the NRC performance objectives for storage of radioactive tailings. Sixteen disposal sites were considered and each was visited and examined closely. Of these, four sites were selected for cost estimate studies; they are presented herein as alternatives. These locations are considered in Alternatives III through VI. Table 8-1 contains the name of each alternate disposal site studied and the distances from the Edgemont site. Figure 8-1 shows the locations of the four proposed disposal sites. Table 8-2 shows the soil characteristics of three of the sites. The soil types are defined in Figure 8-2.

Twelve of the 16 sites were omitted as alternatives prima ly because of inadequate site configuration, the possibility of encroachment on the site, the value of the site for other purposes, the adverse surface hydrology (too much upslope drainage), and the scarcity of suitable earth for use as stabilization cover.

Each of the four alternative sites was evaluated on the basis of hydrology, meteorology, geology, ecology, and economics. The evaluations consisted of literature surveys and on-site investigations, including boring and soil tests. Assessments of the hydrologic and meteorologic conditions were centered on such factors as wind and water erosion, orientation to weathering by the prevailing winds, water contamination, flooding, drainage basin configuration, subsurface and surface drainage, and natural storage basin features. The geologic examination addressed stability problems and soil characteristics, such as evidence of slides and faults, and types of unconsolidated and bedrock materials. The ecological study included evaluation of land use potential, consideration of animal habitats, proximity to population centers, and aesthetic considerations. Economic considerations included preliminary estimates of support facilities such as highways, distance from the site, and the extent of site preparation and long-term maintenance required at the disposal sites. A railroad line runs alongside the Edgemont site and branches in both northeast and northwest directions. Consequently, rail haulage of the tailings and location of storage sites near rail facilities were considered. Private, state, and federal lands were included in searching for acceptable alternate sites.

Three of the four sites are located on privately owned lands, and one is on public land currently administered by the U.S. Bureau of Land Management (BLM).

8.2 GENERAL DESCRIPTION OF ALTERNATE DISPOSAL SITE AREAS

The area within a 15-mi radius surrounding the Edgemont site was researched for possible alternate storage site locations. Considered were items such as haul routes, haul methods to be used, and haul distance. The configuration of the specific potential site was evaluated along with the availability of suitable stabilization cover and storage dike or dam materials. The orientation with respect to sun, wind, and upslope drainage was also a factor in the selection.

Several possible sites were located that could be adapted as alternate disposal sites for the tailings within the Cheyenne River Valley and some of its tributaries, which include Cottonwood Creek, Red Canyon Creek, and numerous unnamed draws and washes. Locations at the head of washes which had horseshoe-type basins or configurations were sought so that dams or dikes easily could be constructed to form storage basins. Locations were sought which would enable the objectives outlined in Chapter 6 to be met.

Populated areas or areas where population growth appears likely were eliminated from site consideration. Also eliminated was land used for farming or with farming or irrigation potential.

The topography of the area provided locations where sharp breaks in slope, and thus drainage direction changes, occurred. Thus, some potential storage sites were steep and others were more gradual. There are several locations within reasonable and economical haul distances of the Edgemont site which could be adapted into excellent disposal sites.

If a new mill were built approximately 12 mi northwest of the existing mill, then additional tailings storage area could be provided there. For example, at one such location, within 1 mi of a potential millsite, pond areas could be developed with sufficient volume capacity to contain the new tailings production and the existing tailings. However, there are several disposal locations which are closer to the existing Edgemont tailings that would offer storage at a lower cost and would have more favorable storage conditions than at a location close to the new mine area.

The suggested disposal sites are all similar. They are located at the head of drainage areas in naturally formed horseshoe-shaped depressions or ravines. The sites have little or no evidence of heavy recent wind or water erosion. Access to the sites would be primarily over dirt, paved, or graveled public roads. At some sites, haul roads would need to be constructed. Where dirt roads would be traversed by trucks carrying tailings, the estimates involve the construction of a gravel-based surface suf-

ficient to handle the heavy loads and traffic. Dust control costs also are included, but no costs for repairs or for maintenance of public roads are included. Transportation, site preparation, and maintenance costs are discussed fully in Chapter 9.

8.3 DESCRIPTIONS OF SPECIFIC ALTERNATE DISPOSAL SITES

Site names are based upon their locations in a certain section of the USGS Quadrant Map in which the site is located.

8.3.1 East Section 18, Edgemont (Site 2)

This site is located 2.5 mi south and slightly east of the Edgemont mill. It is within a 120-acre, "L-shaped" parcel of vacant public domain land which is under the jurisdiction of the BLM. Currently the property is leased for grazing purposes. The site is bounded on the east by an unpaved, unnumbered county township road. This road runs from Edgemont (and the southern extreme of the Edgemont tailings area) in a southeasterly direction, and it serves the ranches southeast of Edgemont and east of the Igloo/Provo area. No more than six or seven vehicles per day pass over that road. The portion of the site suggested as a disposal location is at the head of an intermittent drainage basin. From this basin drainage eventually flows eastward into the Cheyenne River. The configuration of the basin is a natural horseshoe-shaped area that opens to the east. On the north and west of the high part of the site, the downward slopes will allow precipitation to drain into Cottonwood Creek.

About 50 acres of the site could be used for tailings disposal and dike construction. There are two natural abutments on the site which would form the extreme ends of a containment dike to be constructed. There are no structures on the site, and apparently it has been used for occasional grazing. Vegetation, which covers about 80% of the site, consists mostly of grasses and sagebrush; there are no trees. There is about a 120-ft difference in elevation between the county road and the highest point on the site. Therefore, the elevation at the base of the dike would be about 3,720 ft above sea level. Downslope from the low point of the site, there is a water storage reservoir of about 0.25 acre that is being used for livestock watering. The closest residence to the site is a ranch house, about 1.5 mi to the southeast. A barbed-wire fence is installed along the east side of the site just west of the road. No population growth is projected for the area that would infringe upon the site. Exposure of the site would be to the east, offering ideal conditions for revegetative processes to occur on a stabilized storage pile in that location.

Soil cover at the site consists of about 6 in. to 2 ft of a brown, fine-grained, silty clay topsoil with less than 15% sand and gravel, as shown on Table 8-2. The topsoil is damp, and it contains roots down to about 8 in. From a depth of about 2 to 4 ft a light-brown silty clay exists. A trace of sand, calcareous

concretions and shale fragments exist near the base, but no gravel exists. Both the topsoil and the underlying layer have liquid limits near 45, but the underlying layer has a higher (96%) concentration of silt-clay compared with 86% for the topsoil. The third soil layer at the site consists of a brown, highly weathered upper zone of shale bedrock strata. This layer contains the highest (98%) silt-clay ratio and extends to a depth of about 5 ft. A maximum dry density of 106.8 lb/ft^3 was obtained for that layer.

Bedrock of the site consists of the Greenhorn limestone formation and the underlying Belle Fourche and Mowry shales, all of which are of mid-Cretaceous age.[1] See Figure 2-9 for the stratigraphic section. The sediments are nearly flat-lying with a gentle dip of between 1 to 5 deg to the south. No fractures (faults or joints) are reported in the vicinity. Erosion was observed to be moderately high on the exposed limestone and shale outcrops. Permeability of the fine-grained sediments at the site could be expected to be low, especially at the perched flow weathered zone at the soil-bedrock interface. Migration rates and flow velocities probably are minimal.

Concentrations of ^{226}Ra, ^{230}Th and ^{210}Pb in soil samples from the sites are shown in Table 8-3.

8.3.2 Northwest Section 14, Edgemont (Site 6)

This site is located 5.3 mi northwest of Edgemont, on the east side of an unnumbered county township road (commonly called Road 10) which generally parallels the Cheyenne River and the tracks of the Burlington-Northern Railroad (BNRR) as both head northwest from Edgemont. The site is located 1 mi south of Breakneck Hill, which is on private property and on land where the TVA has leased the mineral rights.

Approximately 60 acres would be required for tailings disposal and dike construction. At this location, there has been a break in surface contours; the net result is that the proposed site is at the very head of a drainage basin from which an intermittent stream drains northwesterly into the Cheyenne River. The basin is a natural "sink" and would require a dike to extend across the downhill side of the basin in a northeasterly-to-southwesterly direction. There are no structures on the site and it is used for intermittent grazing. Vegetation, which covers about 90% of the site, consists mainly of grasses and low sage, with no trees or bushes. The base of the containment dike would be at an elevation of approximately 3,590 ft above sea level. The road which passes near the site is a graveled surface road serving

(1) See end of chapter for references.

ranch and railroad areas northwest of Edgemont. The road is frequently used with about 60 vehicles (including school buses) passing the site per day. The closest residence to the site is 2.5 mi to the southeast. The site is enclosed with three-strand barbed wire fencing attached to wooden posts. Exposure of the site would be to the northwest. Access for hauling and depositing the tailings would be very convenient since the site is not only adjacent to the road, but approximately halfway between the Edgemont mill and the old open-pit mine area.

Soil cover at the site consists of medium-brown silty clay topsoil, moist with roots down to about 1 ft. The topsoil contains 80% silt-clay, about 12% sand, and 8% gravel. The maximum dry density was measured at 99.1 lb/ft^3, with an optimum moisture content of 22%. Table 8-2 shows the soil characteristics in relation to soil conditions at the other alternate sites. The soil immediately beneath the topsoil also is classified as a silty clay with like characteristics to a depth of about 6 ft. The shale bedrock can be found at depths varying across the site from 1 to about 8 ft, depending upon the amount of erosion and/or sediment deposition. The upper surface of the shale is weathered to about 6 in. and contains calcareous deposits. The shale is highly fissile and can easily be parted along the planes of foliation when compression is removed.

Bedrock of the site consists of the Belle Fourche shale of mid-Cretaceous age, as shown in Figure 2-7. The nearly flat-lying sediments dip in a southerly direction at about 5 deg. No fractures (fault or joints) occur within the upper bedrock. The New Castle limestone should lie immediately beneath the shale, but it is reported missing from the section at this locality, as is the remainder of the lower Cretaceous sediments. Sediments of the Jurassic age apparently underlie the Belle Fourche formation in this area. Permeabilities at the site probably would be low with limited migration rates and low flow velocities due to the fine-grained nature of the soils and the flat-lying sediments.

8.3.3 Southeast Section 11, Burdock (Site 7)

This site is located 10.6 mi northwest of the Edgemont mill, about 0.75 mi northeast of the location where the county township road (commonly called Road 10) from Edgemont crosses north over the BNRR tracks south of the old Burdock station. The site is at an elevation of 3,680 ft above sea level and is in the general vicinity of where the TVA has considered the development of an underground mine. The site is on privately owned land of which the mineral rights have been leased by the TVA. The use of the site for a tailings disposal area would require at least 70 acres, and would necessitate the construction of at least three dikes or dams. The land is used for grazing and has only a thin ground cover of grasses and sage, without trees or bushes. The site is at the head of a drainage basin from which drainage flows south, then eventually west into the Cheyenne River. There are no structures

on the site, except the wooden remains of an old shallow water pump system and several pipe stubs protruding from the ground where wells once existed, or where attempts were made to locate wells. The closest residence to the site is a ranch house, approximately 2 mi directly south of the site. There is a small cattle-watering pond at the extreme low elevation of the site. This pond is about 0.17 acre in size, and is in the drainage pattern beginning at the head of the site. Access to the site from the county road is over an unimproved dirt road which now is being used by uranium exploration crews.

Soils at this site consist of about 2 ft of a medium-brown clayey silt (CL-ML) topsoil with some thin calcareous stringers and roots extending down to about 1 ft. The topsoil contains 90% silt-clay and approximately 10% fine sand, as is shown on Table 8-2. Immediately underlying the topsoil to a depth of about 8.5 ft is a light-brown sandy silt (ML) containing 75% silt-clay and 25% fine sand. A maximum dry density is estimated at 100 lb/ft^3, with an optimum moisture content near 15%. The soils are underlain by a fine-grained gray shale decomposed at the surface to about 6 in. The shale is very friable, dry, and contains thin fine sand seams.

Bedrock at the site is of Cretaceous age, with either the Belle Fourche or Skull Creek shale exposed at the surface underlain by the Fall River sandstone and Dakota formation.(1) No major fractures (faults or joint sets) are reported within the site. Some sandstone dikes have been located in nearby valleys but have not been traced through the site. Permeabilities can be expected to be low in the soils and weathered shale zones of the site. Shales could have fairly high permeabilities along partings, but vertical flow would be minimal. Flow velocities can be expected to be low except where shales are highly disturbed.

Data also were collected on a potential tailings storage site located immediately to the southwest of the site in an adjacent valley. Site 16, in the northeast corner of Section 15, is a location that might serve as a potential disposal site for future tailings if a new mill facility were located nearby. Soil analysis data are shown on Table 8-2 for the samples taken across the site. Conditions were found to be similar to those of site 7 but samples exhibited higher percentages of the silt-clay fraction and less sand. These conditions would indicate even lower permeabilities. However, at the back-hoe test pit excavated in the center of the site drainage pattern, ground water seepage was encountered in the upper shale zone.

8.3.4 North Section 1, Burdock (Site 8)

This site is located 12.4 mi northwest of Edgemont. It is bounded on the north by the line separating Fall River County from Custer County, and on the north and east by the Harney National Forest. This location was the source of much of the uranium ore that was fed to the Edgemont mill, and is a large

open-pit mine area. In the vicinity there are three large open-pit mines. Either Darrow pit No. 1 and 3 or pit No. 5 could be used as a disposal location. The pits vary in depth up to 75 ft, and are ringed by piles of the overburden which was removed to mine the ore. There is only sparse vegetation in the pits or on their side slopes, and water erosion has created many gullies on the side slopes. There are no structures on the site, and the closest residence is a ranch house about 1.8 mi west from the site. The elevation at the bottom of the pits is approximately 3,840 ft above sea level. Access into the bottoms of the pits could easily be developed by regrading the former ore-hauling routes.

The bedrock at the site of the two abandoned open-pits is reported as consisting of sedimentary formations of lower Cretaceous age.[(1)] Although a detailed study was not made, it is believed from field observations, reference research, and information provided by the TVA that the formations existing at the site in descending order are the Skull Creek shale, Fall River sandstone, and the Fuson shales of the Lakota formation. The sediments are primarily interbedded black to light grey marine shales, sandstone, and limestones. Bedding is near horizontal with a projected strike of north-northwest and a dip angle less than 5 deg to the south.

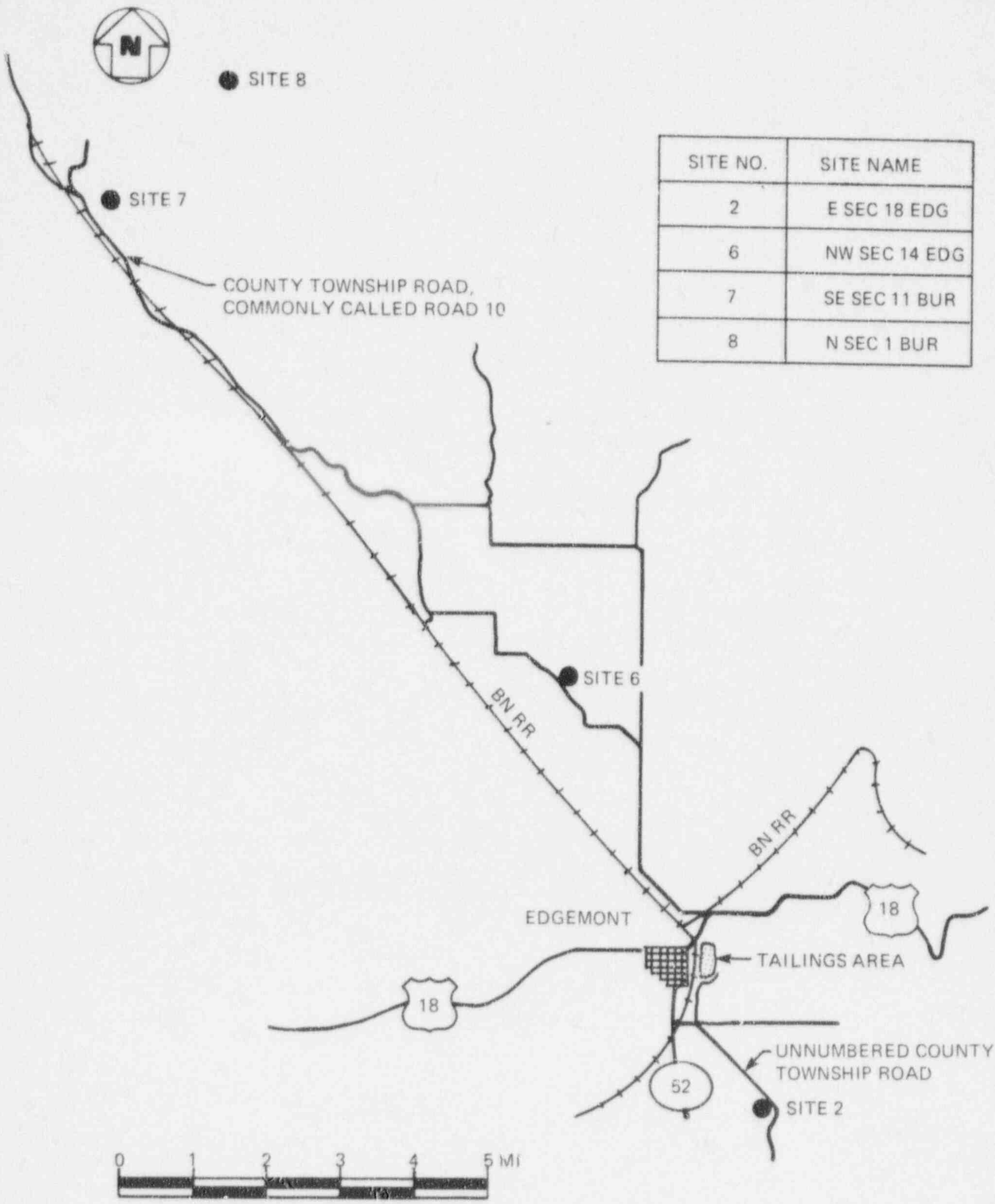
Fractures at right angles to the bedding planes were observed to be sparse and scattered. Partings within the shale layers along foliation planes were common. No major faults were reported within the immediate pit areas.

Erosion of the pit walls was observed to be moderate to high, especially where the softer shale sediments were exposed. The pit bottoms were partially filled with erosional wash and debris from scaling and slough. Water which had originated from a recent storm runoff was found ponded in the lower elevations of the pit bottoms. No ground water seeps nor evidence of major flow zones were noticed although some of the sandstone layers contained iron precipitate deposits indicating historic or intermittent ground water flow.

Relative permeability of the individual formations with respect to outward migration of seepage from the pits was not determined. However, seepage could occur within the sandstones and highly fissile shales or along bedding planes.

8.4 RETURN TO ORIGINAL MINE SOURCES

The return of tailings to each mine from which the ores were initially obtained is impractical. The ore refined at the Edgemont plant came from many mines scattered over a wide area. These mines (some active and others potentially active) are held by many owners and are not available for long-term storage. The last main source of ore for the Edgemont mill was from an open-pit mine approximately 12.4 mi northeast of the mill; this area is included as a possible long-term storage site.



SITE NO.	SITE NAME
2	E SEC 18 EDG
6	NW SEC 14 EDG
7	SE SEC 11 BUR
8	N SEC 1 BUR

FIGURE 8-1. LOCATION OF PROPOSED DISPOSAL SITES

211-00

MAJOR DIVISIONS			GRAPH SYMBOL	LETTER SYMBOL	TYPICAL DESCRIPTIONS
COARSE GRAINED SOILS	GRAVEL AND GRAVELLY SOILS	CLEAN GRAVELS (LITTLE OR NO FINES)		GW	WELL-GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES
				GP	POORLY-GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES
	MORE THAN 50% OF COARSE FRACTION RETAINED ON NO. 4 SIEVE	GRAVELS WITH FINES (APPRECIABLE AMOUNT OF FINES)		GM	SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES
				GC	CLAYEY GRAVELS, GRAVEL-SAND-CLAY MIXTURES
	SAND AND SANDY SOILS	CLEAN SAND (LITTLE OR NO FINES)		SW	WELL-GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES
MORE THAN 50% OF MATERIAL IS LARGER THAN NO. 200 SIEVE SIZE				SP	POORLY-GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES
	MORE THAN 50% OF COARSE FRACTION PASSING NO. 4 SIEVE	SANDS WITH FINES (APPRECIABLE AMOUNT OF FINES)		SM	SILTY SANDS, SAND-SILT MIXTURES
				SC	CLAYEY SANDS, SAND-CLAY MIXTURES
FINE GRAINED SOILS	SILTS AND CLAYS	LIQUID LIMIT LESS THAN 50		ML	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY
				CL	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS
				OL	ORGANIC SILTS AND ORGANIC SILTY CLAYS OF LOW PLASTICITY
MORE THAN 50% OF MATERIAL IS SMALLER THAN NO. 200 SIEVE SIZE	SILTS AND CLAYS	LIQUID LIMIT GREATER THAN 50		MH	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SAND OR SILTY SOILS
				CH	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS
				OH	ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS
HIGHLY ORGANIC SOILS				PT	PEAT, HUMUS, SWAMP SOILS WITH HIGH ORGANIC CONTENTS

NOTE: DUAL SYMBOLS ARE USED TO INDICATE BORDERLINE SOIL CLASSIFICATIONS.

SOIL CLASSIFICATION CHART

SOURCE REF: 2

FIGURE 8-2. UNIFIED SOIL CLASSIFICATION SYSTEM

TABLE 8-1

SITES EVALUATED FOR DISPOSAL OF EDGEMONT TAILINGS

Site No.	Alternative No.	Miles from Edgemont Pile	Site Name[a]
1		0.75	E Section 6, Edgemont
2[b]	III	2.5	E Section 18, Edgemont
3		2.15	W Section 18, Edgemont
4		3.4	E Section 3, Edgemont
5		7.0	S Section 6, Edgemont SW
6[b]	IV	5.3	NW Section 14, Edgemont
7[b]	V	10.6	SW Section 11, Burdock
8[b]	VI	12.4	N Section 1, Burdock
9		2.95	W Section 2, Edgemont
10		5.5	E Side Route 52 (Provo)
11		5.15	NW Section 20, Edgemont
12		5.45	E Section 18, Edgemont
13		4.25	NE Section 23, Edgemont
14		10.25	Igloo Area
15		9.5	SW Section 20, Burdock
16		10.6	NE Section 15, Burdock

[a]Name is derived from the site's location in various section numbers of the USGS quad maps of the Edgemont and surrounding areas.

[b]Sites included as alternatives in Chapter 9, remedial actions.

TABLE 8-2

SOIL CHARACTERISTICS AT ALTERNATE DISPOSAL SITES

Parameter	SITE No. 2 E Sec 18 EDG			SITE No. 6 NW Sec 14 EDG			SITE No. 7 SW Sec 11 BUR			SITE No. 16* NE Sec 15 BUR		
	Surf	A	B	Surf	A	B	Surf	A	B	Surf	A	B
Silt-clay (%)	86	96	98	80	80	--	90	75	--	86	97	97
Clay (% est)[a]	73	52	39	40	40	--	28	20	--	73	45	73
Sand	6	4	2	12	12	--	10	25	--	6	3	3
Gravel	8	0	0	8	8	--	0	0	--	8	0	0
Thickness (ft)	2	2	0.5	1	2-6	--	2	6.5	--	2	3	6
Depth (ft)	(0-2)	(2-4)	(4-4.5)	(0-1)	(1-8)	--	(0-2)	(2-8.5)	--	(0-2)	(2-5)	(5-11.0)
Liquid limit[b]	45	46	--	--	--	--	--	--	--	53	65	63
Soil type[b]	CH	CH	CH	CL	CL	--	CL-ML	ML	--	CH	CH	CH-MH
Maximum dry density (lb/cf^3)	--	--	106.8[d]	99.1	99.1	--	--	--	--	--	--	96.4[d]
Optimum moist content (%)	--	--	17.4	22.0	22.0	--	--	--	--	--	--	21.0
Underlying bedrock[c]	--	--	e	--	--	e	--	--	e	--	--	e

Notes: [a]Percent clay in SL-CL fraction
[b]See Figure 8-2 (unified soil classification chart)
[c]From USGS/TVA reference material
[d]Test on shale
[e]Shale

Surf-A-B denote soil layers.

*Not included as an alternative

Source of data: Reference 2

TABLE 8-3

RADIONUCLIDE CONCENTRATIONS IN SOIL
FROM ALTERNATE DISPOSAL SITES

Site No.	Sample	^{226}Ra pCi/g	^{230}Th pCi/g	^{210}Pb pCi/g
2	H Topsoil	0.94±0.07	1.61±0.09	0.15±0.07
	I Subsoil 1.5-5 ft	0.73±0.06	0.43±0.05	3.19±0.39
	J Bedrock 6-7 ft	3.02±0.20	1.54±0.08	3.30±0.20
6	L Topsoil	0.64±0.08	0.25±0.02	1.87±0.12
	M Weathered shale	0.66±0.05	0.73±0.07	2.08±0.12
	N Shaly subsurface	1.43±0.22	0.96±0.08	0.88±0.10
7	F Clay & sand partings	0.42±0.06	0.51±0.09	0.90±0.14
	G Fine sands with occasional clays	1.91±0.15	0.36±0.05	5.21±1.79
16*	A Topsoil 0-2 ft	0.96±0.11	0.53±0.08	0.04±0.01
	B Clays 2-4 ft	1.36±0.10	0.35±0.07	0.79±0.35
	C Shale 4-4.5 ft	2.36±0.21	0.47±0.05	0.23±0.08
	D Chipped shales	0.92±0.08	0.22±0.03	3.11±0.48

*Not included as an alternative. Site 8 was located near Site 7.

CHAPTER 8 REFERENCES

1. R. C. Culler; Hydrology of the Upper Cheyenne River Basin; U.S. Geological Survey Water-Supply Paper 1531; 1961.

2. Results of Laboratory Testing and Permeability; Letter Report; Dames and Moore; Jan 1978.

CHAPTER 9

REMEDIAL ACTIONS AND COST-BENEFIT ANALYSES

CHAPTER 9

REMEDIAL ACTIONS AND COST-BENEFIT ANALYSES

Various remedial actions for the millsite and tailings piles were identified and investigated. The alternatives presented are those considered to be the most realistic and practical when evaluated in regard to the present technology, cost-health benefits, condition of the mill, land values, equipment, and transportation facilities available. Remedial measures for the site can be separated into two basic categories:

(a) Stabilization of the piles at the current site with demolition and/or decontamination of the buildings and millsite.

(b) Removal of the tailings to an off-site disposal area with the demolition and/or decontamination of the buildings and millsite, leaving the entire site available for unrestricted use.

The analyses presented in Chapter 5 have shown that the reprocessing of the Edgemont tailings would not be economic at this time. Consequently, in none of the alternatives was the possibility of reprocessing any of the existing tailings costed. However, should the economic potential change or should other conditions warrant reprocessing of tailings, a determination would have to be made of the location and costs involved in building a new mill. A decision would have to be made by the TVA whether or not it would be economical to reprocess these tailings at a new mill.

The differences in cost which are apparent in considering complete decontamination of the structures as opposed to partial decontamination or demolition of the structures are included in the discussion of Alternative I.

The cost estimate summary given in Table 9-1 includes a brief description of each of the remedial alternatives and the required costs estimated to implement each. In Alternatives I and II the tailings areas are stabilized in place. In Alternatives III through VI the tailings are moved to an alternate disposal area.

Several of the remedial measures are common to all the alternative approaches costed; these measures were considered but not included in the total cost of each alternative because they were relatively low in relation to the total cost of the remedial action and are roughly equivalent for each alternative. For example, in all of the alternatives, monitoring and maintenance will be required until such time as successful completion of the site reclamation program can be demonstrated.

Performance objectives formulated by the NRC for the siting

and stabilization of uranium mill tailings have been described previously. Several of these objectives can be met by long-term storage of radioactive materials on the Edgemont site with proper stabilization. Most of the objectives may be met if the tailings are to be relocated. In every alternative, the performance objectives have been considered in formulating the remedial actions. A full discussion of stabilization techniques and their applicability to the Edgemont site is included in Chapter 6.

No acquisition costs for alternative long-term storage areas are included in the cost estimates.

The cost of off-site remedial actions relating to windblown tailings off the piles and off-site structures, as described in Chapter 7, are not included in the alternative costs.

9.1 ON-SITE TAILINGS STABILIZATION, SITE DECONTAMINATION (ALTERNATIVE I)

Under this alternative the tailings would remain on site, be reshaped as necessary, and stabilized or confined to reduce the possibility of radioactivity entering the environment.

9.1.1 Site Grading

In order to reclaim land, the following procedure is proposed: make the piles or ponds easier to stabilize for long-term storage, clean up the mill area, and provide for an adequate system of surface drainage (a considerable amount of site grading is included). The economics of providing proper stabilization cover over many large areas as opposed to consolidation and cover also was a governing factor in the suggested grading.

All the rubble, mill debris, etc. left on the site would be collected and placed into pond 1. This would include structures such as the old utility bridges crossing Cottonwood Creek.

The high, steep-banked and unstabilized East sand tailings pile would be relocated, in part, by covering (filling) ponds 3 and 4 with material from the top portion of the East sand pile. Thus, the ground area covered by all three piles would remain the same, but the resulting surface would be shaped like an inverted saucer with an average elevation of about 3,465 ft.

The material in pond 10, along with its dike, would be relocated onto the low portions of pond 7.

The tailings located in sand tailings area B would be relocated into pond 1 as would all of the contaminated material (earth) in the millsite area.

A drainage ditch, approximately 10 ft wide and 4 ft deep, would be formed along the east property line and graded in order to intercept surface water which normally flows onto the site

from the hills to the east. This ditch would be located so as to carry water generally to the north, between ponds 8, 3, and 1, and the sewage pond of the City of Edgemont, and discharge into the Cheyenne River east of pond 1. A ditch runs through part of this location, but it needs to be expanded, cleaned, and extended farther south, east of pond 7 and about half the length of pond 10.

Prior to completion of the placement of stabilization material and riprap (as described in paragraph 9.1.3) the other areas of the site around the bases of the dikes would be graded to carry surface runoff directly into either Cottonwood Creek or the Cheyenne River. Contaminated areas of these two waterways, including some banks, would be decontaminated by relocating the contaminated earth or tailings onto the remaining unstabilized areas prior to completion of the stabilization.

9.1.2 Building Decontamination

The physical condition of the main mill building, along with the presence of radioactive contamination, required that an evaluation be made as to whether it would be less costly to demolish the structure and bury it in the tailings, or decontaminate the building to such a level that it would be available for unrestricted usage. The presence of broken, dilapidated or outmoded uranium processing equipment was another factor that was considered. Each piece of equipment would have to be evaluated on its own as to whether it could be utilized in a uranium milling operation elsewhere, or if it could be decontaminated and used in other operations. Costs are such that it would be less expensive to demolish, cut up and bury (on site) the structure than it would be to decontaminate it ($205,000 vs $267,500). Therefore, the main mill building would be demolished and buried within pond 1. It is also believed probable that decontaminating the structure for unrestricted use is not possible or possible only at a significantly greater cost.

The office building, because of its relatively good condition, would be decontaminated and could therefore be used for any other purpose. The estimated decontamination costs would be $10,000. The water tower would remain, and its superstructure would be decontaminated.

The remainder of the buildings on site and in the mill area, with the exception of the mobile equipment shop, would be demolished and buried within pond 1. The condition and contamination level of these buildings are such that it would be less expensive to remove the buildings rather than decontaminate them for unrestricted use ($27,000 vs $40,000). As with the main mill building, decontamination may not be possible or possible only at a higher cost.

9.1.3 Stabilization

After the grading and demolition activities have been completed, the site will have five areas where tailings are present: the sand tailings Area A; pond 1; pond 2; the area formerly occupied by pond 3, pond 4, and the East sand tailings pile; and the area of ponds 7, 8, and 9. This total area entails approximately 93 acres. Areas that have not been graded would be graded so that their surfaces would generally be convex in configuration. The maximum slope of these pile surfaces would be 3.0 to 1.

Next in the process would be the placement of a compacted 1.5-ft-thick layer of imported impervious clay over each of the five-pile areas. Then a total of 5 ft of imported earth would be placed over the clay. This material would have at least 60% of its composition made up of aggregate 3/4 in. to 5 in. in diameter. The finished surface of this cover would be contour-graded and terraced so as to reduce erosion[(1)] and assist in establishing vegetation. Radon flux reduction calculations are given in Appendix C.

The following step would be the protection of the dikes around the piles or ponds, or of other areas at the base of the piles that would be subject to surface water erosion. The areas of particular interest are the east side of Cottonwood Creek (west of the East sand tailings pile), the west side of Cottonwood Creek (east of the sand tailings area A), the side of the dikes of ponds 1 and 2 which face the Cheyenne River, and both sides of the drainage ditch to be graded along the east property line adjacent to the tailings areas. The proposed protection includes the placement of a layer of riprap, at least 1-ft thick and from 4 to 12 in. in diameter. The vertical height of such cover would reach an elevation of 3,435 ft along the Cheyenne River side of ponds 1 and 2; 3,435 ft in Cottonwood Creek by the East tailings pile; and 3,445 ft in Cottonwood Creek by the sand tailings area A. Riprap covering would be placed in order to eliminate bank erosion in areas subject to flooding. Along Cottonwood Creek the rock protection would have to extend up and downstream from the pile areas at least 400 ft or to where natural breaks in the stream flow occur.

The final step in the process would be the seeding of the surface of the stabilization with grasses and plants native to the area that could survive without irrigation.

9.1.4 Site Restoration

As a result of the grading, tailings consolidation and stabilization process, some areas will have large cavities left in the ground, such as the mill building site and sand tailings area B. These areas would be filled with clean earth so that the millsite would be in a usable condition with proper drainage. Some

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(1) See end of chapter for references.

gravel surfacing on the entry road to the site, which also serves the office building, would need to be replaced.

9.1.5 Security and Maintenance

The stabilized tailings areas would be enclosed within fencing, suitably posted with restricted area warning signs. Gates would be installed at suitable locations so as to provide access for maintenance and monitoring purposes. Physical maintenance to assure the integrity of the stabilization, the vegetation, the dikes and riprap, and the fencing would be required until such time as successful reclamation has been demonstrated.

9.1.6 Resulting Impacts, Advantages and Disadvantages

Choice of this alternative would result in the site reclamation meeting the minimum NRC criteria for existing uranium mills. The reclaimed tailings area would utilize slightly more than half of the site's approximately 213 acres. The rest of the site could be utilized for any other purpose. The water tower and the office building would remain.

Gamma radiation from the piles should be reduced to background levels and radon exhalation should be reduced to about twice background flux. Most of the negative effects associated with the tailings areas would be removed except for their physical presence, which would prevent use of the tailings area, and the possibility of slight seepage from the ponds.

After placement of riprap, the tailings piles along Cottonwood Creek and the Cheyenne River would be protected against normal runoff and probably would withstand the probable maximum flood. The stabilization cover and surface drainage system would be designed and constructed so that only minimum maintenace would be required. The work could be accomplished in about 120 working days, faster than any other alternatives.

A disadvantage is that the tailings would remain near a population center. Five separate storage areas on the site would require a relatively elaborate system to control access and use. Also, while the stabilization techniques suggested would be effective, they would not be as satisfactory and efficient in containing the contaminated material as would a storage system designed and constructed initially to meet NRC performance objectives.

9.1.7 Costs

As shown in Table 9-1, the cost of this alternative is estimated at $6,110,000. The major cost components are as follows:

(a)	Engineering (2% of item b)	$ 104,000
(b)	Remedial action	5,211,000

(c) Contingency (15% of items a and b)		797,000
	Total Cost	$6,110,000

If it were decided that all of the old mill buildings should remain on site and be decontaminated for unrestricted use, the estimated remedial action cost (item b above) would be increased by $71,000, with a resulting total cost of $6,180,000. This cost does not include any decontamination efforts on the equipment or machinery presently located within the main mill building.

9.2 ON-SITE TAILINGS CONSOLIDATION AND STABILIZATION, SITE DECONTAMINATION (ALTERNATIVE II)

This alternative is similar to Alternative I except that three of the tailings or pond areas would be consolidated onto two of the others, resulting in one tailings area which would be stabilized.

9.2.1 Site Grading and Tailings Area Consolidation

The tailings and other contaminated material of pond 1, pond 2, and sand tailings areas A and B would all be relocated onto ponds 7 and 8. A dome-shaped pile with gradual side slopes and surface would be formed to reduce erosion.(1) As described in Alternative I, pond 10 also would be relocated onto pond 7 and the East sand tailings area would be spread over ponds 3 and 4.

The debris from the site, as well as the rubble resulting from building demolition, and millyard decontamination would be placed into pond 7 along with the relocated tailings.

The drainage ditch along the east property line as described in Alternative I would be constructed, and likewise, Cottonwood Creek and the Cheyenne River would be decontaminated as required.

9.2.2 Building Decontamination

This work would be the same as that described for Alternative I, paragraph 9.1.2.

9.2.3 Stabilization

After the grading and demolition activities have been completed, the site would have only one area where tailings are present, the area now occupied by ponds 3, 4, 7, 8 and 9, and the East sand tailings pile. This total area consists of approximately 70 acres.

This resultant pile would be graded so that it would have a convex-shaped surface.

A 1.5-ft layer of imported impervious clay would be placed over the pile after which a 5-ft thick earth cover would be added. This cover would be applied as described in Alternative I.

Riprap would be placed along the bank of Cottonwood Creek by the East sand tailings area and on the base of the pile where erosion from normal runoff and the probable maximum flood may be likely as described in Alternative I. The surface of the pile would then be seeded with native plants and grasses.

9.2.4 Site Restoration

In addition to the work of site restoration as described in Alternative I, the voids left by removal of contaminated millsite materials and the relocation of ponds 1 and 2 and the sand tailings areas A and B would require some filling and grading so as to leave the site in a clean, usable condition.

9.2.5 Security and Maintenance

Security and maintenance would be the same as described in Alternative I, paragraph 9.1.5.

9.2.6 Resulting Impacts, Advantages and Disadvantages

Under this alternative, a total of about 75 acres (70+5 for access, buffer, and fence zones) would be utilized and held as a control area for tailings storage at the present location. Tailings would be removed from all but one side of Cottonwood Community and about 138 acres would be available for other uses.

Radon flux and gamma radiation would be greatly reduced and erosion would be controlled as outlined in Alternative I.[1] Contaminated areas would be completely removed adjacent to the Cheyenne River reducing the possibility of seepage and of flood transport of tailings from normal runoff and from a maximum probable flood in the Cheyenne River and Cottonwood Creek. With the construction of a bridge across Cottonwood Creek, Cottonwood Community would be accessible from the north. Overall, there would be a greater assurance of long-term stability relative to that obtainable with Alternative I.

The disadvantages are that the tailings would remain close to a population center. The cost is in excess of 1 million dollars more than Alternative I, at a net gain of only about 30 acres--or a cost-of-recovery of slightly over $33,000/acre.

9.2.7 Costs

As shown in Table 9-1, the cost of this alternative is $7,270,000. The major cost components are as follows:

(a) Engineering (2% of item b) $ 124,000

(b)	Remedial action	6,200,000
(c)	Contingency (15% of items a and b)	949,000
	Total Cost	$7,270,000

The costs for decontamination of existing structures instead of demolition would add $71,000 to (b) above, or result in a total cost of $7,360,000.

9.3 REMOVAL OF THE TAILINGS TO AN ALTERNATE DISPOSAL AREA (SITE 2, ALTERNATIVE III)

Under this alternative the tailings, the contaminated earth debris, and the building rubble resulting from the demolition of all on-site buildings, except the office building and mobile equipment shop, would be hauled to site 2 southeast of the Edgemont site. The present millsite and tailings areas would be left clean, decontaminated, and available for unrestricted use.

9.3.1 Excavation and Removal of Contaminated Materials and Tailings

Off-road earthmoving equipment would be used to load, haul and deposit at the alternate site all of the tailings, slimes and contaminated rubble, dikes and earth. These vehicles would follow an established route to and from the storage area so that spillage could be recovered. The number and size of vehicles available would determine the removal rate and the frequency of vehicles leaving the site. Recovery of the spillage would be more economical than attempting to cover or to wash down the equipment each time they left the tailings or storage areas. No difficulties should be experienced in removing most of the tailings material by this method. In some ponds and piles and at certain times of the year, if too much moisture were present in the tailings, use of a dragline system might be necessary. The tailings then could be either dried or loaded wet directly onto the transport vehicles.

During loading and moving operations and especially during the dry season of the year, site and haul road dust control methods would be employed.

All contaminated earth, dike materials, and sand and slime tailings would be removed from the Edgemont site. The total amount approximates 2,500,000 yd^3, or 3,960,000 tons. To move this amount of material to this site (2.5 mi average) and to haul it up an 8% grade in places would require about 2 yr with good weather. Implementing a 24-hr shift schedule, the work could be accomplished in approximately 8 mo.

To comply with the decontamination criteria for tailings piles, as described in Chapter 3, paragraph 3.6, the contaminated

soil beneath the piles must be removed. The amount of soil to be removed depends on the depth of contamination. The amount of contaminated soil to be removed at Edgemont has been estimated to be an average of 3 ft beneath all of the piles and ponds, except pond 10. The removal of the subsoil from beneath these ponds assures that the residual concentration in the remaining soil would be less than twice the background value of 1.3 pCi/g.

9.3.2 Building Decontamination

The work associated with this portion of the alternative would be as described in paragraph 9.1.2, except that the building rubble would be hauled by truck to the storage area.

9.3.3 Site Restoration

After the complete removal of the contaminated materials from the Edgemont site, there would be some excavations remaining on the site. These areas would be filled with imported clean material. The site would be graded and contoured to an elevation which would ensure proper drainage. The site would be made usable for other purposes. The millyard would likewise be filled, graded, and paved as required.

9.3.4 Disposal Area Development

This disposal area is located on an L-shaped, 120-acre parcel of federal government land. This land is administered by the BLM. The land is described in Chapter 8, paragraph 8.3.1.

The first step in the preparation of this area would be: the exact selection of the storage area within the site boundaries, the location of the 35-ft-high dam which would be required for containment of the approximately 50 acres of contaminated material, and the haul road required for access and unloading. It is believed that from within the storage basin selected, sufficient suitable material is available to construct the dike and to provide for most of the stabilization cover required. This material would be removed and stockpiled.

A 1-ft-thick impervious clay liner would be placed within the storage area. The contaminated tailings and materials would be deposited on top of this liner, after which a clay cap would be placed and compacted over deposited materials. Earthen materials previously stockpiled then would be placed over the clay cap to a thickness of 5 ft. Some imported rock would be mixed into the final surface of the pile and riprap added to the face of the pile. The final shape of the pile would be a gentle slope, contour-graded to minimize water erosion and to encourage the vegetative process. Upslope from the pile, permanent diversion ditches would be constructed to divert water around the pile.

The final step in the process would be the planting of all disturbed areas with grasses and plants that are native to the

area and which could survive without seasonal irrigation. Figure 9-1 illustrates a schematic representation of how this storage site would be developed.

9.3.5 Security and Maintenance

The Edgemont site would require no maintenance or security. The alternate site, however, would require periodic maintenance and monitoring similar to that for Alternatives I and II. On-site monitoring wells would be located at strategic places.

9.3.6 Resulting Impacts, Advantages and Disadvantages

The entire Edgemont site would be available for unrestricted use. The alternative disposal area land is already in federal government ownership. Economical, fast haul vehicles could be used to relocate the contaminated materials without disruption of normal traffic, and no hauling of such materials would be required through any populated areas. With the use of the storage techniques suggested, the proposed alternate location would provide for safe tailings disposal with only minimum maintenance required. The site is well isolated from the populace and is in an area where no growth (infringement) is expected. Thus, most of the NRC performance objectives would be met.

The disadvantages are that perhaps 60 acres of land now used for intermittent or seasonal range grazing would be lost, and that implementation of this alternative is $4 to $5 million more costly than stabilizing the tailings in place.

9.3.7 Costs

As shown in Table 9-1, the estimated total cost is $10,790,000. The major cost components are as follows:

(a)	Engineering (2% of item b)	$ 184,000
(b)	Remedial action	9,200,000
(c)	Contingency (15% of items a and b)	1,410,000
	Total Cost	$10,790,000

Should it be decided that all of the old mill buildings remain at Edgemont and be decontaminated for unrestricted use, the estimated remedial action cost (item b above) would be increased by $71,000, with a resulting total cost of $10,865,000. This cost does not include any decontamination efforts on the equipment or machinery presently located within the main mill building.

The cost for removal of contaminated subsoil below the 3-ft average depth used in the cost estimate would be $660,000 per additional foot of depth in all tailings areas.

9.4 REMOVAL OF THE TAILINGS TO AN ALTERNATE DISPOSAL AREA (SITE 6, ALTERNATIVE IV)

This alternative is the same as Alternative III, except that the tailings, rubble, and contaminated material would be removed by truck to a disposal area 5.3 mi northwest of Edgemont.

9.4.1 Excavation and Removal of Contaminated Materials and Tailings

Based upon site examination and a review of the physical properties of the tailings, it appears that no difficulties should be encountered in loading the tailings for removal purposes. The contractor performing this work will be able to use any number of conventional loading methods, i.e., front-end tractor loaders, conveyor belt feed to overhead loading, etc. Because of the volumes and scattered locations involved, a loading system utilizing a number of earth and tailings loading techniques probably will be developed. As in Alternative III, a dragline may be required to load some of the tailings because of their moisture content and the unstable conditions on the pile or pond for loading vehicles. The debris on the site, as well as building material rubble, will be loaded by cranes onto flat-bed or high-side boarded dump trucks so that it can be transported to the disposal site without spillage of contaminated material enroute. There is ample room on the tailings site for fast loading and easy truck access.

9.4.2 Hauling and Placing of the Materials

Considering the distance and route required, truck transportation appears to be the most economical means to haul materials to this disposal area. Trucks could move the materials at a rate of about 6,000 tons/day, or 12 truckloads/hr, based upon the loading systems used and traffic capacities on the road to the disposal site. At this rate, on a 5-days-per-week, 10-months-per-year basis, all materials could be removed in approximately 3.3 yr. This method assumes the use of conventional truck and/or truck-trailer combinations. Rapid drying of the tailings and lack of moisture in the native earth during certain seasons of the year would require the use of dust preventative methods in the excavation and loading process. Dust control measures, such as heavy rubber covers and washdown facilities for the trucks, are included in the trucking costs. No costs are included for repair and maintenance of public roads.

Most of the ore processed at the Edgemont site was hauled to the mill along the same road suggested for hauling the tailings to site 6. Therefore, no difficulty is expected in using this road which is locally referred to as County Road 10. During the dry seasons, road dust control is expected to be necessary, which is included in the costs.

In leaving the Edgemont site, leading north to the storage areas, trucks could encounter slowdown problems due to a narrow

road leaving the site to where it meets U.S. Highway 18. There, a stop sign and a right-hand turn leading onto U.S. Highway 18 could be a bottleneck. By the time remedial action is under way, a local traffic problem will have been solved with the completion of a new alignment of U.S. Highway 18 around Edgemont which will eliminate traffic that now backs up several times a day because of trains crossing the road. The haul contractor may find it economical to construct a temporary haul bridge and road bypass which would cross over the Cheyenne River at the northwest corner of pond 2.

9.4.3 Building Decontamination

This work would be the same as that in Alternative III, paragraph 9.3.2.

9.4.4 Site Restoration

This work would be the same as that described in Alternative III, paragraph 9.3.3.

9.4.5 Disposal Site Development

This disposal site is located in a natural basin on privately owned land. It is on the east side of, and parallel to, the haul road, and is described in Chapter 8, paragraph 8.3.2. The procedures for preparing this site for storage of the contaminated materials would be the same as that described in Alternative III, paragraph 9.3.4. This site does not have the deep basin formation, nor the natural dam abutments that site 2 has. Consequently, a longer, lower dike would be required, about 26 ft high and some 300 ft long. Approximately 60 acres would be required to store the material at an average depth of 26 ft. Truck access for unloading would be very easy, as would access back onto the county road for the return trip to the site. The large, unrestricted area and low grade of the disposal site would make for quick and economical unloading. Figure 9-1 illustrates the disposal site preparation and filling procedures.

9.4.6 Security and Maintenance

This effort would be the same as the one outlined in Alternative III, paragraph 9.3.5.

9.4.7 Resulting Impacts, Advantages and Disadvantages

The Edgemont site would be available for unrestricted use. The main advantage of this site is its location with respect to the haul road. At the new site most of the NRC performance objectives would be met.

The disadvantages are that the trucks departing from and returning to the Edgemont millsite every 5 min would create a

traffic problem at the entrance to the present highway just east of the railroad crossing. The new bypass highway north of Edgemont will alleviate some of this disruption. Construction of a temporary bridge over the Cheyenne River directly north of the site would expedite truck traffic to and from the site.

The site is privately owned which is a disadvantage. More land is used for cattle rangeland at this site than at site 2, and it also is closer to existing and potential populations. Its orientation is to the northwest which is not as favorable in re-establishing plant growth as is the southeast exposure of site 2.

9.4.8 Costs

As shown in Table 9-1, the estimated total cost is $15,525,000. The major cost components are as follows:

(a)	Engineering (1.5% of item b)	$ 200,000
(b)	Remedial action	13,300,000
(c)	Contingency (15% of items a and b)	2,025,000
	Total Cost	$15,525,000

The costs for decontamination of existing structures instead of demolition would add $71,000 to (b) above, or result in a total cost of $15,600,000.

The cost for removal of additional contaminated subsoil below the estimated 3 ft would be $900,000 per additional foot.

9.5 REMOVAL OF THE TAILINGS TO AN ALTERNATE DISPOSAL AREA (SITE 7, ALTERNATIVE V)

This alternative is the same as Alternative III, except that the tailings, rubble, and contaminated materials would be removed by truck to a disposal site 10.6 mi northwest of Edgemont in the Burdock area.

9.5.1 Excavation and Removal of Contaminated Materials and Tailings

All of the work involved in excavation, loading, hauling, and placing of the contaminated materials and tailings, as well as the work required in the decontamination of the buildings on site at Edgemont and the restoration of the site, would be as described in Alternative IV, paragraphs 9.4.1 through 9.4.4.

Because of the increased distance, the required time to remove the tailings would be twice as long as in Alternative IV, unless additional trucks were used. Considering traffic conditions and the probability of too much traffic on the unpaved country road, the volume could be increased to 8,000 tons/day. The

time to remove all the tailings would require about 2.5 yr. If a feasible number of trucks were used to haul the materials over a 24-hr/day period, then 12,000 tons/day could be moved requiring a total time of 1.67 yr, considering that weather conditions would halt the process during at least 2 mo/yr.

9.5.2 Disposal Site Development

This disposal site is located in a natural drainage basin on privately owned land. Two hills and a small ridge from the upslope portion of the site are described further in Chapter 8, paragraph 8.3.3. The procedures used for preparing this site would be the same as those for Alternative III, paragraph 9.3.4. This site would require a containment dike on its upslope (northwest) edge and a long dike of approximately 1,300 ft along its southeast edge. Approximately 70 acres would be required to contain all the materials at the Edgemont site to an average depth of 20 ft. The configuration of the disposal site does not lend itself to using less acreage to greater depths.

A haul road of approximately 0.5 mi would have to be constructed to gain access to the site from what is known locally as County Road 10.

Figure 9-1 illustrates the disposal site preparation and filling procedures.

9.5.3 Security and Maintenance

This effort would be the same as that for Alternative III and as described in paragraph 9.3.5.

9.5.4 Resulting Impacts, Advantages and Disadvantages

As in all other alternatives in which the tailings are removed from the Edgemont site, this approach leaves that site available for unrestricted use. One advantage of this site is its proximity to possible subsequent uranium mining and milling, and future tailings storage development. In suggesting such an alternative location for the Edgemont tailings, it was believed advisable to locate all such activity in one area, away from a population center. The possible disposal area could be enlarged to hold all of the Edgemont tailings as well as any newly generated ones. The TVA has suggested that, should their operations in this area materialize, a tailings pond area would be developed in the vicinity. Site 16 is 0.25 mi east of this site, and is in the area that the TVA has considered for a tailings area. The reason that this report suggests site 7 instead, is because of its size; it can contain all existing and potential tailings, whereas site 16 could not without extensive dike and site preparation. Also, site 7 has a natural storage basin configuration and it faces to the southeast making the revegetative process more successful than one facing the southwest. Most of the NRC performance objectives would be met.

The disadvantages of this site are its haul distance from the Edgemont site, the higher haulage costs, the more extensive site preparation costs which are more than at any of the other alternative storage sites, and private ownership of the land. Traffic problems would be the same as those discussed in paragraph 9.4.7.

9.5.5 Costs

As shown in Table 9-1, the estimated total cost is $18,970,000. The major cost components are as follows:

(a)	Engineering (1.5% of item b)	$ 244,000
(b)	Remedial action	16,250,000
(c)	Contingency (15% of items a and b)	2,474,000
	Total Cost	$18,970,000

The cost for decontamination of existing structures instead of demolition would add $71,000 to (b) above and result in a total cost of $19,040,000.

The cost for removal of additional contaminated soils below the estimated 3 ft would be $1,050,000 per additional foot.

9.6 REMOVAL OF THE TAILINGS TO AN ALTERNATE DISPOSAL AREA (OPEN-PIT MINE, SITE 8, ALTERNATIVE VI)

This alternative is the same as Alternative III, except that the tailings, rubble and contaminated material would be removed by truck and stored in an open-pit mine, 12.4 mi northwest of Edgemont in the Burdock area.

9.6.1 Excavation and Removal of Contaminated Materials and Tailings

All of the work involved in excavation, loading, hauling, and placing of the contaminated materials and tailings, as well as the work required in the decontamination of the buildings on site at Edgemont and the restoration of the site would be as described for Alternative V, paragraph 9.5.1.

9.6.2 Disposal Site Development

It is suggested that one of the several pits known locally as the Darrow pits could be used. Either pit No. 1 and 3 or pit No. 5 are large enough to contain all the contaminated materials and debris from the Edgemont millsite without further excavation. Also, there is ample overburden stockpiled adjacent to the pits which would be used for stabilization cover.

There already exist haul roads to the site from County Road 10 which previously were used to haul ore from the pits to the Edgemont mill. These roads would need to be improved to handle the volume of truck traffic which would be generated with selection of this site.

The exposed formations may be sufficiently impermeable to prevent leaching into aquifers, without the necessity of adding a clay liner. However, since data necessary to make a definite conclusion do not exist, it is assumed that clay liners would be used. The clay liner first would be deposited in the bottom and up the sides of the pit as the filling operations proceed. Note that it might be possible to deposit tailings in the pit without a clay liner after backfilling to above the water table; however, this would require further study.

Trucks hauling the contaminated material to this site could drive directly into the pit to unload the material, or an unloading system utilizing a floating boom with a conveyor belt might be developed.

After deposition into the pit, all contaminated materials would be covered with a 1.5-ft layer of impervious clay and a minimum of 5 ft of stabilization cover (overburden). At this point, the elevation should be approximately even with surrounding ground surfaces. Grading would be used to smooth the surface and to divert drainage both off and around the site in the case of any upslope drainage in the area. Natural vegetation would be planted on the surface of the pit.

9.6.3 Security and Maintenance

The storage pit would be enclosed with a 6-ft-high chainlink fence with access gates. Because the storage area is located within a pit, a very minimum amount of physical maintenance is anticipated. Radiation monitoring wells would be located downslope from the storage pit and in other locations where the radiological and hydrological monitoring could be accomplished.

9.6.4 Resulting Impacts, Advantages and Disadvantages

The Edgemont site would be available for unrestricted use and the NRC performance objectives would be met. Periodic sampling of monitoring wells is specified until it is determined that seepage is not occurring.

Advantages of utilizing the open-pit mine as a storage site are many: utilizing the land for a useful purpose; economy in disposal site preparation; smaller disposal area required; removing the hazard of an unreclaimed open pit; isolation from populated areas; minimal maintenance; and no erosion of contaminated materials to the countryside.

The disadvantages are: the haul distance and the associated costs, the private ownership of the site, and the elimination of the possibility of further mining in the pits if uranium-bearing ores are still present. TVA has identified reserves of uranium mineable through adits off the bottom of the Darrow pits. Traffic problems would be the same as those discussed in paragraph 9.4.7.

9.6.5 Costs

As shown in Table 9-1, the estimated total cost is $16,230,000. The major cost components are as follows:

(a)	Engineering (1.5% of item b)	$ 210,000
(b)	Remedial action	13,900,000
(c)	Contingency (15% of items a and b)	2,116,000
	Total Cost	$16,230,000

The cost for installation of the clay liner was estimated at $800,000. If it is possible to deposit tailings in the pit without a clay liner (after backfilling to above the water table) the cost for this option would be reduced to $15,920,000.

The cost for decontamination of existing structures instead of demolition would add $71,000 to (b) above, and would result in a total cost of $16,300,000.

The cost for removal of additional contaminated soils below the estimated 3 ft would be $950,000/ft.

9.7 ANALYSES OF COSTS AND BENEFITS

As summarized in Table 9-1, the total estimated costs for the six remedial action alternatives vary from a low of $6,110,000 to a high of $18,970,000. The purpose of this section is to compare the cost of the various alternatives with the corresponding anticipated benefits.

9.7.1 Health Benefits

Each of the remedial action alternatives considered in this chapter has an associated number of health effects that would be avoided as a result of the action. These avoided health effects are referred to as health benefits. In Chapter 3 the estimated number of health effects was determined for the Edgemont site in its present condition. In order to estimate the number of health benefits attributable to a particular remedial action, the effect of that remedial action on radon exhalation from the site must be determined, because the health effects calculated in Chapter 3 were associated with radon and its daughters.

In this evaluation, the health benefit of each alternative is calculated from the reduction in radon exhalation that is expected for that alternative. For example, if the radon exhalation and, hence, the number of health effects are reduced by 90% for a particular remedial action, there will be a corresponding health benefit. This health benefit is equal to 90% of the number of health effects that would be expected had the remedial action not been implemented. The radon exhalation is reduced by cover material or by physical removal of the tailings to an isolated location. In the case of cover material, the estimated resulting radon exhalation is twice the background radon flux. Physical removal of the tailings results in essentially a 100% reduction in exposure to the population.

The results of the determination of potential cancer cases avoided (health benefits) for each option are given as a function of time in part A of Table 9-2. Alternatives I and II include stabilization of the tailings at the Edgemont site with reduction of radon exhalation flux to twice the background flux in the vicinity. The slight difference in health benefits results from differences in the area covered by the tailings after the remedial actions are completed. The tailings would be moved and the site decontaminated under Alternatives III through VI resulting in the avoidance of all pile radon-induced health effects. The cost per potential cancer case avoided for each alternative is included as part B in Table 9-2.

Another presentation of the data in Table 9-2 is the number of potential cancer cases avoided per million dollars expended as shown in Figure 9-2. Alternatives I and II yield the highest health benefit per unit cost. In contrast, Alternative V yields the lowest benefit per unit cost.

9.7.2 Land Value Benefits

The Edgemont site would most probably find use as industrial property, considering its proximity to the Burlington Northern Railroad and the municipal sewage lagoon. If the entire property were available for unrestricted use, the market value could reach approximately $1,500/acre. Thus, the land value benefit from Alternatives III through VI would be an increase of about $1,350/acre for 213 acres or about $290,000.

Alternatives I and II would have lesser benefits because only 120 to 140 acres would be available for unrestricted use.

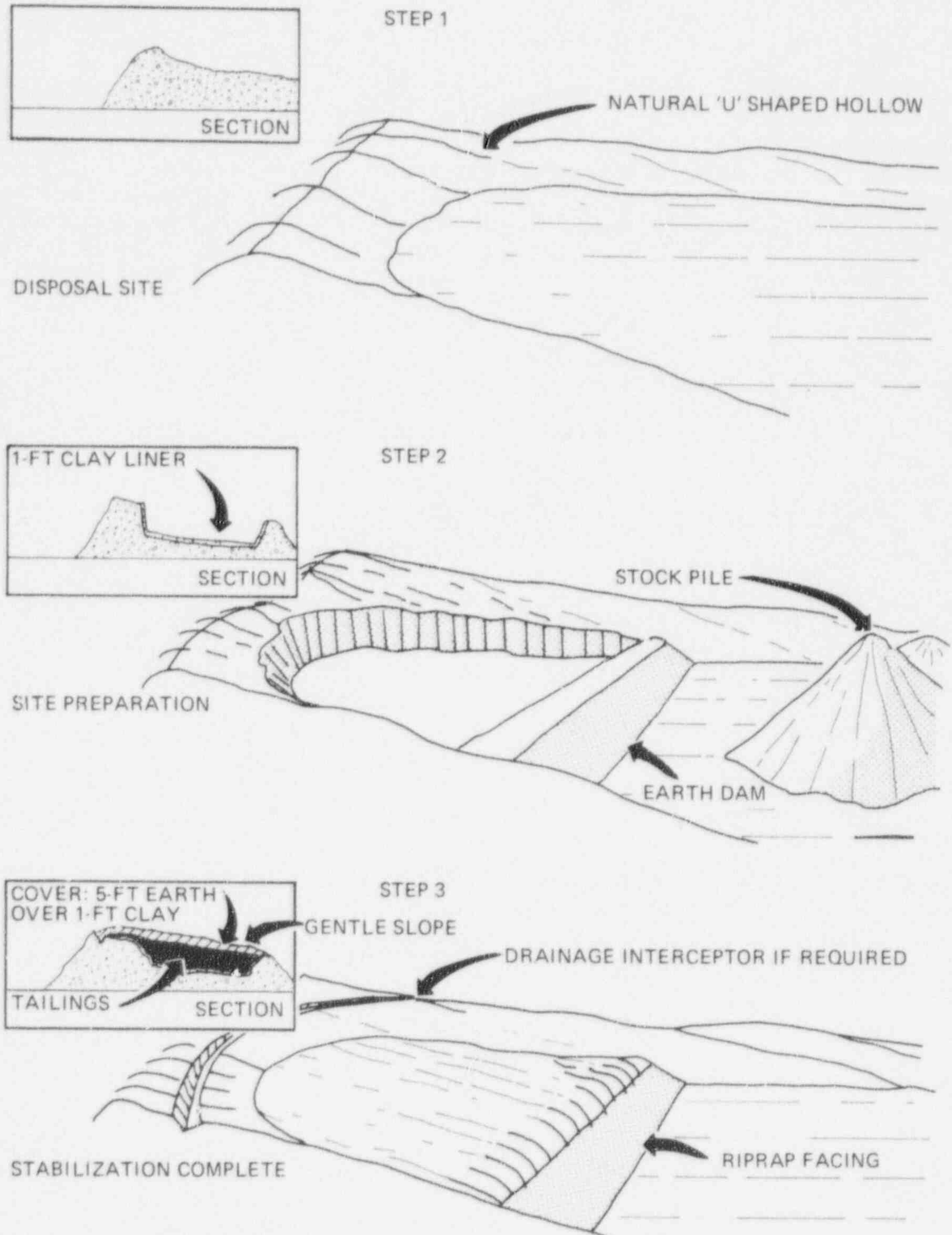

FIGURE 9-1. SCHEMATIC OF TYPICAL TAILINGS DISPOSAL SITE

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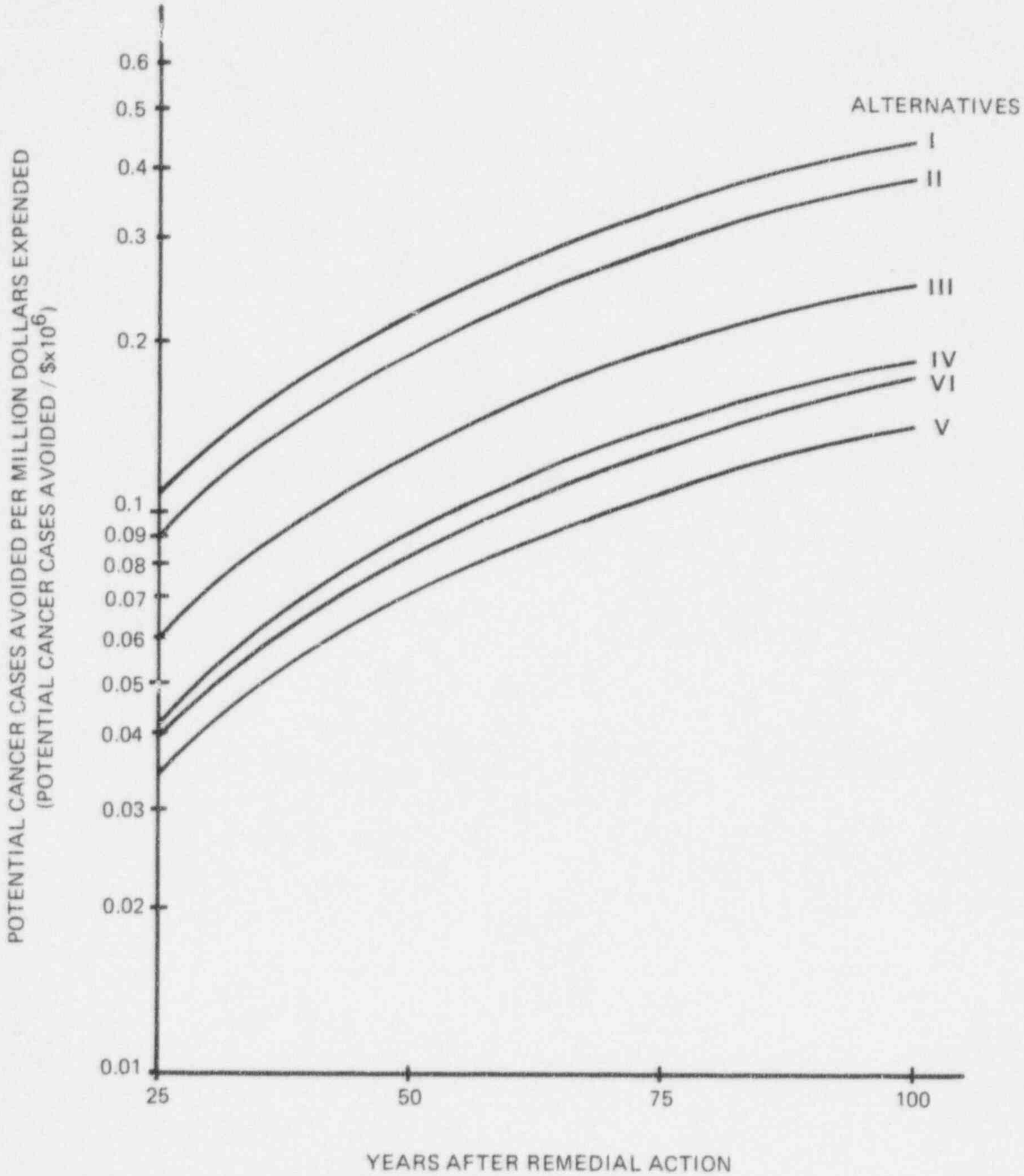

FIGURE 9-2. POTENTIAL CANCER CASES AVOIDED PER MILLION DOLLARS EXPENDED

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TABLE 9-1

COST ESTIMATE SUMMARY

Alternative No.	Description	Alternative Cost	Cost per ft for Removal of Contaminated Soil Beyond 3 ft Below Interface
I	Tailings remain on Edgemont site, mill structure demolition and burial, decontamination of millsite grounds, stabilization of pond/piles in place, erosion protection	6,110,000	--
II	Same as I, except tailings pond/piles consolidated prior to stabilization	7,270,000	--
III*	Complete site decontamination, removal of all tailings and other contaminated materials to site 2, 2.5 mi S.E.	10,790,000	600,000
IV*	Same as III, except tailings removed to site 6, 5.3 mi NW	15,525,000	900,000
V*	Same as III, except tailings removed to site 7, 10.6 mi NW	18,970,000	1,050,000
VI*	Same as III, except tailings removed to site 8, 12.4 mi NW	16,230,000	950,000

Notes: 1. All costs are in 1978 dollars.

2. The costs of the alternatives do not include the estimated costs for off-site remedial actions. These costs are the same for all alternatives and are $200,000 for off-site structures and $50,000 for off-site open lands.

*Involves removal of all contaminated materials from the Edgemont site to an alternate disposal site and includes the demolition of structures which remain, except the office building and mobile equipment shop.

TABLE 9-2

POTENTIAL CANCER CASES AVOIDED AND COST PER POTENTIAL CANCER CASE AVOIDED

A. NUMBER OF POTENTIAL CANCER CASES AVOIDED

Alternatives:	I	II	III	IV	V	VI
Alternative Costs (in million $)	6.11	7.27	10.79	15.53	18.97	16.23
Years After Remedial Action*						
25	0.64	0.64	0.65	0.65	0.65	0.65
50	1.37	1.37	1.39	1.39	1.39	1.39
75	2.09	2.10	2.13	2.13	2.13	2.13
100	2.81	2.82	2.87	2.87	2.87	2.87
Potential Cancer Cases After 100 yr	0.06	0.05	0	0	0	0

B. COST PER POTENTIAL CANCER CASE AVOIDED (Million $)

Alternatives:	I	II	III	IV	V	VI
Alternative Costs (in million $)	6.11	7.27	10.79	15.53	18.97	16.23
Years After Remedial Action						
25	9.5	11	16.6	24	29	25
50	4.5	5.3	7.8	11	14	12
75	2.9	3.5	5.1	7.3	8.9	7.6
100	2.2	2.6	3.8	5.4	6.6	5.7

*Based on double population in 10 yr, followed by annual growth of 0.16% for 15 yr, and then constant population for 75 yr.

APPENDIX A

DETAILED RADIOLOGICAL ASSESSMENT

When evaluated in conjunction with Chapter 3, the information presented in Appendix A permits detailed analysis of the radiological impact of the Edgemont millsite. Calculations of radiation doses have been made for radionuclides and receptors around the site.

A.1 AIR PATHWAY

In analyzing the effects of contaminant transport via the air pathway, both gaseous and particulate transport were considered.

A.1.1 Radon

The model used for diffusion/dispersion transport is the gaussian plume dispersion technique described by Slade,[1] integrated over the area source. The concentration at any point,(x,y) resulting from a differential element source QdA can be described by:

$$C(x,y) = \frac{10^{-3} Q dA f_i}{\pi \sigma_y \sigma_z u_i} \exp\left[\frac{-h^2}{2\sigma_z^2} - \frac{y^2}{2\sigma_y^2}\right] \qquad \text{(A-1)}$$

where,

- $C(x,y)$ = Concentration of radon at point (x,y) (pCi/l)
- Q = Source flux ($pCi/m^2/sec$)
- dA = Differential area element (m^2)
- σ_y = Lateral dispersion coefficient (m)
- σ_z = Vertical dispersion coefficient (m)
- u_i = Wind speed (m/sec)
- h = Elevation of source release (m)
- x = Downwind distance (m)
- y = Distance from plume centerline (m)
- f_i = Frequency for direction i and each stability category

In the calculation of radon concentrations in the vicinity of the Edgemont tailings, three equivalent cylindrical piles are used to represent the radon source from the tailings. The areas and positions of these composite piles are shown in Figure 3-3, Chapter 3. Equation (A-1) is integrated over the areas of the piles. The radon source term, Q, is calculated from the radium concentration data with the following expression:

$$Q = \frac{10^4 D q R E \rho}{P} \tanh qt \qquad \text{(A-2)}$$

where,

- D = Effective diffusion coefficient (0.028 $cm^2 sec$)
- q = $(\lambda P/D)^{1/2}$
- λ = Radon decay constant (sec^{-1})
- P = Porosity of tailings (0.4)
- E = Emanating power (0.20)
- R = Average ^{226}Ra concentration of tailings (pCi/g)
- t = Depth of tailings (cm)
- ρ = Density of tailings (1.6 g/cm^3)

Table A-1 contains the values of key parameters for the composite piles. The total annual average radon concentrations are presented

in Table A-2. The locations given in the table are shown in Figure 3-13, Chapter 3.

A.1.2. Air Particulates

The air pathway model is also used to calculate the concentration of radioactive particulates in air. The effect of particulate deposition is accounted for by the depletion fraction presented in Reference 1, through the expression:

$$\frac{Q'}{Q} = \left[\exp\int_0^x \frac{dx}{\sigma_z \exp(h^2/2\sigma_z^2)}\right]^{-\sqrt{\frac{2}{\pi}}\frac{v_d}{u}} \qquad \text{(A-3)}$$

where Q' is the effective source flux corrected for particle deposition and v_d is the deposition velocity (0.01 m/sec).

The above equation was evaluated numerically using analytical approximations for the values of σ_z.

The particulate source, Q, was determined from comparisons with experimental data at the Edgemont site.(2) The Windspeed dependence of the source term was assumed to be described by the following function:

$$Q = K_1 R u^a$$

where R is the concentration of the nuclide in the tailings (Ci/g).

The K_1 and a were then varied until the calculation of the airborne concentrations of ^{226}Ra for the known experimental conditions was identical to the least squares fit of the available TVA data. The data used and the curve of least squares fit are shown in Figure A-1. The calculated concentrations are identical to the least squares fit.

The resulting expression for Q is given by

$$Q = (4.7 \times 10^{-6})\ Ru^{2.6},\ Ci/m^2/sec \qquad \text{(A-4)}$$

The annual deposition flux F(x,y) was determined by the relation:

$$F(x,y) = C(x,y)\ v_d\ (3.16 \times 10^7),\ Ci/m^2/yr$$

Because of the irregular geometry of the Edgemont site, it was necessary to model the site as several cylindrical and annular sources at different locations, with different characteristics. Composite pile dimensions are given in Table A-1. Airborne concentrations at representative points away from the site resulting from each of the several sources were determined and the individual contributions added to produce the total particulate con-

centrations. The results for ^{226}Ra are given in Table A-2. Corresponding concentrations of ^{238}U, ^{234}U, ^{230}Th, and ^{210}Pb differ from those of ^{226}Ra by the nuclide concentrations in the tailings (Chapter 3).

A.1.3 Annual Dose Commitments

Annual dose commitments are obtained from the usage factors and dose conversion factors in Reference 3. For radon, 1 pCi/l = 1 rem/yr. The results are shown in Tables A-3 and A-5.

A.2 WATER PATHWAY

Specific water pathways investigated include, input to Cottonwood Creek, ground water contamination of a well at nearest permanent resident and surface and ground water releases to the Cheyenne River with subsequent maximum man-uses.

Releases to Cottonwood Creek

Possible releases of ^{226}Ra to Cottonwood Creek are estimated from mass and concentration flow data. The location of flow and concentration monitor points are shown in Figure 2-11, Chapter 2. A flow balance along the creek yields:

$$W_x = W_3 - W_1 - W_2 - W_s \quad \text{(A-5)}$$

where,

W_i = water flow rate at location i (i=1,2,3)
W_s = flow rate from sewage pipe
W_x = possible unknown flow rate (such as ground water).

Table 2-2 contains the values of W_1, W_2 and W_3 that were measured in this work. The value of W_s was about 75 gpm. The sum of W_1, W_2 and W_s is equal to W_3 to within experimental uncertainty.

The concentration balance gives:

$$C_x W_x = C_3 W_3 - C_s W_s - C_1 W_1 - C_2 W_2 \quad \text{(A-6)}$$

Using ^{226}Ra concentrations given in Figure 3-14, Chapter 3.

$$C_x W_x = 27.5 - 21.1 - 14.4 - 16.2$$

$$C_x W_x \lesssim 0 \text{ pCi/sec}$$

Therefore, the dominant source of ^{226}Ra in Cottonwood Creek is the city and sewage overflow.

Even if as much as 1 pCi/l of ^{226}Ra were attributed to the piles, the potential exposure to a maximum man is negligible. Equation (1) of Reference 3 is:

$$\text{Dose} = 1100 \frac{U_{ap} \, M_p \, Q \, D_f}{F} \qquad \text{(A-7)}$$

where,

U_{ap} = intake rate (l/yr)
M_p = mixing ratio at point of exposure
Q = release rate (Ci/yr)
D_f = dose factor (mrem/pCi)
F = flow rate of liquid effluent (ft^3/sec)

Then,

$$\text{Dose} = 1100 \frac{(730)\ (7.1\text{x}10^{-3})\ (5.6\text{x}10^{-7})\ (3\text{x}10^{-2})}{0.63}$$

Dose = 1.5×10^{-4} mrem/yr.

Ground Water from Pile 7 to Nearest Resident

In this investigation, the following second-order differential mass balance equations are used to describe nuclide migration in a two region ground water medium:

$$D\frac{\partial^2 C_1}{\partial x_1^2} - V_1\frac{\partial C_1}{\partial x_1} - K\frac{\partial C_1}{\partial t_1} - K\lambda_d C_1 = 0$$

and (A-8)

$$D\frac{\partial^2 C_2}{\partial x_2^2} - V_2\frac{\partial C_2}{\partial x_2} - K\frac{\partial C_2}{\partial t_2} - K\lambda_d C_2 = 0$$

where,

D = dispersion coefficient (m^2/s)
C = nuclide release rate (Ci/yr)
V = water velocity (m/sec)
λ_d = decay constant (yr^{-1})
K = equilibrium sorption coefficient
x = distance along the region (m)
t = time (yr)

Because studies of ground water flow in soils suggest axial convection and dispersion are much greater than transverse convection and dispersion, a one-dimensional transport path is assumed.

The boundary condition needed to solve the mass balance equation in the first region is provided by the expression for the leach rate of radium (10^{-5} yr^{-1})(4) in the tailings pile, i.e.,

$$C_1\ (x_1 = 0, t_1) = \lambda_L I_o \exp\ (-\lambda_E\ t_1) \qquad \text{(A-9)}$$

where,

I_o = initial inventory (Ci)
λ_L = leach rate (yr^{-1})
$\lambda_E = \lambda_L + \lambda_d$
= inventory total loss constant (yr^{-1})
λ_d = decay constant (yr^{-1})

The boundary condition for the second region is the release rate from the first region, which is approximated by the expression

$$C_2\ (x_2 = 0, t_2) = Ae^{-a(t_2-\tau)} - Be^{-b(t_2-\tau)} \qquad \text{(A-10)}$$

where,

$t_2 > \tau$
τ = arrival time at $x_2 = 0$ (yr)

A,B,a,b = constants determined by the form of the transient at the outlet from region 1.

Using these boundary conditions, the solutions to the mass balance equation for the two regions are found to be

Region 1:

(A-11)

$$C_1\ (x_1,t_1) = \frac{\lambda_L I_o}{2}\left\{\exp\left[\frac{V_1x_1}{2D} - \lambda_E t_1 - G_1x_1\right]\operatorname{erfc}\left[\frac{\sqrt{\frac{K}{D}}\,x_1 - 2\sqrt{\frac{D}{K}}\,G_1t_1}{2\sqrt{t_1}}\right] + \exp\left[\frac{V_1x_1}{2D} - \lambda_E t_1 + G_1x_1\right]\operatorname{erfc}\left[\frac{\sqrt{\frac{K}{D}}\,x_1 + 2\sqrt{\frac{D}{K}}\,G_1t_1}{2\sqrt{t_1}}\right]\right\}$$

where,

$$G_1 = \sqrt{\frac{V_1^{\,2}}{4D^2} - \frac{K(\lambda_E - \lambda_d)}{D}}$$

and

$$\operatorname{erfc}(y) = 1 - \frac{2}{\sqrt{\pi}}\int_o^y e^{-z^2}dz$$

Region 2:

(A-12)

$$C_2\ (x_2,t_2) = \frac{1}{2}\left\{A\ \exp\left[\frac{V_2x_2}{2D} - a(t_2-\tau) - G_2x_2\right] \text{erfc}\left[\frac{\sqrt{\frac{K}{D}}\ x_2-2\sqrt{\frac{D}{K}}\ G_2t_2}{2\sqrt{t_2}}\right]\right.$$

$$-B\ \exp\left[\frac{V_2x_2}{2D} - b(t_2-\tau) - G_3x_2\right] \text{erfc}\left[\frac{\sqrt{\frac{K}{D}}\ x_2-2\sqrt{\frac{D}{K}}\ G_3t_2}{2\sqrt{t_2}}\right]$$

$$+A\ \exp\left[\frac{V_2x_2}{2D} - a(t_2-\tau) + G_2x_2\right] \text{erfc}\left[\frac{\sqrt{\frac{K}{D}}\ x_2+2\sqrt{\frac{D}{K}}\ G_2t_2}{2\sqrt{t_2}}\right]$$

$$\left.-B\ \exp\left[\frac{V_2x_2}{2D} - b(t_2-\tau) + G_3x_2\right] \text{erfc}\left[\frac{\sqrt{\frac{K}{D}}\ x_2+2\sqrt{\frac{D}{K}}\ G_3t_2}{2\sqrt{t_2}}\right]\right\}$$

where,

$$t_2 = t_1 - \tau\ \text{(yrs)}$$

$$G_2 = \sqrt{\frac{V_2^{\ 2}}{4D^2} - \frac{K(\lambda-a)}{D}} \qquad \text{(A-13)}$$

$$G_3 = \sqrt{\frac{V_2^{\ 2}}{4D^2} - \frac{K(\lambda-b)}{D}}$$

This model was used to calculate the maximum ^{226}Ra concentration in well water at the location of the nearest residence. As discussed in paragraph 2.7.3, Chapter 2, an intergranular velocity of 6.8 m/yr was used in the calculations. The parameters used in the calculations and the results are given in Table A-4. The equilibrium sorption coefficient K, as used in the code, is dimensionless. The maximum possible ^{226}Ra concentration in the water was derived from the average ^{226}Ra concentration in the tailings and the sorption coefficient. A water well location was assumed at a location near the first street west of the pond 7 dike. The calculated ^{226}Ra concentration in the water well is given in Table A-4 and the calculated ingestion doses from ^{226}Ra and ^{230}Th to the whole body and to the bone. The highest calculated dose was

12 mrem/yr to the bone from ^{226}Ra. The water pathway to a well in Cottonwood Community is not the critical pathway.

Ground Water from Pile 1 to Cheyenne River

Another estimate of the potential ^{226}Ra release to the Cheyenne River was made by multiplying the ^{226}Ra concentrations in ground water samples from well M1 and M3 (about 1 pCi/l above background), by the estimated ground water flow rate (GW) under pile 1. The GW is given by

$$GW = v_3 wh \qquad (A-14)$$

where,

v_3 = ground water velocity under pile 1 (15.8 m/yr)

w = width of pile 1 (300 m)

h = height of aquifer (1 m)

This gives a value of 4.7×10^6 l/yr for GW, which results in a potential release rate of 4.7×10^{-6} Ci/yr for ^{226}Ra into the river. Application of Equation (A-7) yields:

$$Dose = 1.3 \times 10^{-3}$$

This pathway is also not a critical pathway.

A.3 FOOD PATHWAY

Radioisotopes can enter the human body through the ingestion of meat containing radioactive materials. Radioisotopes enter the meat-ingestion pathway by direct deposition on, and by uptake through the roots of, grass used as feed for beef cattle.

Cattle graze in pastureland adjacent to the Edgemont site. Vegetation samples were obtained in this area (Figure 3-21, Chapter 3). The potential dose commitment to man from the ingestion of beef grazing on this land is estimated using Equation (A-15):

$$Dose = U_a \cdot F_a \cdot C_a \cdot Q_a \cdot D_a \cdot W_v \qquad (A-15)$$

where,

U_a = Consumption rate of beef (90 kg/yr)
F_a = Element transfer factor (0.034 days/kg)
C_a = Concentration of isotope in vegetation (1.1 pCi/g dry weight above background value)
Q_a = Vegetation consumption rate (50 kg/day)
W_v = Vegetation dry-to-wet weight ratio (0.05)
D_a = Ingestion dose factor (mrem/pCi)

The value for U_a is obtained from Reference 5. The values of C_a and W_v are from the experimental data (Figure 3-21, Chapter 3), and the other values are from Reference 3. Solution of Equation (A-15) for ^{226}Ra yields:

$$\text{Dose} = \begin{matrix} 250 \text{ mrem/yr (bone)} \\ 25 \text{ mrem/yr (whole body)} \end{matrix}$$

This is the critical pathway for ingestion.

This potential dose commitment is applicable to a rancher who might slaughter one of his own cattle and eat meat only from an animal grazing adjacent to the site in the windblown tailings area. The nearest rancher would receive no additional dose from the Edgemont site.

Two beef cattle could be supported annually in the windblown tailings area. If these were consumed by the population in 1 yr, a population dose commitment of 1.25 manrem/yr bone dose would be received by the population regardless of where the beef was consumed.

Windblown tailings particulates are deposited in Cottonwood Community and on vegetables grown in small gardens there. A calculation of radionuclide uptake in leafy vegetables was performed for the nuclides shown in Table A-3 using the same relative concentrations. The radium and other nuclide deposition rates were determined by the model calculations in Cottonwood Community at locations listed in Table A-2.

Dose was calculated in the whole body and bone using equations C-5 and (14) in Regulatory Guide 1.109, Revision 1. A very conservative dose calculation resulted from assuming that the total population of Cottonwood Community (about 90 people) consumed one-half of their annual intake of leafy vegetables from local gardens. The man-rem dose commitment was less than the population dose from eating beef cattle and is included in the food pathway dose commitment in Table A-5.

A.4 POPULATION DOSE COMMITMENTS

The population dose commitments from background radiation are obtained by multiplying the background radiation values by the appropriate usage and dose conversion factors and by the population at risk (2,000 persons). Population dose commitments are listed in Table 3-10, Chapter 3. The two largest factors in the background dose commitments are external gamma radiation and the ingestion dose from the ^{226}Ra content of the Edgemont city water supply, neither of which are related to the presence of uranium tailings at the millsite.

Annual population dose commitments from the Edgemont site are listed in Table A-5 and Table 3-10, Chapter 3 where they may

be compared with background dose commitments. The external gamma dose commitment was calculated by multiplying the average gamma radiation rate above background in Cottonwood Community by the population in the community (about 90 people). Values for the inhalation pathway were determined by integrating radon concentrations given in Table A-2 over the population distribution shown in Figure 2-5, Chapter 2, and then applying appropriate usage and dose conversion factors.[3] In a similar manner, inhalation dose commitments from radioactive particulates were calculated using airborne ^{226}Ra concentration distribution from Table A-2 and other nuclides and concentration ratios listed in Table A-3. Inhalation dose commitments to the population are listed in Table A-5 from airborne particulates. The population dose commitment to the bronchial epithelium from inhalation of radon is listed separately in Table A-5 and is not included in the lung dose.

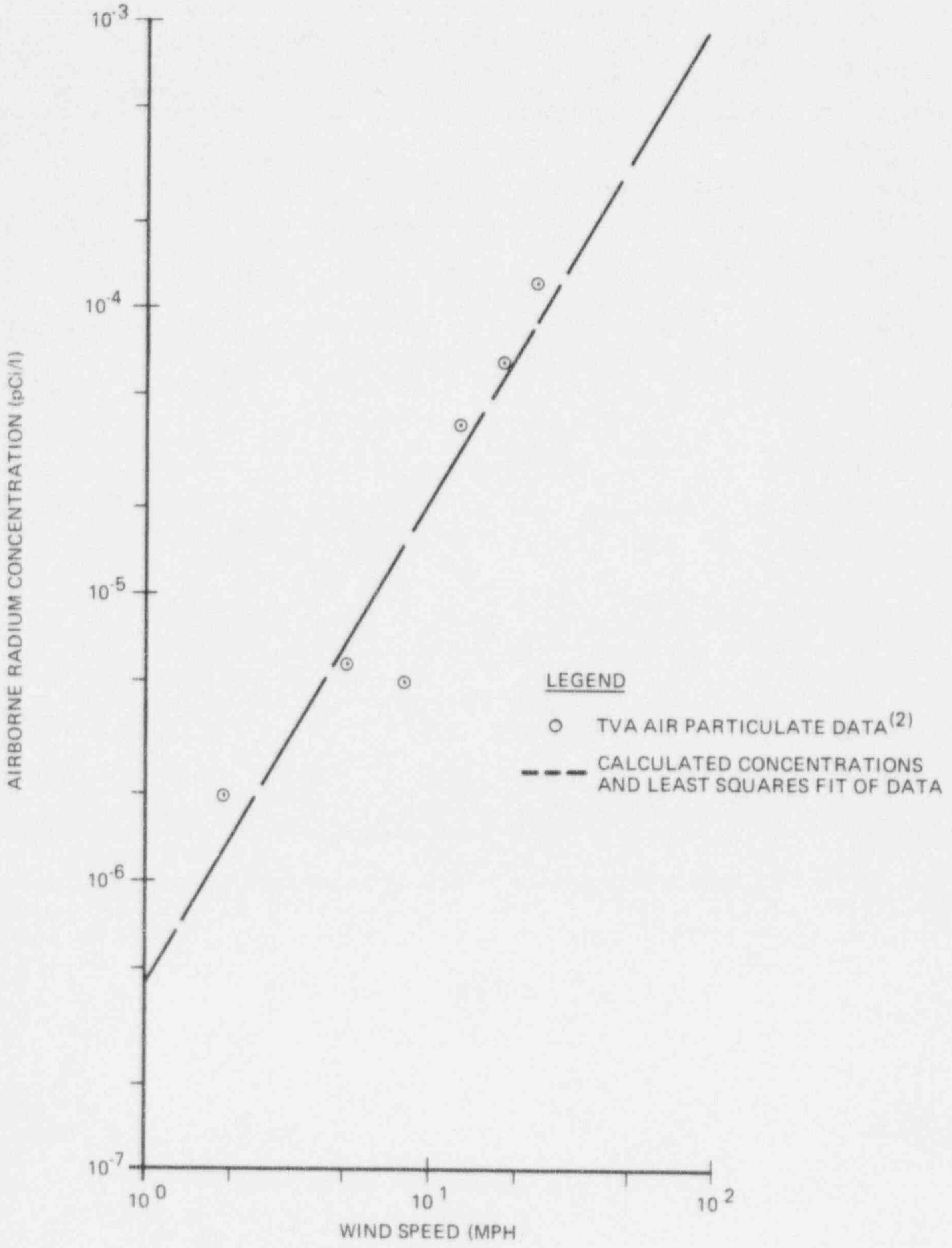

FIGURE A-1. AIR PARTICULATE CONCENTRATION VS WIND SPEED

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TABLE A-1

VALUES OF KEY PARAMETERS FOR COMPOSITE PILES

Composite Pile For Radon	Area (m^2)	Radius (m)	Thickness (m)	Radium Concentration[a] (pCi/g)	Q ($pCi/m^2 \cdot sec$)
A	150,000	219	4.9	141	189
B	30,000	98	4.7	143	192
C	190,000	246	1.5	321	292

Composite Pile For Particulates	Inner Radius (m)	Outer Radius (m)	Net Area (m^2)	Avg Height (m)	^{226}Ra Concentration pCi/g
A	60	132	43,000	7.6	76
B	63	117	31,000	4.6	76
C	--	149	70,000	0.8	192
D	--	122	47,000	1.4	76

[a]Weighted average concentration based upon TVA analyses of samples collected from each pile or pond.

TABLE A-2

RESULTS OF AIR PATHWAY CALCULATIONS

Location	Radon Concentration (pCi/l)	Airborne Radium Concentration (pCi/l)	Annual Deposition Flux (pCi/m^2yr)
C-1	0.55	7.2×10^{-6}	2300
C-2[a]	1.03	1.0×10^{-5}	3200
C-3	0.33	1.8×10^{-6}	570
C-4	0.53	3.8×10^{-6}	1200
C-5	0.57	2.5×10^{-6}	790
E-1	0.21	1.4×10^{-6}	440
E-2	0.28	1.6×10^{-5}	5000
E-3	0.16	2.4×10^{-6}	760
E-4	0.11	1.6×10^{-6}	500
E-5	0.12	8.7×10^{-7}	270
E-6	0.05	6.8×10^{-7}	220
E-7	0.23	3.2×10^{-6}	1000
E-8	0.28	3.2×10^{-6}	1000
E-9	0.25	2.4×10^{-6}	760
E-10	0.08	1.2×10^{-6}	380
E-11	0.28	--	--

[a]Location for maximum individual dose

TABLE A-3

ANNUAL DOSE BY INHALATION OF SELECTED NUCLIDES[a]

Nuclide and Volume Weighted Concentration (pCi/g)[d]	Whole Body		Lung		Bone	
	DCF[b] rem/µCi	Dose mrem/yr	DCF[c] rem/µCi	Dose mrem/yr	DCF[b] rem/µCi	Dose mrem/yr
^{210}Pb (670)	1.0	0.4	370	137	32	11.8
^{226}Ra (145)	190	15.2	1000	80	260	20.8
^{230}Th (66)	68	2.5	440	16.0	2300	83.6
^{238}U (6.1)	0.52	0.002	400	1.3	9	0.03
^{234}U (6.1)	0.60	0.002	440	1.5	9.8	0.03
Total		18		236		116
Total[e]		21		176		308

[a]Dose to nearest resident in Cottonwood Community. Dose to bronchial epithelium from inhalation of radon and radon daughters is listed in Table 3-9.

[b]Dose conversion factor for solubility class W.(6)

[c]Dose conversion factor for solubility class Y.(6)

[d]Based upon TVA data on nuclide concentrations in ponds and piles.

[e]Annual dose assuming equilibrium of ^{226}Ra, ^{210}Pb and ^{230}Th at 145 pCi/g and ^{238}U and ^{234}U at 6.1 pCi/g.

TABLE A-4

GROUND WATER PATHWAY TO WELL

	Parameter	Value
K	Equilibrium sorption coefficient	500 (dimensionless)
λ_L	Leach rate	10^{-5} yr^{-1}
	Average ^{226}Ra concentration in tailings	680 pCi/g [a]
	Maximum possible ^{226}Ra concentration in water	1360 pCi/l
V_1	Vertical ground water velocity to aquifer	0.35 m/yr
	Distance from pond 7 to aquifer	10 m
V_2	Horizontal ground water velocity	6.8 m/yr
	Aquifer distance to well	270 m
D	Dispersion coefficient	5 m^2/yr
	Calculated ^{226}Ra concentration in well water	0.5 pCi/l
	Calculated potential dose rate from ^{226}Ra	12 mrem/yr (bone) 1.2 mrem/yr (body)

[a] Based on average of ^{226}Ra concentration in sands and slimes in Pond 7.

TABLE A-5

ANNUAL POPULATION DOSE COMMITMENTS[a]
FROM SITE EFFLUENTS

Pathway	Dose (man-rem/yr) Whole Body	Lung	Bone	Bronchial Epithelium
Inhalation	8.6	104	52	321
Food	0.2	--	2.5	--
Water	0.1	--	1	--
External Gamma	12	12	12	--

[a]Population of Edgemont = 2,000 people

A.5 REFERENCES

1. D. H. Slade, ed; Meteorology and Atomic Energy 1968; TID-24190; AEC; Jul 1968.

2. Semi-Annual Effluent Release Reports; No. 3, RH-77-6-ED1, and No. 4, RH-77-6-ED2; Tennessee Valley Authority; 1977.

3. "Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I"; Regulatory Guide 1.109; Rev. 1; NRC; Office of Standards Development; March 1976 and Oct 1977.

4. Radioactive Waste Disposal Classification; FB&DU; in preparation for U.S. Nuclear Regulatory Commission.

5. Draft Environmental Statement, Related to Operation of Moab Uranium Mill; NUREG-0341; NRC; Office of Nuclear Material Safety and Safeguards; Nov 1977.

6. J. Houston, D. Strenge, and E. Watson; DACRIN - A Computer Program for Calculating Organ Dose for Acute or Chronic Radionuclide Inhalation; BNWL-B-398; Battelle Pacific Northwest Laboratories; Richland, Washington; Dec 1974.

APPENDIX B

REMEDIAL ACTION CRITERIA

B.1 Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of License for Byproduct, Source, or Special Nuclear Material

B.2 Surgeon General's Guidelines

B.1 GUIDELINES FOR DECONTAMINATION OF FACILITIES AND EQUIPMENT PRIOR TO RELEASE FOR UNRESTRICTED USE OR TERMINATION OF LICENSES FOR BYPRODUCT, SOURCE, OR SPECIAL NUCLEAR MATERIAL*

The instructions in this guide in conjunction with Table I specify the radioactivity and radiation exposure rate limits which should be used in accomplishing the decontamination and survey of surfaces or premises and equipment prior to abandonment or release for unrestricted use. The limits in Table I do not apply to premises, equipment, or scrap containing induced radioactivity for which the radiological considerations pertinent to their use may be different. The release of such facilities or items from regulatory control will be considered on a case-by-case basis.

1. The licensee shall make a reasonable effort to eliminate residual contamination.

2. Radioactivity on equipment or surfaces shall not be covered by paint, plating, or other covering material unless contamination levels, as determined by a survey and documented, are below the limits specified in Table I prior to applying the covering. A reasonable effort must be made to minimize the contamination prior to use of any covering.

3. The radioactivity on the interior surfaces of pipes, drain lines, or ductwork shall be determined by making measurements at all traps, and other appropriate access points, provided that contamination at these locations is likely to be representative of contamination on the interior of the pipes, drain lines, or ductwork. Surfaces of premises, equipment, or scrap which are likely to be contaminated but are of such size, construction, or location as to make the surface inaccessible for purposes of measurement shall be presumed to be contaminated in excess of the limits.

4. Upon request, the Commission may authorize a licensee to relinquish possession or control of premises, equipment, or scrap having surfaces contaminated with materials in excess of the limits specified. This may include, but would not be limited to, special circumstances such as razing of buildings, transfer of premises to another organization continuing work with radioactive materials, or conversion of facilities to a long-term storage or standby status. Such requests must:

   a. Provide detailed, specific information describing the

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*From U.S. Nuclear Regulatory Commission, Division of Fuel Cycle and Material Safety, Washington, D.C. 20555, Nov 1976.

premises, equipment or scrap, radioactive contaminants, and the nature, extent, and degree of residual surface contamination.

   b. Provide a detailed health and safety analysis which reflects that the residual amounts of materials on surface areas, together with other considerations such as prospective use of the premises, equipment or scrap, are unlikely to result in an unreasonable risk to the health and safety of the public.

5. Prior to release of premises for unrestricted use, the licensee shall make a comprehensive radiation survey which establishes that contamination is within the limits specified in Table I. A copy of the survey report shall be filed with the Division of Fuel Cycle and Material Safety, USNRC, Washington, D.C. 20555, and also the Director of the Regional Office of the Office of Inspection and Enforcement, USNRC, having jurisdiction. The report should be filed at least 30 days prior to the planned date of abandonment. The survey report shall:

   a. Identify the premises.

   b. Show that reasonable effort has been made to eliminate residual contamination.

   c. Describe the scope of the survey and general procedures followed.

   d. State the findings of the survey in units specified in the instruction.

Following review of the report, the NRC will consider visiting the facilities to confirm the survey.

TABLE I

ACCEPTABLE SURFACE CONTAMINATION LEVELS

NUCLIDES[a]	AVERAGE[b c f]	MAXIMUM[b d f]	REMOVABLE[b e f]
U-nat, U-235, U-238, and associated decay products	5,000 dpm $\alpha/100\ cm^2$	15,000 dpm $\alpha/100\ cm^2$	1,000 dpm $\alpha/100\ cm^2$
Transuranics, Ra-226, Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-125 I-129	100 dpm/100 cm^2	300 dpm/100 cm^2	20 dpm/100 cm^2
Th-nat, Th-232, Sr-90, Ra-223, Ra-224, U-232, I-126, I-131, I-133	1,000 dpm/100 cm^2	3,000 dpm/100 cm^2	200 dpm/100 cm^2
Beta-gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except SR-90 and others noted above	5,000 dpm $\beta\gamma/100\ cm^2$	15,000 dpm $\beta\gamma/100\ cm^2$	1,000 dpm $\beta\gamma/100\ cm^2$

[a] Where surface contamination by both alpha- and beta-gamma-emitting nuclides exists, the limits established for alpha- and beta-gamma-emitting nuclides should apply independently.

[b] As used in this table, dpm (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.

[c] Measurements of average contaminant should not be averaged over more than 1 square meter. For objects of less surface area, the average should be derived for each such object.

[d] The maximum contamination level applies to an area of not more than 100 cm^2.

[e] The amount of removable radioactive material per 100 cm^2 of surface area should be determined by wiping that area with dry filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of less surface area is determined, the pertinent levels should be reduced proportionally and the entire surface should be wiped.

[f] The average and maximum radiation levels associated with surface contamination resulting from beta-gamma emitters should not exceed 0.2 mrad/hr at 1 cm and 1.0 mrad/hr at 1 cm, respectively, measured through not more than 7 milligrams per square centimeter of total absorber.

The remedial action criteria used for the Phase II assessment of the cleanup of mill tailings are presented in the following documents:

B.2 SURGEON GENERAL'S GUIDELINES

DEPARTMENT OF HEALTH, EDUCATION AND WELFARE,
PUBLIC HEALTH SERVICE,
Washington, D. C., July 1970.

DR. R. L. CLEERE,
Executive Director, Colorado State Department of Health, 4210 E. 11th Avenue, Denver, Colorado

DEAR DR. CLEERE: I am pleased to respond to your letter of January 29 in which you asked Dr. M. W. Carter, Director of our Southwestern Radiological Health Laboratory, for Public Health Service and/or U. S. Atomic Energy Commission assistance in providing exposure guidelines applicable to homes with high concentrations of radon progeny.

The enclosed graded recommendations for action have been developed within the framework of existing Federal Radiation Council guidance for occupational exposure to airborne concentrations of radon and its daughters (progeny). Also, graded action levels applicable to external gamma radiation are included.

You will note in the accompanying Explanatory Notes that these recommendations apply specifically to dwellings constructed with or on uranium mill tailings. Further qualifications in the Explanatory Notes should be consulted before these recommendations are applied.

The specific information which your Department is developing on the variability of radon daughter concentrations in dwellings and on optimum control measures will be essential towards making those decisions necessary in applying the recommendations.

These recommendations have been directed to the Atomic Energy Commission for comment. Because of the urgency attached to your receiving the recommendations as soon as possible, they have been forwarded to you in advance of receiving AEC views and comments. We will advise you of the AEC response when received.

Sincerely yours,

PAUL J. PETERSON,
Acting Surgeon General

Enclosure:

RECOMMENDATIONS OF ACTION FOR RADIATION EXPOSURE LEVELS IN DWELLINGS CONSTRUCTED ON OR WITH URANIUM MILL TAILINGS

External gamma radiation:

Level:	Recommendations
Greater than 0.1 mR/hr . . .	Remedial action indicated.
From 0.05 to 0.1 mR/hr . . .	Remedial action may be suggested.
Less than 0.05 mR/hr. . .	No action indicated.

Radon daughter concentration:

Level:	Recommendations
Greater than 0.05 WL	Remedial action indicated.
From 0.01 to 0.05 WL	Remedial action may be suggested.
Less than 0.01 WL	No action indicated.

EXPLANATORY NOTES

1. These recommendations are written specifically for dwellings constructed on or with uranium mill tailings. This situation may involve continuous exposure of members of the public to radon daughter product activities and whole-body gamma irradiation levels in excess of the background radiation levels found within dwellings in the area not constructed with or on uranium mill tailings.

2. Although the initial concern was the presence of radon daughter product activities within these dwellings, preliminary surveys have indicated that in some instances, the gamma radiation levels were of prime importance. Thus, recommendations are made concerning both types of radiation. The recommendations applicable to a particular dwelling will be determined by whichever type of radiation has the high level.

3. Three levels for action are recommended for both external gamma and radon daughter product exposures. This graded system of actions is proposed to allow latitude in the middle ranges for the judgment of the on-site investigators.

4. The external gamma and radon daughter product levels proposed constitute exposures which are in addition to the natural background levels found within dwellings in the area not constructed on or with uranium mill tailings. In the Grand Junction, Colorado, area these levels are approximately 0.01 mR/hr (approximately 90 mrem/yr) and 0.004 Working Levels (WL) (approximately 0.2 CWLM/yr) respectively (1).

5. The expected health effects of concern will be different for the two types of radiation; i.e., leukemia for whole-body gamma radiation exposure and lung cancer for exposure to inhaled radon daughter products. This expectation is based, in part, on findings derived from population studies such as the Japanese atomic bomb

survivors and uranium miners. These specific health effects are considered to be mutually exclusive. The basis for this assumption is that the expected radiation contribution to whole-body exposure from inhaled radon and daughter products would be considerably less than the direct exposure from external gamma radiation at the levels encountered in the dwellings. Conversely, the external gamma radiation contribution to the lung dose is considered to comprise a negligible additional risk of lung cancer.

6. (a) A Working Level (WL) is the term used to describe radon daughter product activities in air. This term is defined as any combination of short-lived radon daughter products in 1 liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy (2). The numerical value of the WL is derived from the alpha energy released by the total decay through Ra C' of the short-lived radon daughter products, Ra A, Ra B and Ra C, at radioactive equilibrium with 100 pCi of ^{222}Rn per liter of air (3).

6. (b) A Working Level Month (WLM) is the term used to express the occupational exposure incurred in one working month of 170 hours by a uranium miner laboring in an atmosphere containing radon daughter products; i.e., one working month in a mine atmosphere containing 1 WL of radon daughter products equals 1 WLM.

6. (c) Cumulative Working Level Months (CWLM) is the term used to express the total accumulated occupational exposure to radon daughter products in air; i.e., an air concentration of radon daughter products of 1 WL would, in one working month, equal 1 WLM, and in 1 year or 12 months would equal 12 CWLM.

6. (d) Since occupational exposures are based upon 170 hours per month and continuous exposure involves approximately 170 hours per week, then an occupational exposure to an air concentration of 1 WL is equivalent to continuous exposure to 0.025 WL.

7. These recommendations are based on the assumption of a linear, non-threshold dose-effect relationship. The lack of definitive information precludes allowances for possible differences in radio-sensitivity due to age, sex, or other biological characteristics.

8. No action is indicated when the external gamma exposure rate is less than 0.05 mR/hr and the radon daughter product activity is less than 0.01 WL since under conditions of continuous exposure these levels would result in maximum annual exposures of approximately 400 mrem and 0.5 CWLM, respectively. The maximum annual value of 400 mrem is less than the dose limits recommended for an individual body exposure to external gamma irradiation.

The ICRP (5) recommends that the annual dose limit for members of the public shall be 1/10 of the corresponding annual occupational maximum permissible dose. The maximum annual value of 0.5 CWLM of radon daughter product exposure is approximately 1/10 of the 4 CWLM annual occupational exposure limit recommended by the FRC (6) for implementation on 1 January 1971, and less than 1/20 of the

annual occupational exposure limit of 12 CWLM recommended for uranium miners in the present FRC regulations (4).

9. Remedial action may be suggested in the case of external gamma exposure rates of 0.05-0.10 mR/hr or radon daughter product activities of 0.01-0.05 WL since under conditions of continuous exposure these levels would result in maximum annual exposures of approximately 400-900 mrem and 0.5-2.5 CWLM. The upper limit of these ranges exceeds the strictly applied recommendations of the FRC and ICRP for exposures of an individual member of the public. However, this extension seems justified in situations in which unforeseen exposures have occured, since as stated by ICRP (5) "in general it will be appropriate to institute countermeasures only when their social cost and risk will be less than those resulting from the exposure." It is further stated by the ICRP (5) that very low levels of risk are implied in the dose limits for members of the public and that it is likely to be of minor consequence to their health if the dose limits are marginally or even substantially exceeded.

10. Remedial action is indicated at gamma exposures greater than 0.1 mR/hr or at radon daughter product activities greater than 0.05 WL. Under conditions of continuous exposure, these levels would result in minimum annual exposures of 900 mrem and 2.5 CWLM. All values above these would indicate the necessity for remedial action, since at these levels the maximum annual exposures recommended by the FPC and ICRP for an individual member of the public is exceeded.

11. With respect to the external gamma irradiation, from the estimates published by ICRP (7), it can be interpolated that the annual risk of leukemia under conditions of continuous exposure to 500 mrem per year is an increased incidence of about 10 cases per year per million persons exposed. The natural annual incidence of leukemia for all ages is given by ICRP (8) as 10-100 cases per million persons. With respect to radon daughter product exposures, it has been estimated by Archer and Lundin (9) that an exposure of 120 CWLM to a group of white adult males in the United States appears to approximately double the normal lung cancer incidence which for this population is about 2-3 cases per year per 10,000 persons. At an annual exposure of 2.5 CWLM, 48 years would be required to reach 120 CWLM.

12. It is considered that implementation of these recommendations for the various exposure ranges would make it highly unlikely that any serious health effects would result from exposure to radon daughter products or external gamma irradiation in this particular situation.

13. It is suggested that remedial action be taken only after an adequate number of measurements taken under a diversity of temporal and climatic conditions have clearly established that the average exposure is in excess of 0.1 mR/hr or 0.05 WL exist and in instituting corrective measures. However, it is considered that the additional health risks from continued exposure over this time period are of lesser consequence than the economic and social discomfitures of precipitous action.

Approved.

/s/ PAUL J. PETERSON,
for Jesse L. Steinfeld, M.D.,
Surgeon General, Public Health Service

July 27, 1970

REFERENCES

1. Personal communication, Mr. Robert D. Siek, Colorado State Department of Health.

2. U.S. Public Health Service Publication No. 494, Control of Radon and Daughters in Uranium Mines and Calculations on Biologic Effects, 1957.

3. Federal Radiation Council Report No. 8 Revised, Guidance for the Control of Radiation Hazards in Uranium Mining, 1967.

4. Federal Radiation Council Report No. 1. Background Material for the Development of Radiation Protection Standards, 1960.

5. Recommendations of the International Commission on Radiological Protection, ICRP Publication 9, 1966.

6. Federal Register, Vol. 34, No. 10, pp 576-577, 1969.

7. The Evaluation of Risks from Radiation, ICRP Publication 8, 1966.

8. Radiosensitivity and Spatial Distribution of Dose, ICRP Publication 14, 1969.

9. V.E. Archer and F. E. Lundin, Jr., Radiogenic Lung Cancer in Man: Exposure-Effect Relationship, Environmental Research 1, pp 370-383, 1967.

APPENDIX C

RADON FLUX REDUCTION CALCULATIONS

RADON FLUX REDUCTION CALCULATIONS

The simplified formula used in calculating the attenuation in radon flux produced by the proposed cover system is:

$$J_{(x)} = Jp \exp\left(-\sqrt{\lambda/(De/V)}\ x\right)$$

or,

$$J_{(x)} = Jp \exp\left(-\sum_{i=1}^{n}\sqrt{\lambda/(De/V)_i}\ x_i\right)$$

where,

i = particular cover material of a multicomponent cover (n is the number of components)

λ = decay constant for $^{222}Rn = 2.1 \times 10^{-6}$

De/V = effective diffusion coefficient (cm^2/s)

x = depth of cover (cm)

$J_{(x)}$ = resulting radon flux after attenuation through a thickness x of material with a given De/V (pCi/cm^2-s)

Jp = radon flux at the surface of the planar tailings source (pCi/cm^2-s)

The effective diffusion coefficient (De/V) for the clay cover was estimated to be 6.6×10^{-4} cm^2/s (the geometric average of the diffusion coefficient for montmorillonite clay with 30% moisture (6.5×10^{-5} cm^2/s) and the diffusion coefficient for varved clays (7.0×10^{-3} cm^2/s) and the De/V for the soil was estimated to be 1.2×10^{-2} cm^2/s. Using the preceding formula, the radon attenuation factor for the 1.5 ft of compacted bentonitic clay is 0.076 and for the 4.5 ft of overburden and topsoil, assuming 10% moisture is 0.163. Overall, the effective radon flux attenuation factor is estimated to be 0.0124 (0.076 x 0.163) or an attenuation of about a factor of 80. The cover material is also a source of radon from the natural uranium content of the soil. A 4.5 ft soil cover would exhale about 75% of the background exhalation value for an infinite soil thickness or about 2.1 pCi/m^2-s. The tailings exhalation must be reduced to a value equal to the difference between twice the average background radon exhalation rate and the exhalation rate from the cover or approximately 3.5 pCi/m^2-s. Source fluxes must then be less than 280 pCi/m^2-s.

The proposed tailings cover is expected to accomplish the required radon flux reduction, except for portions of ponds 2, 3, and 7. In Alternatives I and II, contaminated materials from the site cleanup and at least 5 ft of sand tailings would first

be placed over these high flux areas. This additional material would attenuate the flux from the high flux areas by a factor of about 10. Then the specified cover materials would reduce the radon surface flux to less than 5.6 pCi/m^2-s (twice the background flux).

FROM	DATE OF DOCUMENT	DATE RECEIVED	NO
Ford, Bacon, & Davis Utah	May 1978	07-25-78	10331

LTR	MEMO	REPORT	OTHER
X			

TO	ORIG	CC	OTHER
LCRouse	1		

ACTION NECESSARY ☐ NO ACTION NECESSARY ☐ CONCURRENCE ☐ COMMENT ☐ DATE ANSWERED: BY:

CLASSIF	POST OFFICE	REG NO	FILE CODE
U			40-1341

DESCRIPTION (Must Be Unclassified)

Engineering Assessment of Inactive Uranium Mill Tailings

REFERRED TO	DATE	RECEIVED BY	DATE
~~Docket File Cy~~	7/25		
LCRouse (4)			
JMartin (ltr & control)			
I&E (2)			
PDR			
		10331 ced	

ENCLOSURES

18 cys rec'd
All extras sent to ETRager

REMARKS

U.S. NUCLEAR REGULATORY COMMISSION

MAIL CONTROL FORM

FORM NRC-326 (1-75)