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Environmental Assessment

Remedial Action at the Tuba City Uranium Mill Tailings Site Tuba City, Arizona

November, 1986

Uranium Mill Tailings Remedial Action Project UMTRAP

DOE/EA-0317

ENVIRONMENTAL ASSESSMENT

OF

REMEDIAL ACTION AT THE TUBA CITY

URANIUM MILL TAILINGS SITE

TUBA CITY, ARIZONA

November, 1986

U.S. DEPARTMENT OF ENERGY

UMTRA PROJECT OFFICE

ALBUQUERQUE, NEW MEXICO

ENVIRONMENTAL ASSESSMENT OF REMEDIAL ACTION AT THE TUBA CITY URANIUM MILL TAILINGS SITE TUBA CITY, ARIZONA

U.S. DEPARTMENT OF ENERGY

ABSTRACT

This document assesses and compares the environmental impacts of various alternatives for remedial action at the Tuba City uranium mill tailings site located approximately six miles east of Tuba City, Arizona. The site covers 105 acres and contains 25 acres of tailings and some of the original mill structures. The Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA), Public Law 95-604, authorizes the U.S. Department of Energy to clean up the site to reduce the potential health impacts associated with the residual radioactive materials remaining at the site and at associated properties off the site. The U.S. Environmental Protection Agency promulgated standards for the remedial actions (40 CFR Part 192). Remedial actions must be performed in accordance with these standards and with the concurrence of the Nuclear Regulatory Commission. The proposed action is to stabilize the tailings at their present location by consolidating the tailings and associated contaminated materials into a recontoured pile. A radon barrier would be constructed over the pile and various erosion control measures would be taken to assure the long-term stability of the pile. Another alternative which would involve moving the tailings to a new location is also assessed in this document. This alternative would generally involve greater short-term impacts and costs but would result in stabilization of the tailings at a more remote location. The no action alternative is also assessed in this document.

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1.1 PROJECT SUMMARY

The Tuba City tailings site is located on the Bennett Freeze Order Area approximately six air miles east of Tuba City in Coconino County, Arizona (Figures 1.1 and 1.2). The site is situated in the southern Kaibito Plateau, and the topography of the surrounding area consists of dissected sand dunes, mesas, and alluvial terraces. Moenkopi Wash flows southwestward approximately two air miles south of the site.

The Tuba City area has an arid climate with an average annual precipitation of 6.2 inches. Plant species common to the area include Mormon tea, Indian ricegrass, galleta, blue grama, yucca, rabbitbrush, and fourwing saltbush. The dominant land use is livestock grazing. Tuba City, with an estimated 1983 population of 5195, is the closest community. The nearest residents are those that occasionally occupy the former mill housing less than 0.5 mile distant.

The Tuba City site consists of the tailings pile, three former emergency spill ponds, the abandoned mill and office buildings, several concrete pads and foundations, and buried conduits. The pile covers approximately 25 acres and contains approximately 689,000 cubic yards of tailings. The total volume of contaminated materials, including the contaminated soils beneath and around the tailings, is approximately 1.3 million cubic yards.

The principal potential hazard associated with the tailings results from the production of radon, a radioactive decay product of the radium contained in the pile. Radon, a radioactive gas, can diffuse through the pile and be released into the atmosphere where it and its radioactive decay products (radon daughters) may be inhaled by humans. Increased exposure to radon and its decay products over a long period of time will increase the probability that health effects (i.e., cancers) may develop in persons living and working near the pile. Exposure to gamma radiation, the inhalation of airborne radioactive particulates, the ingestion of contaminated food produced in the area around the tailings, and the ingestion of surface and ground waters contaminated by the tailings also pose potential hazards. If the tailings are not properly stabilized, erosion by wind or water or human removal of contaminated materials could spread the contamination over a much wider area and increase the potential for public health hazards.

The Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA), Public Law 95-604, authorized the U.S. Department of Energy (DOE) to perform remedial action at the Tuba City tailings site (as well as at many other sites) to reduce the potential public health impacts from the residual radioactivity remaining in the pile. The U.S. Environmental Protection Agency (EPA) promulgated standards (40 CFR Part 192) in March, 1983, for this remedial action.

The proposed remedial action for the Tuba City tailings is stabilization in place. All of the tailings and other contaminated materials

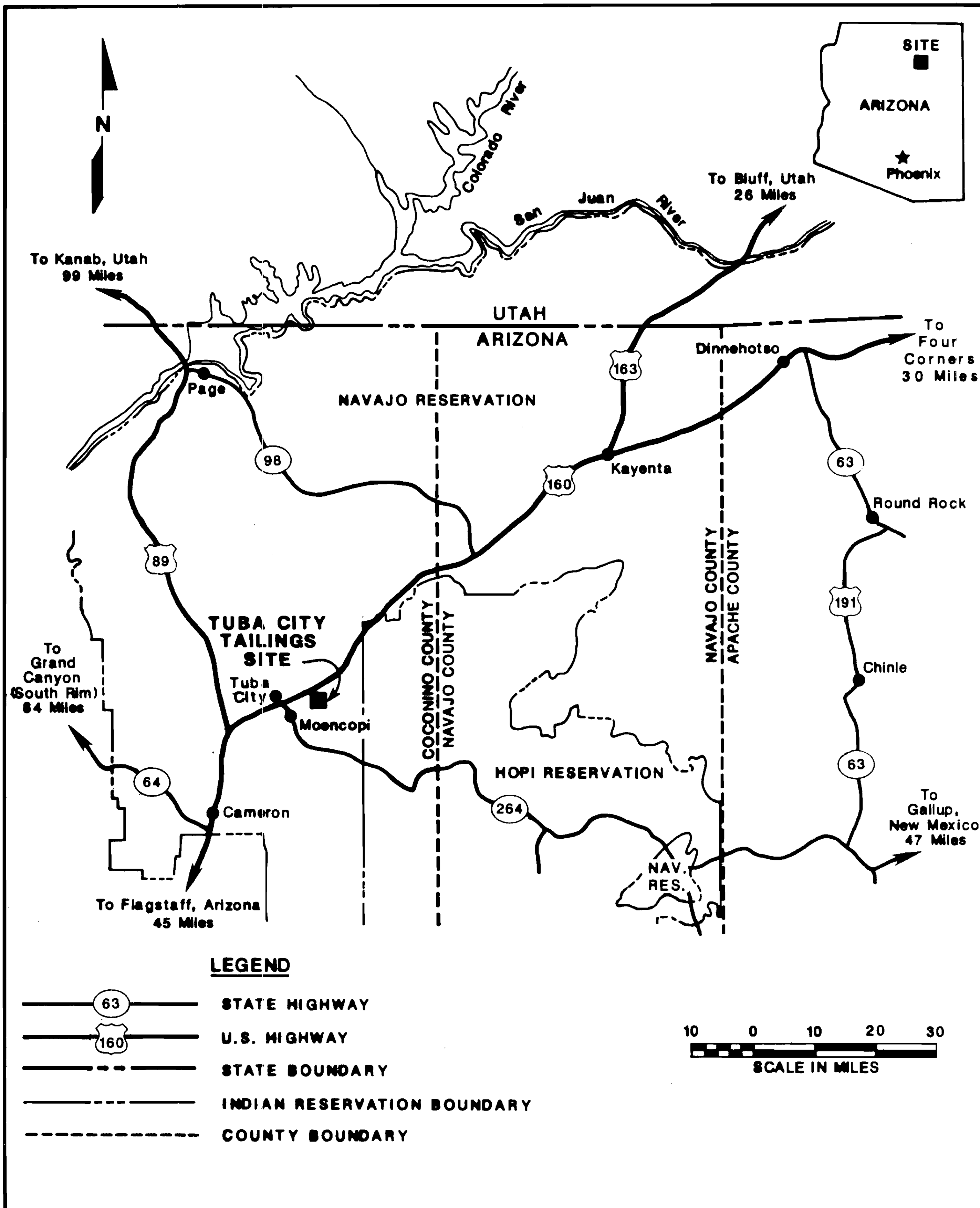


FIGURE 1.1

TUBA CITY SITE LOCATION

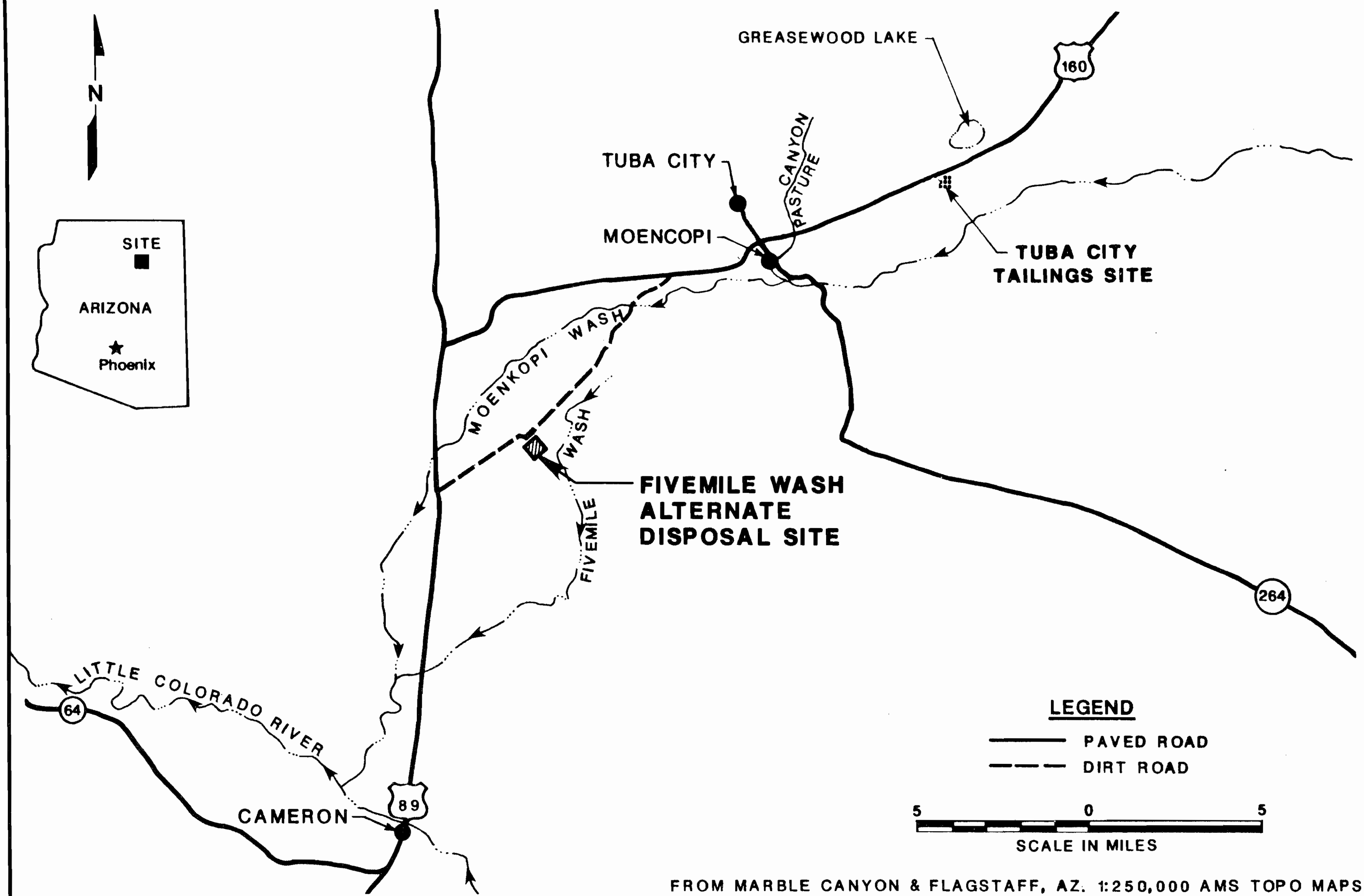


FIGURE 1.2
ALTERNATE DISPOSAL SITE LOCATION

would be consolidated with the existing tailings pile, and the resulting pile would be recontoured to have 20 percent sideslopes (five horizontal to one vertical) and a gently sloping top. The pile would then be covered with 1.5 feet of compacted earth to inhibit radon emanation and water infiltration and to ensure compliance with the EPA standards. The top and sides of the pile would be covered with a one-foot-thick layer of gravel-sized rock to protect the pile against erosion, penetration by animals, and inadvertent human intrusion. The south sideslope and the drainage ditches surrounding the pile would be covered with a two-foot-thick layer of large rock. The top of the stabilized pile would average approximately 33 feet above the surrounding terrain. A drainage ditch would divert surface runoff around and away from the pile. Areas disturbed by remedial action would be recontoured, revegetated as required, and released for unrestricted use.

DOE will mitigate contaminated ground water by applying institutional controls on water development around the site. When EPA issues revisions to the water protection standards (40 CFR 192.20(a)(2)-(3)) that were remanded by the U.S. Tenth Circuit Court of Appeals, DOE will re-evaluate the ground-water issues at the Tuba City site to assure that the revised standards are met. Performing remedial actions to stabilize the tailings prior to EPA issuing new standards will not affect the measures that are ultimately required to meet the revised water protection EPA standards.

The no action alternative would consist of taking no remedial action at the tailings site. The tailings would remain in their present location and condition and would continue to be susceptible to erosion and unauthorized removal and use by man. This alternative would not be consistent with the UMTRCA (PL95-604) and would not result in DOE's compliance with the EPA standards (40 CFR Part 192).

Disposal of the tailings at the Fivemile Wash alternate disposal site would involve moving all of the contaminated materials to a site approximately 16 road miles southwest of the existing tailings site (Figure 1.2). This site also occurs within the Bennett Freeze Order Area. This land is used primarily for low density livestock grazing. The site is approximately two air miles from the nearest residence. The design objectives for the alternate disposal site would be identical to those selected for stabilization in place. The contaminated materials would be consolidated in a partially below-grade pile and covered with compacted earth and rock similar to stabilization in place. The existing tailings site would be recontoured to promote surface drainage, revegetated as required, and released for any uses consistent with local land use controls.

1.2 IMPACT SUMMARY

This section contains a quantitative listing of the environmental impacts of the proposed action (Table 1.1) and a brief discussion of the major differences between the proposed action and the other alternatives. The impacts presented in this document are based on conservative impact assessment methods and represent a realistic upper limit of the severity of the potential impacts for stabilization in place.

Table 1.1 Environmental impacts of the proposed action

Environmental component	Impacts
Remedial action worker health	0.005 excess fatal cancers; 3.0 injuries (equipment use only)
Public health	0.03 excess fatal cancers in first 10 years; 0.5 excess fatal cancers in 1000 years
Mineral resources	Consumption of 288,900 cubic yards of borrow materials (earth and rock)
Soils	408 acres of soils temporarily disturbed; 327 acres of soils restored following remedial action
Water resources	Gradual reduction in existing contaminant levels
Water consumption	8,500,000 gallons
Air quality (nonradiological, 24-hour maximum)	218 micrograms per cubic meter increase in TSP; small increase in fuel combustion pollutants; exceeds Federal primary TSP standards
Wildlife	Permanent loss of 60 acres of habitat
Vegetation	Permanent loss of 60 acres of vegetation
Threatened and endangered species	None anticipated[a]
Aesthetic resources	Pile noticeable to persons passing by but subordinate to regional view; could not be seen from Tuba City
Historic and cultural resources	None anticipated[b]
Noise	72 dBA at nearest residence during day; limited potential for annoyance and hearing impacts
Land use	Restricted use of 60 acres; no limitation on future use of adjacent lands
Population	Short-term increase of 24 persons; negligible increase in Tuba City's population

Table 1.1 Environmental impacts of the proposed action (Concluded)

Environmental component	Impacts
Employment	Average of 48 persons for 18 months; peak of 77 persons; induced employment of an additional 21 persons
Social services	None
Transportation networks	Maximum of 31 round-trips per day on U.S. Highways 89 and 160 (two-lane, moderately traveled); maximum of 54 crossings per day on U.S. Highway 160; 0.03 traffic fatalities; 0.22 traffic injuries; 0.41 property damage accidents
Energy resources	Consumption of 468,000 gallons of fuel and 273,000 kilowatt-hours of electricity
Construction costs ($)[c]	$7,500,000

[a]No threatened and endangered species are known to be present at the Tuba City tailings site or the Greasewood Lake, Shadow Mountain, or Pediment Gravel borrow sites. There is a possibility for the presence of the endangered peregrine falcon at the Shadow Mountain borrow site. Prior to remedial action, a site-specific survey of the Shadow Mountain borrow site would be conducted to verify the presence or absence of the peregrine falcon.

[b]A cultural resource survey of the designated Tuba City tailings site verified the absence of any significant historic or cultural resources at the site. No survey was conducted at the Shadow Mountain borrow site, and partial surveys were conducted at the Greasewood Lake and Pediment Gravel borrow sites and the area of windblown tailings. Prior to remedial action, site-specific surveys of the sites to be affected would be conducted to verify the absence of historic or cultural resources at the sites.

[c]This estimate does not include the costs of: (1) property acquisition, (2) engineering design, (3) construction management and field supervision, (4) overall project management, (5) long-term surveillance and maintenance, and (6) vicinity properties cleanup.

No action alternative

Selection of the no action alternative would not be consistent with the intent of Congress in UMTRCA (PL95-604) and would not result in the DOE's compliance with the EPA standards (40 CFR Part 192). This alternative would result in the continued dispersion of the tailings over a wide area by wind and water erosion. The ground water would continue to be contaminated, and the tailings would not be protected against unauthorized removal by humans. Continued dispersion and unauthorized removal and use of the tailings could cause radiological contamination of other areas and could result in greater public health impacts than those calculated for this alternative.

Fivemile Wash disposal alternative

Tailings relocation to the Fivemile Wash site would result in stabilization of the tailings at a more remote location, but would generally involve greater short-term impacts and costs than stabilization in place.

The major differences between the Fivemile Wash disposal and stabilization in place alternatives are as follows:

- The Fivemile Wash disposal site is on remote land 16 road miles southwest of the Tuba City tailings site and approximately two miles from the nearest residence.

- The Fivemile Wash alternative would result in fewer predicted public health effects per year after remedial action.

- The Fivemile Wash alternative would have a greater impact on remedial action worker health, nonradiological air quality, transportation networks, and the consumption of water and energy.

- The construction costs of the Fivemile Wash alternative would exceed those for stabilization in place by more than 50 percent.

2.0 REMEDIAL ACTION ALTERNATIVES

2.1 THE NEED FOR REMEDIAL ACTION

2.1.1 Background

In response to public concern over the potential public health hazards related to uranium mill tailings and the associated contaminated materials left abandoned or otherwise uncontrolled at inactive processing sites throughout the United States, Congress passed the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA), Public Law 95-604, which was enacted into law on November 8, 1978. In the UMTRCA, Congress acknowledged the potential health hazards associated with uranium mill tailings and identified 24 sites that were in need of remedial action. The Tuba City site is one of these sites.

Title I of the UMTRCA authorized the U.S. Department of Energy (DOE) to enter into cooperative agreements with affected states or Indian tribes to clean up those inactive sites contaminated with uranium mill tailings and required the Secretary of the DOE to designate sites to be cleaned up. Title I also required the U.S. Environmental Protection Agency (EPA) to promulgate standards for these sites and defined the role of the U.S. Nuclear Regulatory Commission (NRC).

Effective March 29, 1985, the DOE, the Navajo Nation, and the Hopi Tribe entered into a cooperative agreement under the UMTRCA. The cooperative agreement set forth the terms and conditions for the DOE and Tribal cooperative remedial action efforts including the DOE's development of a remedial action plan (concurred in by the Navajo Nation and the Hopi Tribe), the DOE's preparation of an appropriate environmental document, real estate responsibilities, and other concerns.

The EPA published an Environmental Impact Statement (EIS) (EPA, 1982) on the development and impacts of the standards (40 CFR Part 192) and issued final standards (48 FR 590-604) which became effective on March 7, 1983. In developing these standards, EPA determined "that the primary objective for control of tailings should be isolation and stabilization to prevent their misuse by man and dispersal by natural forces" and that "a secondary objective should be to reduce the radon emissions from the piles." A third objective should be "the elimination of significant exposure to gamma radiation from tailings piles." More detailed discussions of the EPA standards are provided in Appendix A, EPA Standards, of the Environmental Assessment of Remedial Action at the Shiprock Uranium Mill Tailings Site, Shiprock, New Mexico (DOE, 1984a) and the Plan for Implementing EPA Standards for UMTRA Sites (DOE, 1984b).

All remedial actions performed under the UMTRCA must be completed in accordance with the EPA standards and with the concurrence of the NRC. The NRC will issue a license to the DOE, or other Federal agency having custody of the site, to perform surveillance, maintenance, and contingency measures to ensure continued compliance with the EPA standards.

2.1.2 The remedial action process

The remedial action process for the Tuba City site began with site characterization and will conclude with long-term surveillance and maintenance. Preliminary radiological investigations and engineering assessments have been completed and published. Currently, a series of four related reports that address the site-specific engineering concepts, surveillance and maintenance requirements, and licensing are under preparation. The anticipated publication schedule for each of these documents is shown in Table 2.1.

Table 2.1 Document publication schedule

Document	Scheduled publication date
Remedial Action Plan (including Health and Safety Plan, Radiological Support Plan, Site Characterization Report, and Site Conceptual Design)	Summer, 1987
Final Design and Specifications	Summer, 1987
Site Licensing Plan	Summer, 1988
Site Surveillance and Maintenance Plan	Summer, 1988

2.1.3 The Tuba City tailings site

The Tuba City tailings site is located in Coconino County, Arizona, approximately six air miles east of Tuba City (Figure 1.1). The site is on the Bennett Freeze Order Area.

The tailings site is situated on the southern Kaibito Plateau at an elevation of approximately 5100 feet above sea level. The topography of the area consists of dissected sand dunes, mesas, and alluvial terraces. Moenkopi Wash flows southwestward toward the Little Colorado River approximately two air miles south of the site. The climate of the area is arid with average annual precipitation of less than seven inches. Vegetation consists of species common to southwestern plateaus (e.g., Mormon tea, galleta, Indian ricegrass, blue grama, and rabbitbrush).

The Rare Metals Corporation constructed the Tuba City mill in 1956, and the facility was operated until 1966. Remaining at the site are the tailings pile, three former emergency spill ponds, an emergency dump pit, a sewage lagoon, the abandoned mill and office buildings, several concrete pads, and foundations (Figure 2.1). Buried conduits, including electrical and water lines, also remain on the site. Tailings are the residue of the uranium ore processing operations and are in the form of finely ground rock, much like sand. The tailings pile occupies approximately 25 acres of the 105-acre designated site and contains approximately 689,000 cubic yards of tailings. The total amount of contaminated materials, including the tailings and soils beneath and around the tailings, is estimated to be approximately 1.3 million cubic yards.

2.1.4 The purpose of this document

This environmental assessment (EA) is prepared pursuant to the National Environmental Policy Act (NEPA) which requires Federal agencies to assess the impacts that their actions may have on the environment. This EA examines the short-term and the long-term effects of the DOE's proposed remedial action for the Tuba City tailings site. Alternatives to the proposed action are also examined.

The DOE will use the information and analyses presented here to determine whether the proposed action would have a significant impact on the environment. If the impacts are determined to be significant, a more detailed document called an "Environmental Impact Statement" will be prepared. If the impacts are not judged to be significant, the DOE may issue a "Finding of No Significant Impact" and implement the proposed action. These procedures and documents are defined in regulations issued by the Council on Environmental Quality (CEQ) in Title 40, Code of Federal Regulations, Parts 1500 through 1508.

Vicinity properties are properties that are located outside a designated tailings site boundary and that may have been contaminated by tailings dispersed by wind or water erosion or by removal by man before the potential hazards of the tailings were known. Vicinity properties are typically identified by aerial radiological surveys or by mobile gamma-ray scanning. There are six vicinity properties associated with the Tuba City tailings site. The potential environmental impacts of remedial action at these vicinity properties were previously assessed in a programmatic environmental report (DOE, 1985a) and are therefore not considered in this document.

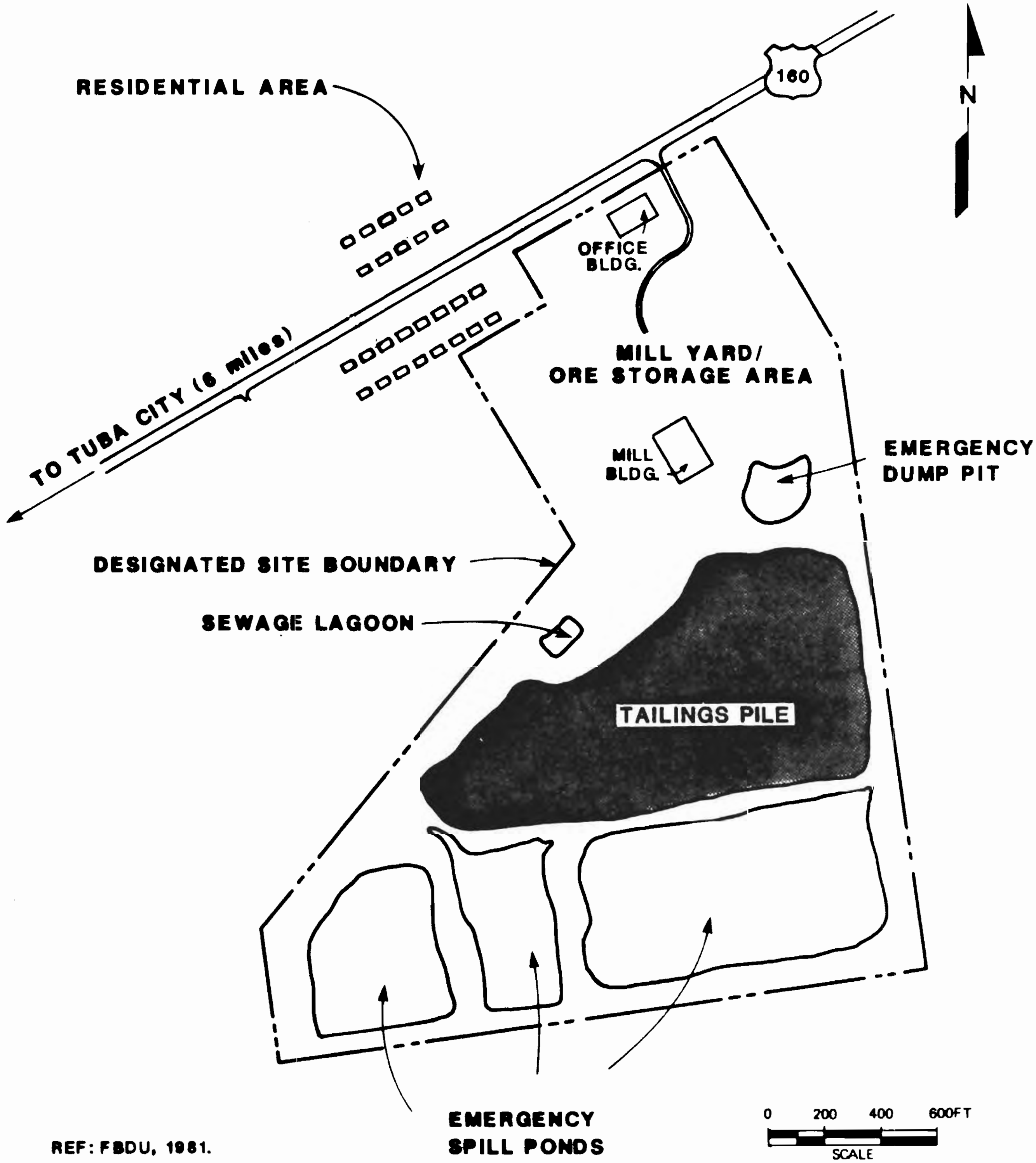


FIGURE 2.1
TUBA CITY TAILINGS SITE

Section 2.0 of this document describes the proposed action and the alternatives to it. Section 3.0 discusses the present condition of the environment. Section 4.0 assesses the environmental impacts of the proposed action and the alternatives to it. This document does not contain all of the details of the studies on which it is based. The details are contained in the appendices at the end of this document and in the referenced supporting documents.

2.2 THE PROPOSED ACTION - STABILIZATION IN PLACE

The proposed action for the Tuba City tailings site is to stabilize the tailings pile at its present location. All contaminated materials from around the pile would be consolidated with the tailings, and the pile would be covered with compacted earth to inhibit radon emanation and water infiltration. A rock erosion barrier would be placed over the pile to inhibit wind and water erosion and discourage animal and human intrusion.

The concept for stabilization in place was developed to comply with the EPA standards, and other objectives. Details of the concepts are provided in Appendix A, Engineering Summary, and in the draft Remedial Action Plan and Site Conceptual Design for Stabilization of the Inactive Uranium Mill Tailings Site at Tuba City, Arizona (DOE, 1985b).

Description of final condition

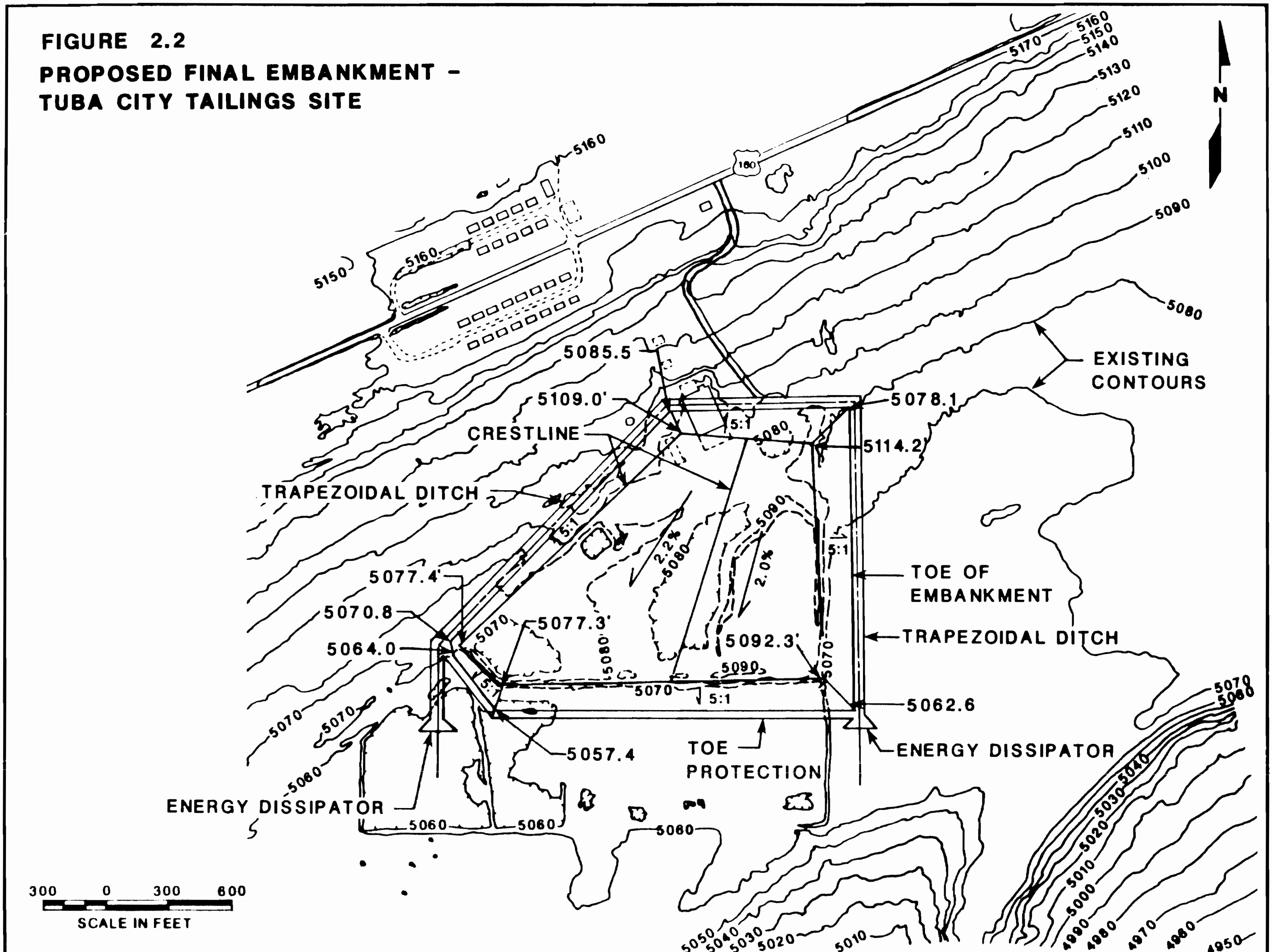
The stabilized pile would be roughly triangular in shape, with a maximum side of 1940 feet in length and minimum sides of 1585 feet (Figure 2.2). The tailings and contaminated materials would be covered with 1.5 feet of compacted earth and one foot of graded rock for erosion protection. The stabilized tailings pile would have maximum sideslopes of 20 percent and a topslope of two to three percent. The average height of the pile above the surrounding terrain would be approximately 33 feet (Figure 2.3).

The rock erosion barrier on top of the pile would tie into a two-foot-thick layer of rock armoring on the south side of the pile and into rock-armored drainage channels on the north, east, and west sides of the pile. A drainage ditch would divert surface runoff around and away from the pile. Concrete posts with warning signs would be placed around the pile.

The stabilized tailings pile would occupy an area of 48 acres situated entirely within the designated site boundary. The entire disposal area would cover 60 acres. After remedial action, disturbed areas surrounding the stabilized tailings pile would be restored to a condition compatible with the surrounding terrain by recontouring to promote surface-water drainage and revegetating as required for erosion control. Approximately 45 acres of the present site would be released for any use consistent with local land use controls following the completion of remedial action.

FIGURE 2.2

PROPOSED FINAL EMBANKMENT - TUBA CITY TAILINGS SITE



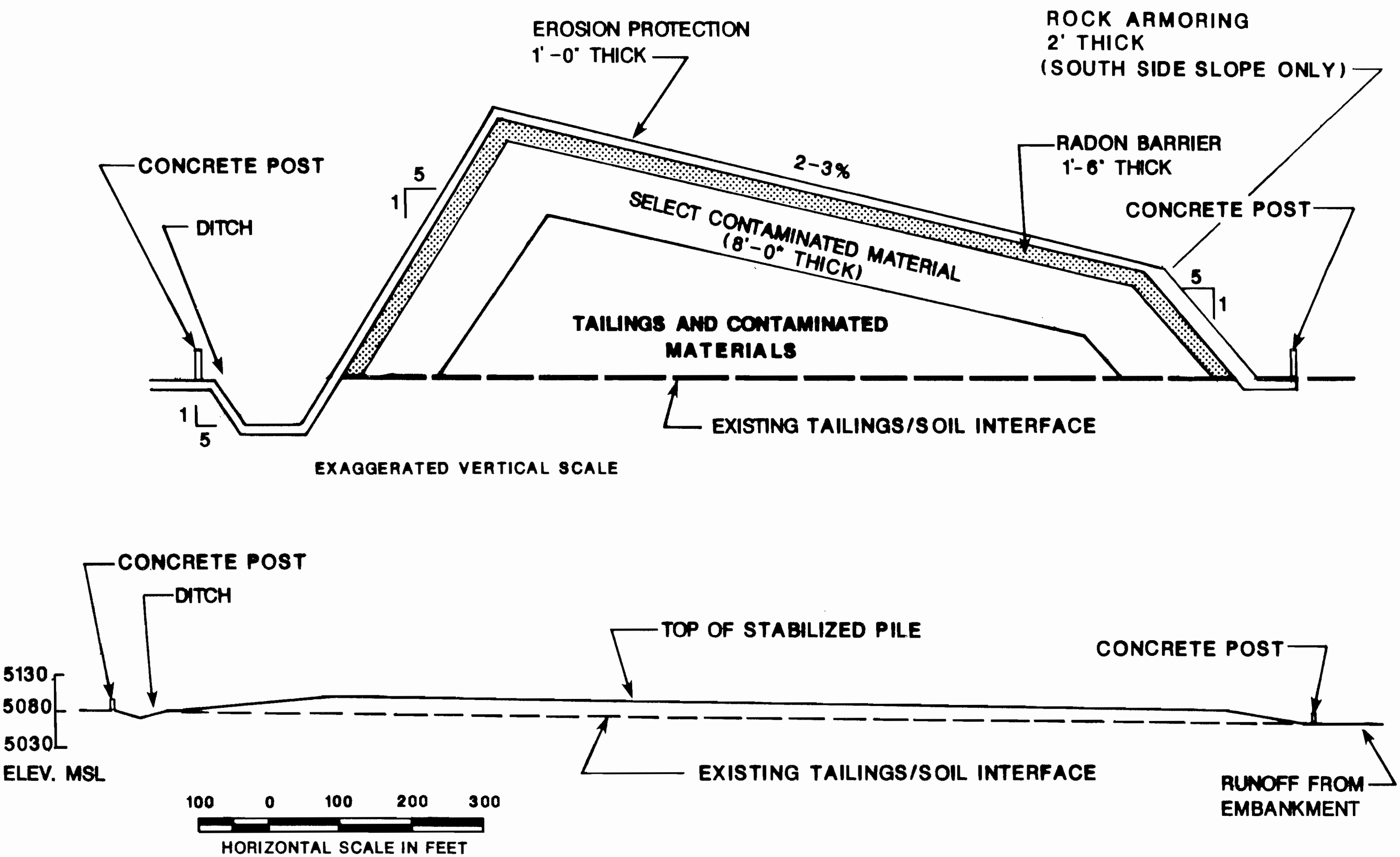


FIGURE 2.3

STABILIZATION IN PLACE
TYPICAL CROSS-SECTION

Features incorporated in the design to control radon emissions, ensure long-term stability, and protect ground water are detailed in Appendix A, Engineering Summary.

Major construction activities

The remedial action would be performed using conventional construction practices and technologies that comply with applicable regulations (Appendix E, Permits, Licenses, Approvals) and that would ensure the safe and environmentally sound stabilization of the tailings and other contaminated materials. The major construction activities for stabilization in place would be site preparation, demolition of existing structures, construction of drainage control measures, consolidation of all contaminated materials onto the existing tailings pile, upgrading of haulage roads to the borrow sites, excavation of borrow materials, placement of cover materials onto the tailings pile, and restoration of the area surrounding the tailings pile and the borrow sites.

Construction of the stabilized tailings pile would require the use of borrow materials (earth and rock). The Greasewood Lake borrow site is located approximately two road miles northeast of the tailings site (Figure 2.4) and would be used as the source of fine-grained earthen materials for the radon barrier cover. Other fine-grained material for the radon cover would be obtained from the excavation of drainage channels adjacent to the site. The Shadow Mountain borrow site is located approximately 25 road miles west of the tailings site (Figure 2.4) and would be used as the source of large rock materials for erosion protection. The Pediment Gravel borrow site is adjacent to the west boundary of the site and would be used as the source of gravel-size rock for erosion protection. An additional borrow site has been identified near the Tuba City site and would be used only if the Pediment Gravel borrow site does not contain a sufficient volume of gravel-size rock. These borrow sites are shown in Figure 2.4.

Details of the construction activities and a schedule for the remedial action are contained in Appendix A, Engineering Summary.

Construction estimates

Estimates of personnel requirements, energy and water consumptions, volumes of materials, and costs for stabilization in place are contained in Appendix A, Engineering Summary.

2.3 OTHER ALTERNATIVES

2.3.1 No action

The CEQ regulations (40 CFR Parts 1500 through 1508) require that all environmental assessments address the no action alternative. This alternative consists of taking no steps toward remedial action at the tailings site. The tailings pile would

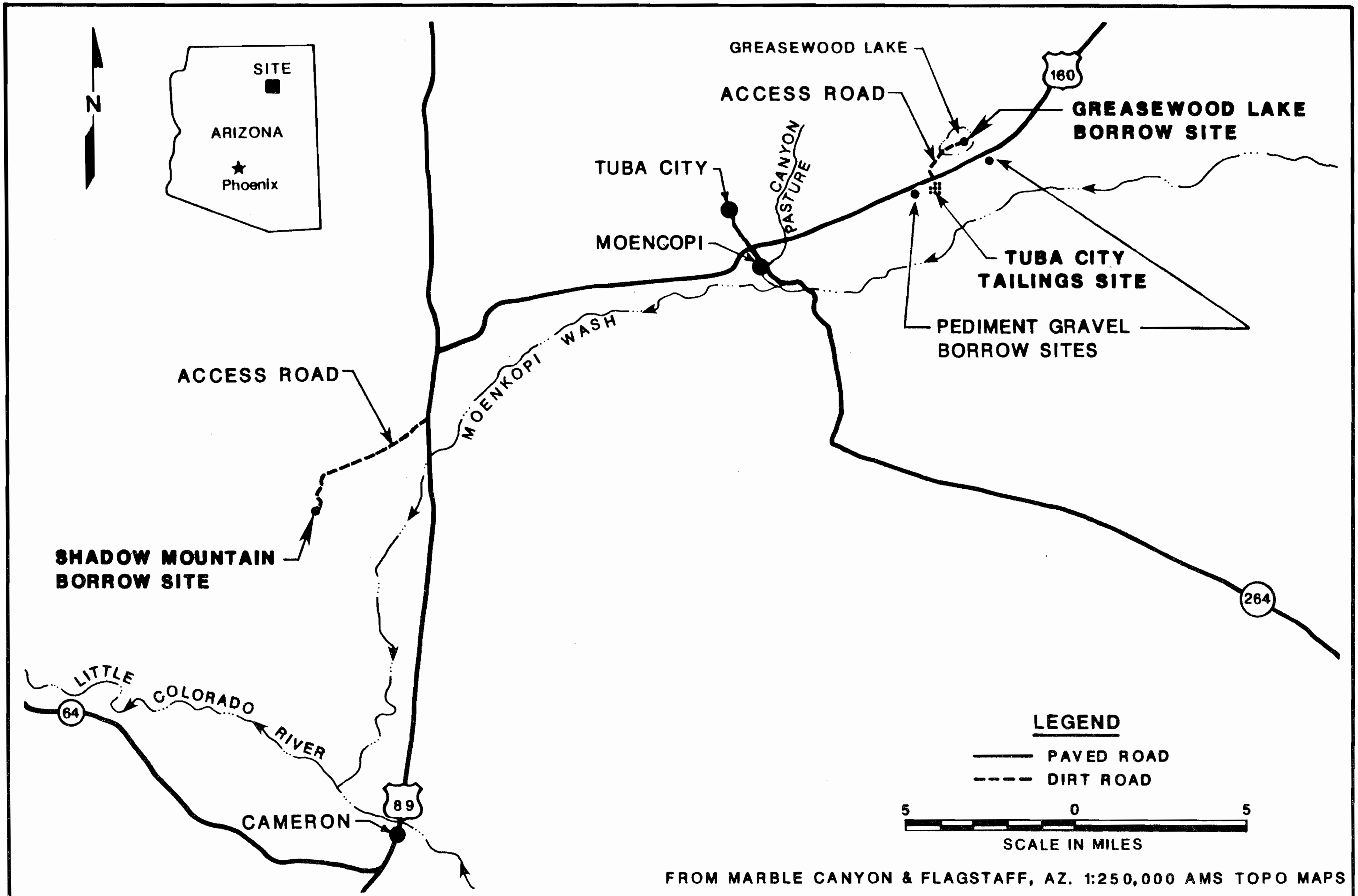


FIGURE 2.4
LOCATIONS OF BORROW SITES

remain in its present condition and would continue to be subject to dispersal by wind and water erosion and unauthorized removal by man. The selection of this alternative would not be consistent with the intent of Congress in the UMTRCA (PL95-604) and would not result in DOE's compliance with the EPA standards (40 CFR Part 192).

2.3.2 Disposal at the Fivemile Wash site

An extensive process was used by the DOE to locate and evaluate alternate disposal sites for the Tuba City tailings (Section 2.4). This process led to the selection of the Fivemile Wash site (Figure 1.2), which is located approximately 16 road miles southwest of the Tuba City tailings site.

Disposal of the tailings at the Fivemile Wash alternate disposal site would involve moving all of the contaminated materials to a site approximately 16 road miles southwest of the existing tailings site (Figure 1.2). This land is used primarily for low density livestock grazing. The site is approximately two air miles from the nearest residence. The design objectives for the alternate disposal site would be identical to those selected for stabilization in place (Appendix A, Engineering Summary).

The contaminated materials would be consolidated in a partially below-grade pile and covered with compacted earth and rock similar to stabilization in place. The existing tailings site would be recontoured to promote surface drainage, revegetated, and released for any uses consistent with local land use controls. The conceptual design for the alternate disposal site is based on existing unpublished data. If this alternative were selected, additional site-specific data would be obtained before the final engineering design was prepared.

2.4 REJECTED ALTERNATIVES

Alternate disposal sites

An alternate disposal site selection process was used by the DOE to locate and evaluate alternate disposal sites for the Tuba City tailings. This process consisted of the following phases: (1) designation of a search region; (2) development of guidelines for eliminating unacceptable areas from the search region; (3) application of the guidelines; (4) evaluation and field reconnaissance of potential sites; and (5) selection of a single disposal site for comparison with the proposed action, stabilization in place.

An area within a five-mile radius of the tailings site was designated as the initial search region. Although the selection of the initial search region was somewhat arbitrary, a mechanism for expanding the search region was incorporated into the site selection process. The area was subsequently expanded, since suitable sites for tailings relocation were not identified in the initial search region.

Twenty-two regional screening guidelines were developed specifically for the region surrounding the Tuba City site (Table 2.2). The guidelines were used to eliminate broad areas from consideration that, if included, might have required greater complexity in the design (e.g., steep slopes) or posed problems of a regulatory nature (e.g., cultural resource clearance). Three candidate sites were identified in the remaining areas not excluded by application of the guidelines (Figure 2.5).

The three candidate disposal sites were evaluated on the basis of hydrologic, meteorologic, geologic, environmental, and economic data in the literature and collected during field reconnaissance. Hydrologic and meteorologic conditions were assessed for erosional factors, existing water quality, drainage and flooding characteristics, precipitation, and location of aquifers. Special consideration was given to drainage basin configuration, infiltration potential, and location of ground-water recharge and discharge areas. Geologic evaluation addressed stability and soil characteristics such as the presence of slides or faults and types of unconsolidated and bedrock materials. The potential mineral resource values of the candidate sites were also considered. The environmental evaluation assessed land use potential, animal habitats, cultural resource values, proximity to population centers and dwellings, and aesthetics. Economic considerations included estimates of impacts to support facilities such as highways, distances from the Tuba City site, and the extent of anticipated site preparation and long-term maintenance.

The alternate site selection process led to the selection of a single disposal site, the Fivemile Wash site. The major factor in this selection process was that the Fivemile Wash site is stratigraphically lower than the Navajo Sandstone, the principal aquifer in the region. The Pipeline site and the Coal Mine Mesa site are situated stratigraphically on or above the Navajo Sandstone. Disposal at either of these sites would require greater consideration of ground-water protection measures in the design of the stabilized tailings pile. A conceptual design for tailings relocation to the Fivemile Wash site was developed and the impacts of this alternative are qualitatively compared to the proposed action in this document.

Reprocessing the tailings

The feasibility of reprocessing the tailings to recover residual uranium, vanadium, and molybdenum was evaluated. A drilling and sampling program was conducted to determine the total recoverable amounts of these metals in the tailings and underlying materials. Laboratory testing was then performed to determine the best reprocessing method: conventional plant processing (milling), vat leaching, or heap leaching. Finally, the economics of the best reprocessing method were evaluated (MSRD, 1982).

The evaluation concluded that although the recovery of additional uranium, vanadium, and molybdenum from the tailings is technically feasible, it would not be economical at the present market values for these products ($34.50 per pound combined value in 1982). The combined market value for uranium, vanadium, and molybdenum would have to increase to approximately $108.00 per pound for the reprocessing to "break even" (MSRD, 1982).

Table 2.2 Tuba City alternate site selection final regional screening guidelines

Characteristic	Criteria definition
Geologic faults	Areas within 0.25 mile of mapped geologic faulting.
Liquefaction potential	Within 0.25 mile of visible surface indications of disrupted drainage or broken ground.
Landslides	Areas within 0.25 mile of visible indications of slope instability.
Unstabilized dunes	Areas within 0.25 mile of major active sand dunes.
Erosive soils	Areas of known highly erosive soils.
Slopes and escarpments	Slopes steeper than 33 percent grade; or areas from the top of an escarpment in excess of 10 feet in height established by the intersection of the ground surface with a plane inclined at a 20° angle from a horizontal plane passing through the toe of the escarpment, or 100 feet, whichever is greater.
Subsidence areas	Within 0.25 mile of areas susceptible to subsidence by natural or man-made causes.
Mineral resources	Significant known recoverable resources of oil, gas, coal, and other minerals (except uranium and gravel).
Floodplains	100-year floodplains as defined by the U.S. Department of Housing and Urban Development, the U.S. Department of Energy, or within 0.25 mile of stream centerline.
Surface water	Areas within 0.25 mile of stock ponds, reservoirs, rivers, springs, or perennial streams, including Moenkopi Wash.
Ground water	Areas directly overlying, or recharge areas for, sole-source aquifers or aquifers containing potable water; unless, the ground waters in those aquifers are hydrologically isolated from downward migration of contaminants by low permeability geologic formations or strata.

Table 2.2 Tuba City Alternate site selection final regional screening guidelines (Concluded)

Characteristic	Criteria definition
Playa areas	Enclosed drainage areas lower in elevation than five feet above the elevation of a playa.
Drinking water supplies	Areas within one mile (horizontal distance) of drinking water supplies, including wells.
Potential source of ground-water contamination (other than tailings)	Areas within one mile downgradient of potential sources of ground-water contamination.
Wetlands	Wetlands as defined by the U.S. Fish and Wildlife Service.
Communities	Areas within one mile of community limits (legal boundary).
Dwellings	Areas within 0.25 mile of existing dwellings.
Transportation and communication corridors	Areas within the rights-of-way of state, Federal, or county roads, gas pipelines, or electrical transmission lines.
Archaeological and cultural resources	Within 100 feet of known archaeological or cultural resources and sites on the National Register of Historic Places.
Wilderness and natural areas	Within 0.25 mile of designated wilderness areas, wilderness study areas, natural areas, areas of critical environmental concern, and features listed in the National Registry of Natural Landmarks.
Critical habitat	Within 0.25 mile of designated critical habitat for threatened or endangered species and botanically and geologically unique or sensitive areas.
Prime agricultural lands	Within 0.25 mile of soils with USDA Soil Conservation Service classification I or II.

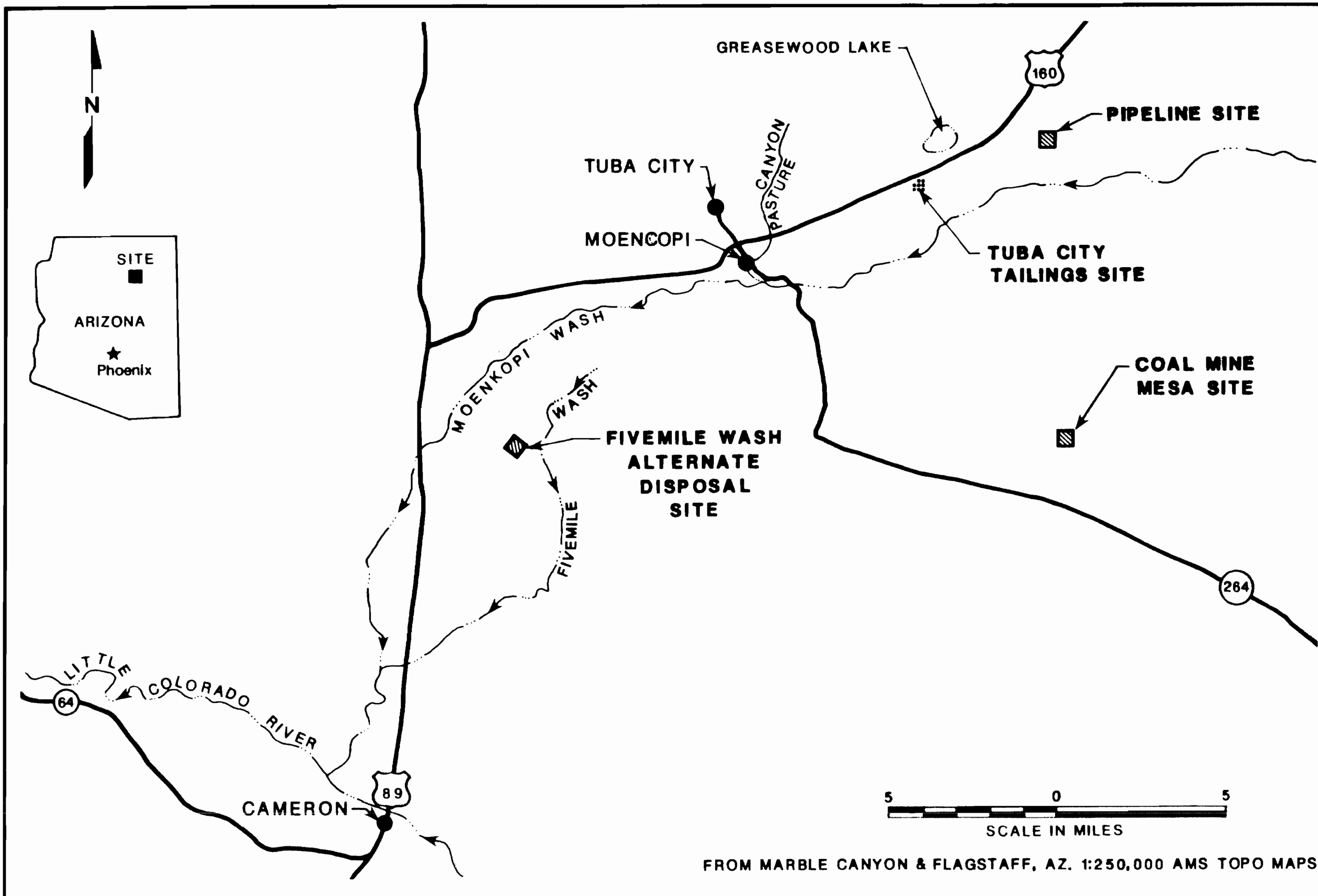


FIGURE 2.5
LOCATIONS OF CANDIDATE DISPOSAL SITES

Reprocessing of the tailings would not reduce the radium content of the tailings. Because radioactive decay of radium is the source of radon gas, there would be no reduction of the hazard from radon and radon daughters; hence, the reprocessed tailings would still require remedial action to meet the EPA standards. Reprocessing was therefore not considered in detail in this EA.

Returning the tailings to the original mines

It was determined that it would not be feasible to return the tailings to the mines from which the uranium ores were originally obtained. The ore processed at the Tuba City site came from scattered mines in the Cameron and Grand Canyon areas of Arizona which are approximately 30 road miles and 85 road miles from the tailings site, respectively (FBDU, 1981). The excessive cost and many environmental concerns associated with stabilizing the tailings at the mines makes this option infeasible.

Aquifer restoration

Aquifer restoration is not proposed for the following reasons:

- The cost of the various aquifer restoration methods was more than the potential value of the water (page B-79).
- The present lack of the use of ground water in the contaminated area (page B-71).
- The relatively low potential for impacts on future use (Section B.2.7, page B-73).
- Availability of ample alternate water supplies in the area (page B-71).
- Use of institutional controls to restrict usage of contaminated ground water costs less than aquifer restoration (page B-79). Furthermore, the Navajo Nation and Hopi Tribe require the permitting of water wells drilled on the Navajo and Hopi Reservations. For the Navajo Nation, the permitting process has been successful since 1984, when the Tribal Council enacted the Water Code.

DOE will mitigate contaminated ground water by applying institutional controls on water development around the site. When EPA issues revisions to the water protection standards (40 CFR 192.20(a)(2)-(3)) that were remanded by the U.S. Tenth Circuit Court of Appeals, DOE will re-evaluate the ground-water issues at the Tuba City site to assure that the revised standards are met. Performing remedial actions to stabilize the tailings prior to EPA issuing new standards will not affect the measures that are ultimately required to meet the revised water protection EPA standards.

REFERENCES FOR SECTION 2.0

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3.0 AFFECTED ENVIRONMENT

3.1 DESCRIPTION OF THE EXISTING TAILINGS SITE

The Tuba City mill was built in 1956 by the Rare Metals Corporation of America, who operated the mill from 1956 until 1962. In 1962, the Rare Metals Corporation merged with the El Paso Natural Gas Company which operated the mill until 1966.

The Tuba City mill was originally designed to process uranium ores using an acid leach and resin-in-pulp ion exchange process. Using this process, the mill was operated from June, 1956, through April, 1962, processing 300 tons per day. In 1962, a high-lime content ore became the primary feed source, and the mill was modified to use a carbonate leach process. It operated with this process from April, 1963, through September, 1966, processing 200 tons per day. During milling operations, approximately 800,000 tons of ore were processed to produce 2348 tons of uranium in concentrate (Brown et al., 1974).

There are two distinct physical features of the Tuba City tailings. The eastern portion of the pile contains the tailings from the original acid leaching process. The center and western portions of the pile contain the tailings from the carbonate leaching process. The entire tailings pile covers approximately 25 acres and averages approximately 17 feet in depth. Approximately 689,000 cubic yards of tailings are contained in the pile.

In 1968, the El Paso Natural Gas Company, in cooperation with the U.S. Bureau of Mines, applied a chemical stabilizer to the surface of the tailings pile to control the dispersion of tailings by wind and water erosion (Havens and Dean, 1969). The crust formed by the chemical stabilizer remained intact for several years; however, its long-term performance proved inadequate. Currently, only scattered remnants of the crust exist on the tailings pile. No further attempts were made to stabilize the pile.

The 105-acre designated site consists of the tailings pile (25 acres), three former emergency spill ponds (34 acres), the mill yard and ore storage area (28 acres), and the remainder of the site, including the emergency dump pit and sewage lagoon (18 acres) (Figure 2.1). The mill and office buildings remain at the site, but have deteriorated due to vandalism and lack of maintenance since mill closure. The emergency spill ponds lie immediately southwest of the tailings pile. These ponds contain few tailings. A smaller pond southeast of the mill building was used as an emergency dump pit; however, the type of material it received is not known. A sewage lagoon is located adjacent to the tailings pile to the north. A security fence was constructed around the designated site in 1984.

Wind and water erosion have spread the contamination over approximately 222 acres outside of the designated site boundary. The main cause of erosion is from wind; however, surface-water runoff has caused some erosion of the tailings dikes and windblown tailings. Most runoff from the dikes settles in the former emergency spill ponds, the emergency dump pit, or the sewage lagoon. Overland water flow has transported some of the tailings from the eastern dikes and windblown areas away from the site. The dikes are effectively protecting the rest of the tailings from water erosion.

3.2 WEATHER

The climate of the Tuba City area is arid. Very light precipitation, warm summers, cool winters, and occasionally strong seasonal winds are characteristic of the area.

The annual average temperature at Tuba City is 54.7°F. Due to the high elevation and low humidity at Tuba City, large daily temperature variations are typical. Normal daily highs range from 45°F in January to 95°F in July, while normal daily lows range from 19°F in January to 61°F in July (Table 3.1). Extreme temperatures were a minimum of -13°F and a maximum of 110°F for a 41-year period of record from 1931 to 1972 (NOAA, 1976).

The average annual precipitation at Tuba City for a 30-year period of record from 1941 to 1970 was approximately 6.2 inches (Table 3.1). Of this amount, 3.8 inches occurred as snow, sleet, or hail. The greatest monthly rainfall occurs in August which is the peak of the late summer thunderstorm season. The driest month is June (NOAA, 1976).

Table 3.1 Temperature and precipitation at Tuba City, Arizona[a]

	Temperature (°F)		Precipitation (inches)
Month	Mean daily maximum	Mean daily minimum	Mean monthly (total)
January	44.8	18.6	0.42
February	53.0	24.0	0.37
March	60.4	28.9	0.60
April	70.6	36.8	0.34
May	88.0	44.8	0.37
June	89.7	52.1	0.22
July	95.0	61.0	0.65
August	92.3	58.5	0.99
September	85.6	50.4	0.64
October	73.4	39.2	0.65
November	57.0	28.7	0.38
December	46.8	21.6	0.55
Annual	70.7	38.7	6.18

[a]Period of record, 1941 to 1970.

Ref. NOAA, 1976.

No wind data are available for the Tuba City area; however, the distribution of windblown tailings and formation of sand dunes in the area indicate a predominant wind direction from the southwest (FBDU, 1981a). Wind data from the National Weather Service station at Winslow, Arizona (Table 3.2), are considered representative of regional wind conditions. Winslow is located 85 miles south-southeast of Tuba City, at an elevation of 4900 feet. During late fall and winter, the prevailing wind direction in Winslow is from the southeast. In spring and summer, the winds flow primarily from the southwest. During the spring months, occasional high winds pick up significant quantities of dust; however, the annual average wind velocity is less than 10 mph.

The meteorological conditions at the borrow sites are expected to be very similar to the conditions at the Tuba City site.

Table 3.2 Wind direction, distribution, and average speed at Winslow, Arizona

Direction (from)	Frequency of occurrence (%)	Average speed (mph)
N	3.5	8.1
NNE	1.4	6.7
NE	1.5	6.7
ENE	1.9	6.9
E	5.6	8.0
ESE	8.3	8.3
SE	6.3	7.5
SSE	2.9	7.9
S	6.9	11.1
SSW	7.4	12.6
SW	14.2	12.8
WSW	9.4	12.0
W	5.8	10.1
WNW	3.9	9.9
NW	4.4	10.1
NNW	3.3	10.0
Calm	13.3	--
Overall	100.0	8.8

Ref. NOAA, 1984.

3.3 AIR QUALITY

Table 3.3 lists the Federal Ambient Air Quality Standards. The primary standards define levels of air quality necessary, with an adequate margin of safety, to protect the public health. Secondary standards define levels of air quality necessary to protect the public welfare from any known or anticipated adverse effect of pollutants. Annual standards are not to be exceeded at all, while short-term standards are not to be exceeded more than once per year (EPA, 1982). State ambient air quality standards for Arizona are the same as the Federal standards (Arizona Ambient Air Quality Standards, 1984).

Table 3.3 Federal Ambient Air Quality Standards[a]

Pollutant	Federal primary standard[b]	Federal secondary standard[b]
Total suspended particulates (TSP)		
24-hour average	260 microg/m^3	150 microg/m^3
Annual geometric mean	75 microg/m^3	60 microg/m^3
Sulfur dioxide (SO_2)		
24-hour average	365 microg/m^3 (0.14 ppm)	---
Annual arithmetic mean	80 microg/m^3 (0.03 ppm)	---
3-hour average	---	1300 microg/m^3 (0.5 ppm)
Carbon monoxide (CO)		
8-hour average	10 mg/m^3 (9 ppm)	10 mg/m^3 (9 ppm)
1-hour average	40 mg/m^3 (35 ppm)	40 mg/m^3 (35 ppm)
Ozone (O_3)		
1-hour average	0.12 ppm (235 microg/m^3)	0.12 ppm (235 microg/m^3)
Nitrogen dioxide (NO_2)		
24-hour average	---	---
Annual arithmetic mean	100 microg/m^3 (0.05 ppm)	100 microg/m^3 (0.05 ppm)
Lead (Pb)		
Calendar quarterly arithmetic average	1.5 microg/m^3	1.5 microg/m^3

[a]State ambient air quality standards for Arizona are the same as the Federal ambient air quality standards (Arizona Ambient Air Quality Standards, 1984).

[b]Microg/m^3 - micrograms per cubic meter; mg/m^3 - milligrams per cubic meter; ppm - parts per million.

Ref. EPA, 1982.

The project area lies within the Coconino County subdivision of the Arizona Bureau of Air Quality Control. Ambient air quality in this region is considered to be good. No air quality monitoring station exists at Tuba City. In Coconino County, there are air quality monitoring stations at Flagstaff, Page, and Grand Canyon (approximately 85, 80, and 80 miles to the south, north, and west of the tailings site, respectively) from which data were collected in 1983 (Table 3.4). Measurements of pollutants at Flagstaff, Page, and Grand Canyon indicate that pollutant concentrations in 1983 were within state and Federal standards, with the occasional exception of total suspended particulates (TSP) measured at Flagstaff. It is likely that concentrations of gaseous pollutants and TSP in the Tuba

City area would be lower than levels measured at Flagstaff. Potential exceedences of the TSP standard at Tuba City would probably be associated with high winds carrying fugitive dust from natural sources.

Table 3.4 Air pollutant concentrations near the Tuba City tailings site[a]

Pollutant	Flagstaff	Grand Canyon	Page
Total suspended particulates (TSP)			
Maximum 24-hour	193 microg/m^3	58 microg/m^3	141 microg/m^3
Annual geometric mean	68 microg/m^3	5 microg/m^3	41 microg/m^3
Sulfur dioxide (SO_2)			
Maximum 3-hour	N.A.	N.A.	324 microg/m^3
Maximum 24-hour	N.A.	N.A.	92 microg/m^3
Annual arithmetic mean	N.A.	N.A.	6 microg/m^3
Carbon monoxide (CO)			
Maximum 8-hour	8 mg/m^3	N.A.	N.A.
Maximum 1-hour	13 mg/m^3	N.A.	N.A.
Ozone (O_3)			
Maximum 1-hour	0.08 ppm	0.07 ppm	0.07 ppm
Nitrogen dioxide (NO_2)			
Maximum 24-hour	N.A.	N.A.	42 microg/m^3
Annual arithmetic mean	N.A.	N.A.	8 microg/m^3

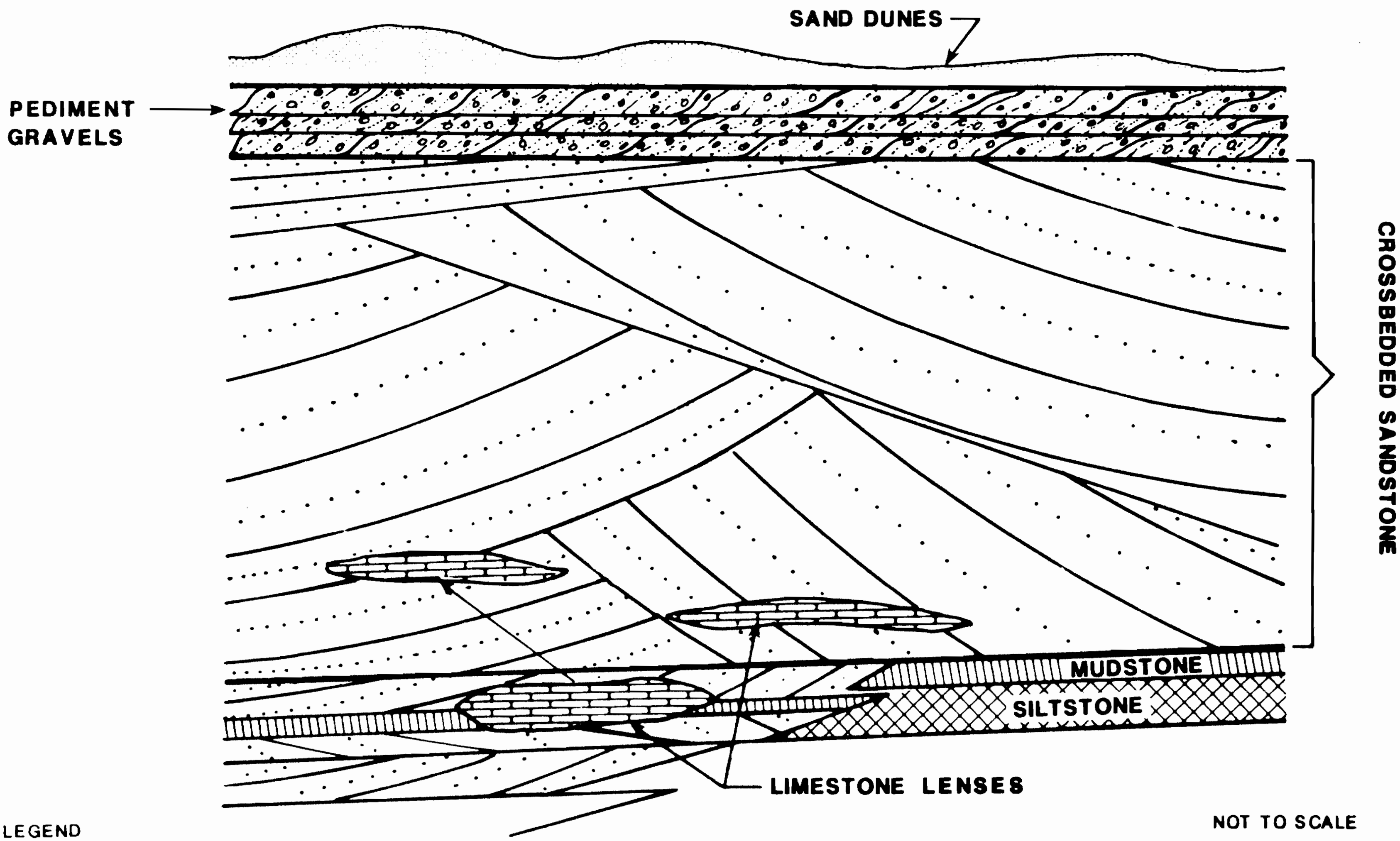
[a]Microg/m^3 - micrograms per cubic meter; mg/m^3 - milligrams per cubic meter; ppm - parts per million; N.A. - not available.

Ref. ADHS, 1984.

3.4 SURFACE AND SUBSURFACE FEATURES

The Tuba City site lies in the southern Kaibito Plateau, part of the Navajo Section of the Colorado Plateau physiographic province (TAC, 1985a). The Colorado Plateau is a major continental block exhibiting slow regional uplift. Uplifting has been occurring since late-Tertiary time (22,500,000 years ago) at a rate of approximately two millimeters per year (SHB, 1985). The geological structure of the project area is not complex, having formations with gentle dips associated with low amplitude anticlines and synclines (TAC, 1985a).

The stratigraphy of the Tuba City area (Figure 3.1) is characterized by sedimentary units of Mesozoic age (65,000,000 to 225,000,000 years old). The bedrock in the project area is composed of the following



LEGEND

PEDIMENT GRAVEL (PLEISTOCENE) POORLY SORTED, MODERATELY CEMENTED ANGULAR TO WELL ROUNDED SANDS, GRAVELS AND PEBBLES

NAVAJO SANDSTONE (JURASSIC AND TRIASSIC) FINE-TO MEDIUM-GRAINED EOLIAN SANSTONE; LOCALLY CALCAREOUS CEMENTATION; NUMEROUS THIN LENTICULAR BEDS OF CHERTY LIMESTONE; CONSPICUOUS LARGE-SCALE TROUGH-TYPE CROSSBEDDING

KAYENTA FORMATION (UPPER TRIASSIC) 'SILTY FACIES', MUDSTONE AND SILTSTONE AND FINE GRAINED SANDSTONE, LOCALLY INTERTONGUES WITH OVERLYING AND UNDERLYING FORMATIONS.

FIGURE 3.1 GENERALIZED STRATIGRAPHIC COLUMN, TUBA CITY AREA

formations, from oldest to youngest: (1) the Kayenta Formation of Triassic age (195,000,000 to 225,000,000 years old); (2) the Navajo Sandstone of Jurassic and Triassic age (136,000,000 to 225,000,000 years old); (3) the Carmel Formation, Entrada Sandstone, and Summerville Formation of Jurassic age (136,000,000 to 195,000,000 years old); and (4) the Dakota Sandstone and Mancos Shale of Cretaceous age (65,000,000 to 136,000,000 years old) (Haynes and Hackman, 1978). Surficial deposits overlying the bedrock are pediment gravels, eolian deposits, and alluvium (TAC, 1985a).

The topography of the Colorado Plateau has been greatly influenced by erosional processes occurring concurrently with regional uplift. Landforms such as entrenched river channels, broad mesas, and deep canyons are typical of the region. In the immediate vicinity of the tailings site, Moenkopi Wash has dissected the terrain, forming cliffs, gullies, and alluvial terrace deposits. The major topographic features of the area are Moenkopi Wash and Greasewood Lake.

Tuba City tailings site

The tailings site is situated on a gently sloping terrace surface approximately 6000 feet northwest of Moenkopi Wash. Borings show eolian and alluvial deposits of Quaternary age (less than 1,800,000 years old) directly beneath the tailings pile. The eolian material is composed of silt and sand derived from the Navajo Sandstone and is underlain by alluvial deposits. The alluvial deposits consist of rounded and sub-rounded sandstone fragments in a silty, cemented matrix (SHB, 1985). The thickness of the eolian and alluvial deposits beneath the tailings is approximately 20 feet (FBD, 1983). The Navajo Sandstone underlies the alluvial deposits.

The Navajo Sandstone is a tan to light orange, fine- to medium-grained, weakly cemented sandstone unit which displays large-scale cross-bedding. The sandstone outcrops at several locations on the site, including areas between the tailings site and U.S. Highway 160 and near the southeast corner of the site. Geophysical logs of wells located approximately one mile north of the site indicate that the thickness of the Navajo Sandstone is approximately 650 feet. The Navajo Sandstone conformably overlies the Kayenta Formation. The Kayenta Formation outcrops south of the tailings site along Moenkopi Wash and consists of interbedded mudstone, siltstone, fine-grained sandstone, and some thinly-bedded sandy limestone (Cooley et al., 1969). Bedrock at the site dips approximately two degrees northeast toward the axis of the Tuba City syncline which trends northwest-southeast approximately one mile northeast of the mill site (Haynes and Hackman, 1978).

Near-surface soils at and near the designated tailings site are derived primarily from the Navajo Sandstone. The Navajo Sandstone is deeply weathered, and is easily eroded by wind. This results in the formation of active sand dunes and sandy soil deposits. Soils in the area are mapped as Sheppard series soils which are reddish-brown to reddish-yellow, well-drained, loamy fine- to medium-textured sands. The taxonomic classification of Sheppard soils is mixed, mesic Typic

Torripsamments (SCS, 1972). Test drilling in the former emergency spill ponds has indicated the presence of soils of approximately 72 inches in depth (FBDU, 1981a). The soil is underlain by fluvially deposited Quaternary gravels; however, the parent material for the soil is the Navajo Sandstone. Near the site, vegetation has stabilized the sandy soils into numerous isolated hummocks.

No earthquakes have been recorded at Tuba City for the 110-year period of record from 1870 to 1980. Historically, most of the seismic activity in the Colorado Plateau has occurred along the plateau margins. One earthquake, interpreted as Intensity VIII (Modified Mercalli scale), occurred in 1906 near Flagstaff which is approximately 80 miles southwest of Tuba City (SHB, 1985).

The Tuba City site is located in a seismic region where a horizontal ground acceleration of 0.09g (the force of gravity, g, is an acceleration of 32 feet per second per second) could occur as a result of a seismic event (Figure 3.2) (Algermissen and Perkins, 1976). An earthquake of this magnitude has a 90 percent probability of not being exceeded in 50 years. Such an earthquake would result in moderate damage to buildings and other structures in the affected area.

The impact of a Design Earthquake established by seismic studies was used for establishing earthquake design parameters. A Design Earthquake of magnitude 6.2 (Richter scale) was estimated for a floating earthquake on the Colorado Plateau. An earthquake of this magnitude occurring 15 kilometers (9.3 miles) from the site would generate horizontal free field accelerations at the site of 0.21g. A complete description of site geology, geomorphology, and seismicity is contained in the draft Remedial Action Plan (DOE, 1985).

Mineral resources in the Tuba City area are minimal. Uranium host rocks occur throughout the Tuba City area with developed deposits and prospects present west of Tuba City along the western side of U.S. Highway 89. Coal occurs in the Dakota Sandstone (TAC, 1985a), and was mined at a location approximately 16 miles southeast of Tuba City until 1950 (Kiersch, 1956). Several alluvial terraces containing sand and gravel deposits occur in the immediate vicinity of the tailings site (Kiersch, 1955a). Limestone and bentonitic clay deposits are also present in the area (Kiersch, 1955b; Arizona Bureau of Geology and Mineral Technology, 1965). No mineral leases have been issued for the Tuba City tailings site (Store, 1985).

Borrow sites

The Greasewood Lake borrow site is located in Greasewood Lake, a dry playa containing fine-grained alluvial and eolian surface deposits underlain by the Navajo Sandstone. The thickness of the surface deposits is approximately 10 feet. Generally, the major soil type available at this borrow site is a low plasticity clayey sand.

The Shadow Mountain borrow site is located in rugged terrain at the base of an extinct volcano. Residual basalt surface deposits of approximately four feet in thickness overlie a three- to nine-foot-thick zone

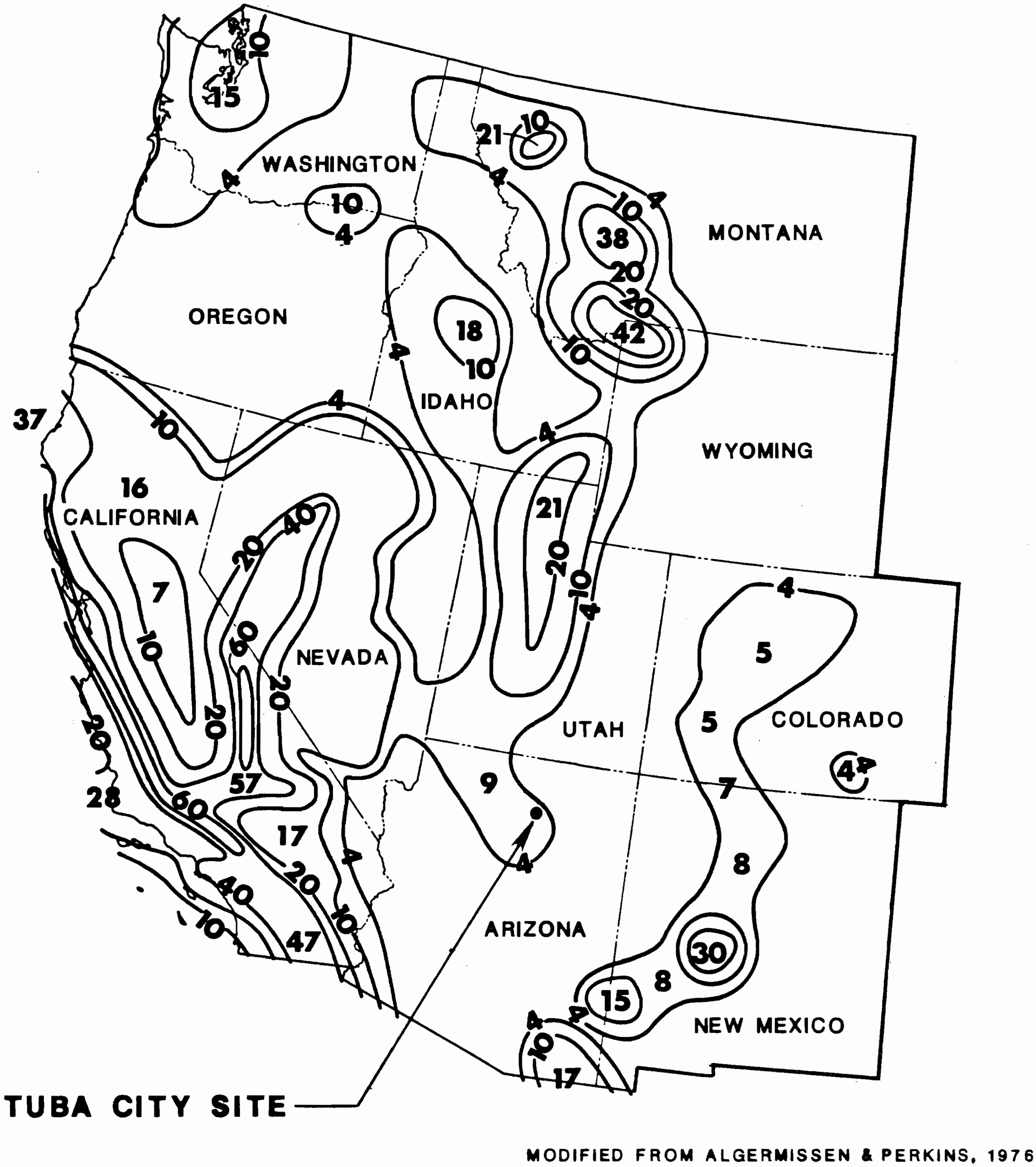


FIGURE 3.2
PRELIMINARY MAP OF HORIZONTAL ACCELERATION
(EXPRESSED AS A PERCENT OF GRAVITY)
IN ROCK WITH 90% PROBABILITY OF NOT BEING EXCEEDED IN 50 YEARS

of hard, black, glassy cinder. The cinder zone is underlain by an eight- to 10-foot-thick layer of vesicular basalt. This layer grades with depth into the material to be quarried which is a more dense, less vesicular basalt. The lava flow is approximately 50 feet thick, and is underlain by the Chinle Formation of Triassic age (195,000,000 to 225,000,000 years old) (Haynes and Hackman, 1978).

The Pediment Gravel borrow site is adjacent to the northwest side of the Tuba City site and has the same geologic features as described above for the Tuba City site. The gravel deposit occurs approximately three feet below the surface and varies in thickness up to 12 feet. The rock sizes range in diameter up to two inches.

The borrow sites (see Figure 2.4) are on the Bennett Freeze Order Area (Norton, 1986) and the mineral revenues are shared by the Hopi Tribe and the Navajo Nation (Store, 1986). There are no mineral leases on file for, or mineral development activities at or near, the Greasewood Lake, Shadow Mountain, or Pediment Gravel borrow sites (Store, 1985).

3.5 WATER

3.5.1 Surface water

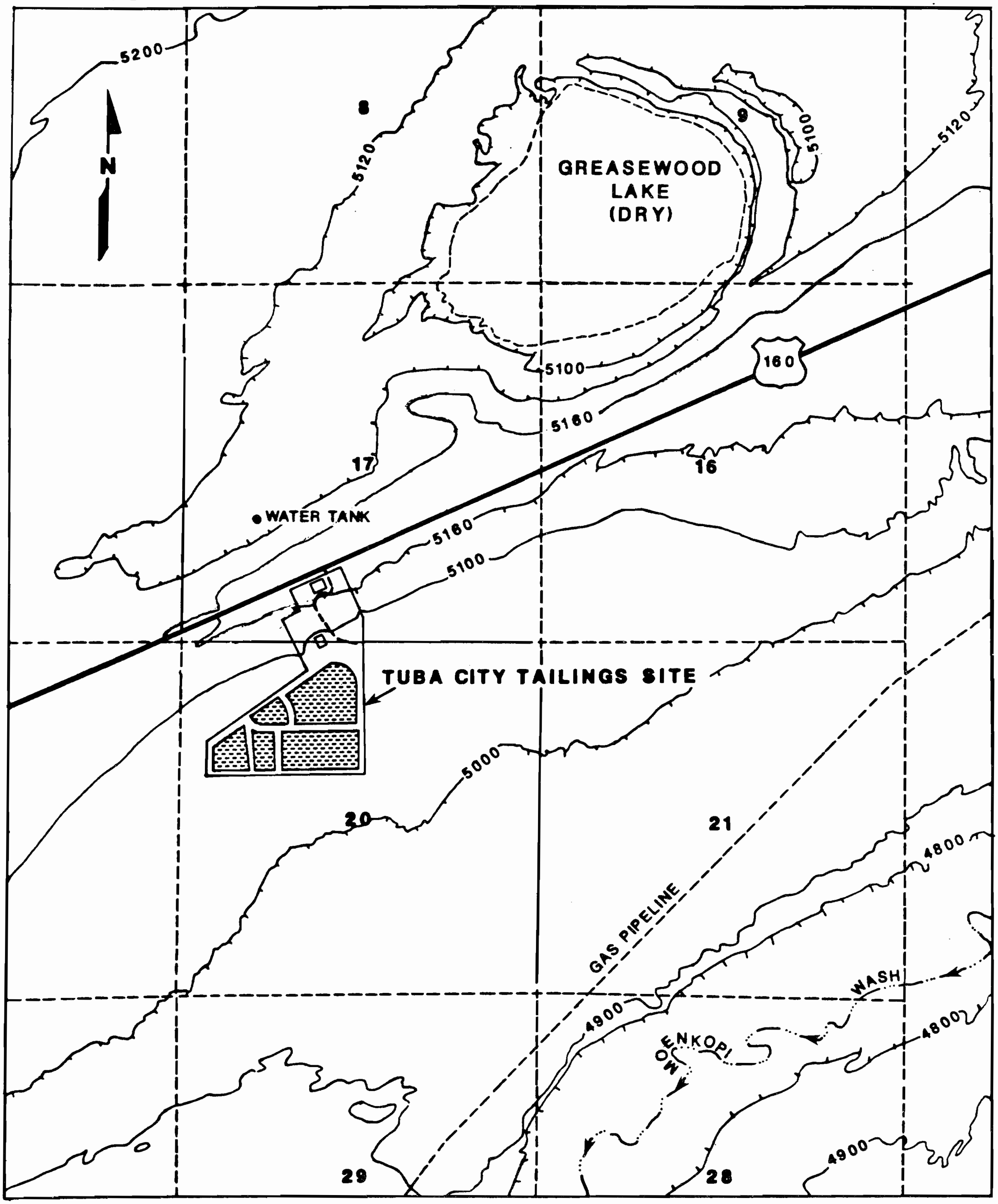
Section 3.5.1 describes surface-water occurrence, flow patterns, uses, and quality for the Tuba City tailings site and the Greasewood Lake, Shadow Mountain, and Pediment Gravel borrow sites. Additional details on surface water are provided in Section B.1 of Appendix B, Water.

Tuba City tailings site

The Tuba City tailings site is located approximately 8000 feet northwest of Moenkopi Wash, an intermittent stream that drains to the southwest into the Little Colorado River. No other established watercourses, intermittent or ephemeral, exist in the vicinity of the tailings site. Figure 3.3 illustrates the surface drainage in the area.

The wash has a drainage area of approximately 2500 square miles near the Tuba City tailings site. Surface drainage for the tailings site is to the southeast toward Moenkopi Wash. The drainage area above the tailings site is bounded by U.S. Highway 160 which runs along a low ridge. All drainage on the north side of the highway flows toward Greasewood Lake, a large depression centered approximately 1.5 miles northeast of the tailings site.

There are no U.S. Geological Survey (USGS) stream gaging stations currently operating on Moenkopi Wash in the vicinity of the Tuba City tailings site. A former station located at the bridge near U.S. Highway 89 (11 miles southwest of Tuba City) recorded average annual flows of approximately 10,650 acre-feet for the 15-year period of record from 1926 to 1941. The magnitude of this flow varied substantially, ranging from several days of no



FROM TUBA CITY & TUBA CITY NE, AZ. USGS 7 1/2 MIN. QUADS

1000 0 1000 2000
SCALE IN FEET

FIGURE 3.3

EXISTING DRAINAGE CONDITIONS - TUBA CITY SITE

flow to a measured peak flow of 14,500 cubic feet per second on August 28, 1934. This peak flow was at a depth of 12.85 feet (Beal, 1985).

No data are available for flooding of Moenkopi Wash. However, the tailings pile is approximately 300 feet in elevation above and 6000 feet away from the streambed; therefore, the potential for floodwaters reaching the tailings pile is considered negligible.

In the Tuba City area, the surface waters of Moenkopi Wash are used for livestock watering and irrigation.

Analysis of surface-water samples from four points on Moenkopi Wash near the tailings site indicates that the water is high in total dissolved solids, sulfates, iron, sodium, and calcium (TAC, 1985b). Even though surface water in the area is not used for domestic purposes, a comparison of the water quality with drinking water standards promulgated by the U.S. Environmental Protection Agency (EPA) (40 CFR Part 141) is useful in defining water quality. Except for iron, sulfate, total dissolved solids concentrations, and gross alpha particle activity in Moenkopi Wash, no other contaminants were found in the surface water that exceeded the EPA's National Primary Drinking Water Standards or National Secondary Drinking Water Standards for public water supplies (Appendix B, Water).

The data also show that the concentrations of most constituents increase in the downstream direction. The flow rate of ground water from the tailings toward Moenkopi Wash and the distance of discharge points along the wash from the tailings indicates that the increases are due to natural causes and are not due to the discharge of ground water contaminated by the tailings to Moenkopi Wash.

Borrow sites

The Greasewood Lake borrow site (see Figure 2.4) is in the bottom of a dry desert basin (playa) with interior drainage. The elevation at the center of Greasewood Lake is 5087 feet. The total drainage area for Greasewood Lake is approximately 20,000 acres.

The Shadow Mountain borrow site (see Figure 2.4) is approximately 150 feet north of an ephemeral stream that drains the area southwest of the borrow site toward Moenkopi Wash. The ephemeral stream meets Moenkopi Wash approximately 3.2 miles south of the borrow site at an elevation 440 feet below the borrow site. The total drainage area for the borrow site is approximately 19.3 acres.

The Pediment Gravel borrow site (see Figure 2.4) is located approximately 6500 feet northwest of Moenkopi Wash on the slope of an alluvial terrace. The site has drainage characteristics which are very similar to the conditions described above for the Tuba City site.

3.5.2 Ground water

The existing ground-water conditions at the Tuba City tailings site and the proposed borrow sites are summarized in this section. Ground-water data from the tailings site and detailed analyses of these data are presented in Section B.2 of Appendix B, Water.

Tuba City tailings site

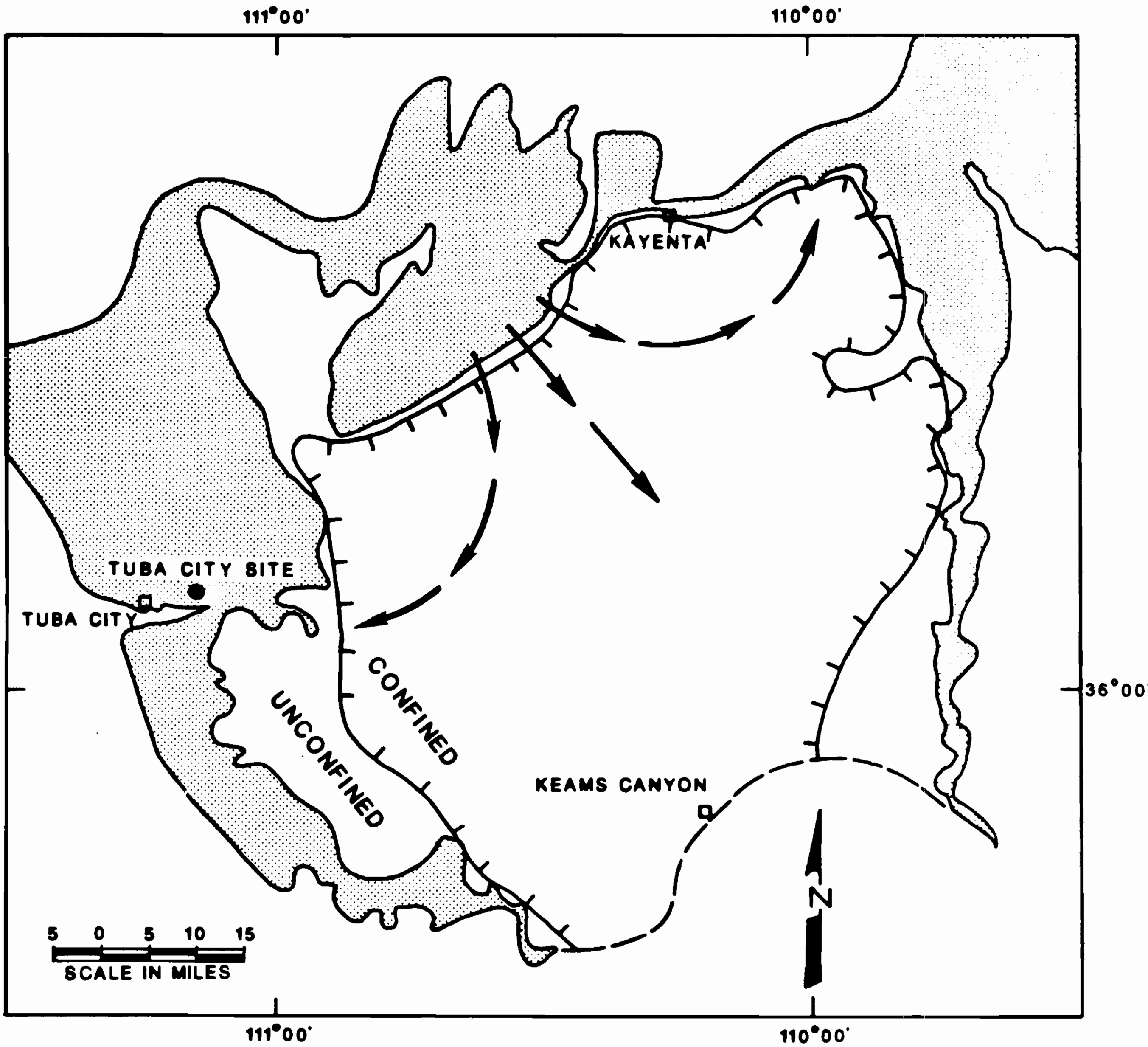
The Tuba City site is underlain by approximately 650 feet of Navajo Sandstone, a fine to medium-grained sandstone that is locally cemented by carbonaceous materials. The Navajo Sandstone intertongues with the underlying Kayenta Formation, a series of interbedded, fine-grained sandstones and mudstones. There is no continuous hydraulic barrier to ground-water flow between the Navajo and the Kayenta, and together they comprise the N-aquifer, the major aquifer of the Navajo and Hopi Reservations.

According to Eychaner (1983) the aquifer's major recharge area is in the vicinity of Shonto, about 40 miles northwest of Tuba City. Ground-water flow diverges from the recharge area, some flowing northeast toward Laguna Creek, and some flowing south toward Tuba City and Moenkopi Wash (Figure 3.4). In addition to the recharge area around Shonto, it is likely that other unconfined portions of the aquifer are recharge areas, especially where precipitation may percolate through dune sands, such as in the area around the tailings site.

The N-aquifer is unconfined near the site and the water table ranges from about 20 feet to 150 feet below land surface. The ground water flows in a southeasterly direction from the site toward Moenkopi Wash, approximately 8000 feet away in the downgradient direction (Figure 3.5). Calculated ground-water flow rates range from about five feet per year (ft/yr) to about 140 ft/yr.

Leachate from the tailings pile has contaminated the underlying ground water with a variety of heavy metals, radionuclides, and constituents associated with the milling process (Figure 3.6). Within the contaminant plume, concentrations of cadmium, gross alpha, selenium, and nitrate exceed the EPA Primary Drinking Water Standards. Concentrations of iron, manganese, TDS, and sulfate exceed the EPA Secondary Drinking Water Standards. The contaminant plume extends to more than 1300 feet and less than 2000 feet downgradient of the pile.

Details on ground-water quality are contained in Section B.2 of Appendix B, Water.



REF: EYCHANER, 1983

AREA OF NAVAJO SANDSTONE (N AQUIFER) OUTCROP.

APPROXIMATE BOUNDARY BETWEEN CONFINED AND UNCONFINED AQUIFER.

GENERALIZED DIRECTION OF GROUND-WATER FLOW.

APPROXIMATE SOUTH LIMIT OF AQUIFER.

FIGURE 3.4
HYDROLOGIC FEATURES OF THE NAVAJO SANDSTONE

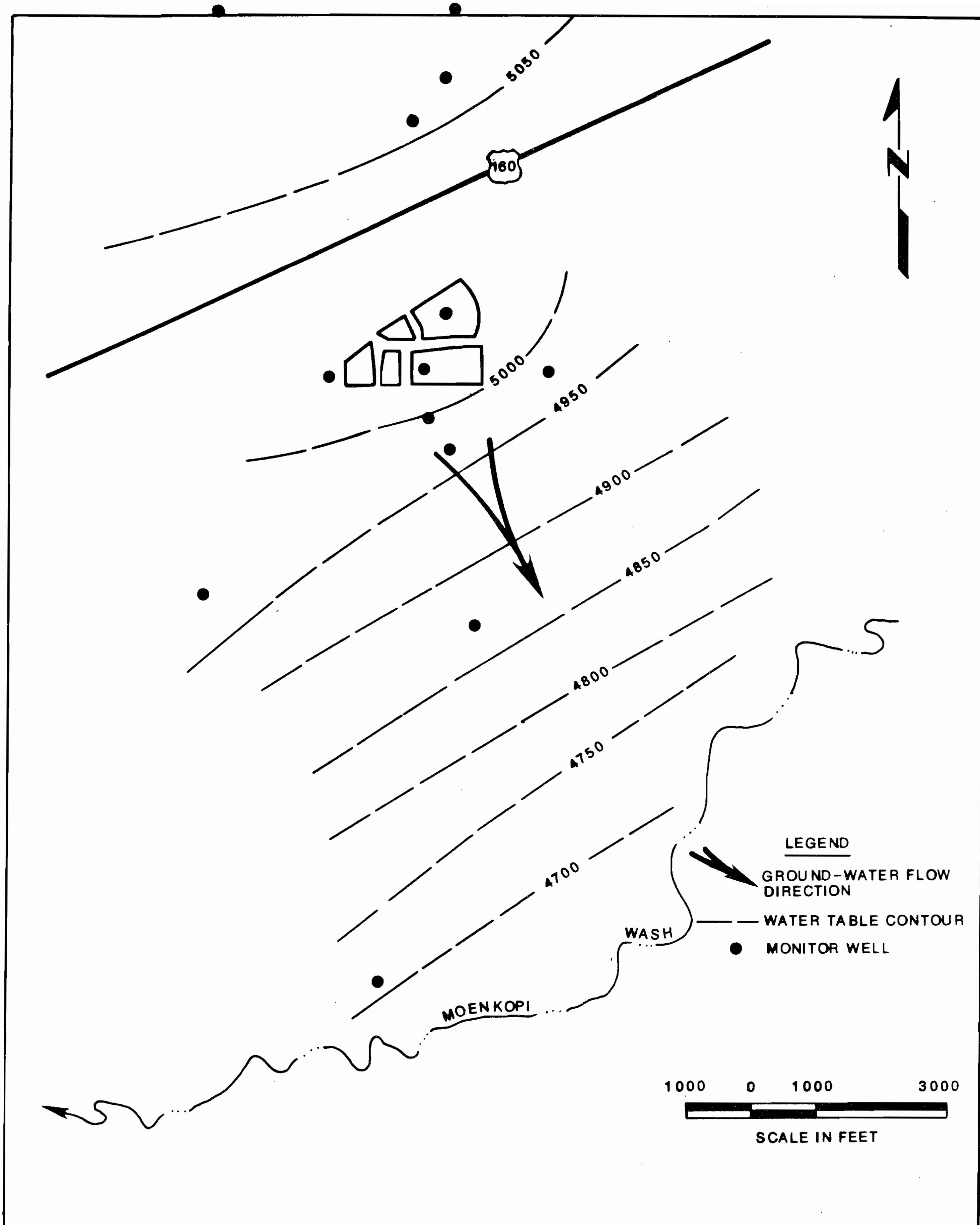


FIGURE 3.5

WATER TABLE ELEVATIONS, NAVAJO SANDSTONE 1985-1986

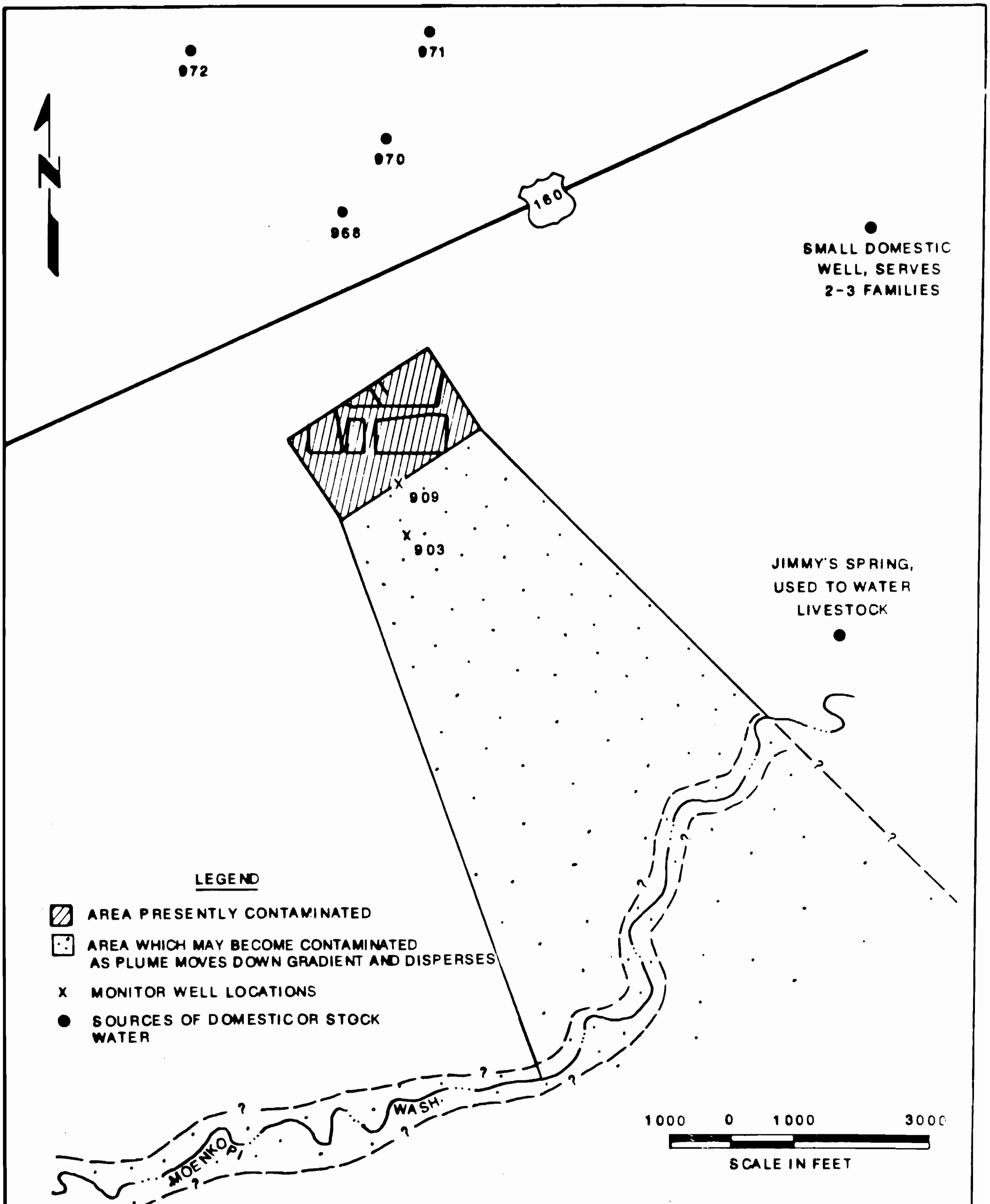


FIGURE 3.6

AREA PRESENTLY CONTAMINATED AND AREA WHICH MAY BECOME CONTAMINATED

Borrow sites

Surficial deposits at the Greasewood Lake borrow site consist of approximately 10 feet of unconsolidated clay to gravel-sized materials. These materials are unsaturated. They are underlain by the Navajo Sandstone, the major aquifer of the Navajo and Hopi Reservations. The Navajo Sandstone is unconfined in this area and the water table ranges from about 20 feet to about 60 feet below land surface.

No ground-water studies have been performed in the Shadow Mountain area. Surficial deposits at the site consist of residual basalt underlain by the Shinarump Member of the Chinle Formation. The Shinarump yields small amounts of poor quality water in some areas (Akers et al., 1962; Cooley et al., 1969).

Unconfined ground water occurs approximately 120 feet below the surface at the Pediment Gravel borrow site. The site is upgradient from the ground-water contamination caused by the tailings pile. The ground-water characteristics at the Pediment Gravel borrow site are very similar to the characteristics described above for the Tuba City site.

3.6 FLORA AND FAUNA

The Tuba City area has an arid, high desert environment. The area is part of the Colorado Plateau ecoregion (Bailey, 1980, 1976) within the Great Basin Desertscrub biotic community, which is generally dominated by various species of sagebrush, shadscale, or blackbrush. Rabbitbrush, horsebrush, winter fat, and Mormon tea are also important shrub species (Lowe and Brown, 1973; Brown, 1982). Species diversity is characteristically low in all major plant communities within the Great Basin Desertscrub biome (Brown, 1982). Appendix C, Flora and Fauna, contains listings of the plant and animal species that could be found at or in the vicinity of the tailings and borrow sites.

Tuba City tailings site

The Tuba City site has been severely disturbed, resulting in the loss of native plant species. Except for a few Russian thistles growing at the toe of the tailings pile, the pile itself is devoid of vegetation. Native plant species common to the Tuba City area include Indian ricegrass, galleta, Mormon tea, rabbitbrush, yucca, and blue grama (Roth, 1985a). Productivity of the rangeland adjacent to the tailings site equals 100 pounds of usable forage per acre with a grazing capacity of 90 acres per animal unit month (Roth, 1985b).

Wildlife data do not exist for the area around the tailings site. Due to the absence of vegetation, it is doubtful that any wildlife would be inhabiting the tailings pile. The lower edge of the tailings pile could be inhabited by small mammals. Nocturnal rodents and black-tailed jackrabbits would be the principal mammals found on the site. The lack of habitat diversity limits the number of birds likely to use the Tuba City tailings site. During spring and fall migrations, a variety of transient bird species may occur in the project area. A few species such as the mourning dove and the poor-will may be found nesting on the site. The presence of amphibian species is also expected to be minimal, with the possibility of a few individuals using temporary pools formed during summer rains. There are several reptiles that could be expected to inhabit the site. The side-blotched lizard and western whiptail are the principal reptile species that could be found on the site.

No listed, proposed, or candidate threatened or endangered plant or animal species are known to occur at the Tuba City tailings site (Metz, 1984).

Borrow sites

The Pediment Gravel borrow site is located adjacent to the Tuba City tailings pile and is dominated by the same plant species as described above for land adjacent to the tailings pile. Wildlife use of this area would consist of a few species of reptiles, nesting birds, and nocturnal rodents.

The Greasewood Lake borrow site is within a small interior drainage basin which is practically devoid of vegetation. The playa surface is very sparsely vegetated with kochia, and the perimeter of the basin has scattered shadscale and Mormon tea. The perimeter area has the most potential for wildlife habitat. This area would be used primarily by a few nocturnal rodents, birds, reptiles, and amphibians.

The Shadow Mountain borrow site is sparsely vegetated with shadscale, Russian thistle, Mormon tea, bunchgrasses, and prickly pear. Portions of the site have been disturbed previously during quarrying activities by the Arizona Department of Transportation. The disturbed areas are of limited use as wildlife habitat. Mammals expected in the area include nocturnal rodents and blacktailed jackrabbits. A limited number of birds would be expected including black-throated sparrows, horned larks, and rock wrens. The rocky terrain would provide excellent habitat for reptiles. Western whiptails, side-blotched lizards, and gopher snakes are reptiles that could be found at the site.

The peregrine falcon, a Federally listed endangered species, may occur in the vicinity of the Shadow Mountain borrow site (Baucom, 1985). This species nests in areas of steep cliffs, usually near water. No other Federally listed threatened or endangered species occur in the area.

Floodplains and wetlands

No floodplain maps have been prepared for the areas that would be affected by the remedial action. According to the U.S. Army Corps of Engineers (COE), there are no floodplains at the Tuba City tailings site (Harrell, 1985). The tailings site and the Shadow Mountain borrow site would only be subject to flooding from local runoff because of the small size of the drainage area above the sites (less than one square mile). The Greasewood Lake borrow site has a larger watershed area, and a filling frequency analysis is being conducted by the COE to determine the flooding potential and the presence or absence of floodplains at the Greasewood Lake borrow site. It is anticipated that the Greasewood Lake borrow site would not be classified as a floodplain; however, in the event it is classified as such, it may require a Section 404 permit from the COE and would not affect the remedial action plan.

According to the United States Fish and Wildlife Service (USFWS) and the COE, there are no wetlands in the areas that would be affected by the remedial action (Metz, 1985; Fast, 1985; Kiebala, 1985).

3.7 RADIATION

The existing radiation levels at the Tuba City tailings site are discussed below. Appendix D, Radiation, contains a detailed discussion of radiation and radiation measurements.

3.7.1 Background radiation

Radioactive elements occur naturally throughout the air, water, soil, and rock of the earth. The concentrations of these elements vary greatly throughout the United States depending on such factors as local mineralization, geographical location, elevation, and latitude. The concentration of radioactive elements in the Tuba City area is slightly higher than the average for other areas primarily because of increased cosmic radiation due to elevation.

The average background gamma radiation exposure rate for the Tuba City area from both terrestrial and cosmic sources, measured at three feet above the ground, is 10.1 microroentgens per hour (microR/hr), with a range of 9.4 to 10.8 microR/hr (BFEC, 1984). Cosmic rays (radiation from the sun and other sources external to the earth) contribute approximately 5.6 microR/hr (55 percent) of the 10.1 microR/hr background gamma radiation exposure rate.

A background airborne radon concentration of 0.7 picocuries per liter (pCi/l) was measured at a location 5.5 miles west of the existing tailings site (FBDU, 1981b).

The average background levels of radiation in ground and surface waters in the Tuba City area can be estimated from the concentrations of radium-226 (Ra-226) in water samples taken upgradient of the tailings pile. The maximum Ra-226 concentrations in upgradient monitoring wells completed in the unconfined aquifer of the Navajo Sandstone were measured to be 0.4 pCi/l (Appendix B, Water).

Average background soil radioactivity levels typical of the Tuba City area have been established as 1.0 picocurie per gram (pCi/g), with a range of 0.0 to 2.0 pCi/g (BFEC, 1984).

3.7.2 Radiation levels

The average Ra-226 content of the tailings pile is 959 pCi/g (MSRD, 1982; BFEC, 1984). The thorium-230 (Th-230) concentrations of the tailings pile were not measured; however, if the Ra-226 is in equilibrium with the Th-230, the average Th-230 concentration would be approximately 862 pCi/g.

A gamma radiation exposure rate from the tailings of approximately 2400 microR/hr has been calculated based upon an estimated 2.5 microR/hr per pCi/g (Schiager, 1974). Gamma radiation exposure rates in the mill and ore storage areas were measured to be less than 100 microR/hr (FBDU, 1981a), and exposure rates ranging from 100 to 400 microR/hr were measured in the windblown tailings immediately northeast of the tailings pile. The average gamma radiation exposure rate for surface measurements taken at 617 locations north and east of the tailings pile is approximately 37 microR/hr (BFEC, 1984). Background exposure rates are reached within 1850 feet of the tailings pile in all directions except northeast. To the northeast is an area of windblown contamination extending approximately 5000 feet.

The radon air concentration at the center of the tailings pile was calculated to be 8.6 pCi/l. The radon flux source term from the tailings pile was calculated using this value and the RAECOM model (NRC, 1984). The calculation resulted in an annual average radon flux of 705 picocuries per square meter per second (pCi/m^2s) from the bare tailings based upon an average Ra-226 concentration of 959 pCi/g.

The maximum levels of radiation in ground water near the Tuba City site can be estimated by the radioisotope concentrations in downgradient or on-pile water samples. The maximum Ra-226 concentration in downgradient monitoring wells was 2.0 pCi/l. The maximum concentrations of uranium-238, uranium-234, thorium-230, and lead-210 were measured at 95 pCi/l, 122 pCi/l, 0.1 pCi/l, and 0.9 pCi/l, respectively.

The soil beneath the tailings pile exceeds the EPA standards of 15 pCi/g of Ra-226 to an average depth of approximately two feet. The average concentration in this material is approximately 27 pCi/g (MSRD, 1982). Isolated areas of deep contamination in excess of EPA standards exist beneath the tailings pile at depths of up to 30 feet. An area immediately north of the mill building contains terrace gravels contaminated to a depth of 10.5 feet. The ore storage area contains Ra-226 concentrations exceeding five pCi/g above background to a depth of one foot or less. The depth of contaminated soil in the emergency spill ponds and adjacent areas is generally less than two feet (BFEC, 1984).

Dispersion of the tailings by wind and water erosion has contaminated soils adjacent to the tailings pile. A field survey of the designated tailings site and the area surrounding it was conducted to determine the areal extent of the displaced tailings. The windblown contamination is generally surficial; however, an area of windblown contamination immediately northeast of the tailings pile exhibits Ra-226 contamination to a depth of up to three feet (BFEC, 1984). Figure 3.7 shows the limits of contamination at the Tuba City site.

3.8 LAND USE

Land use in the immediate vicinity of the tailings site is limited to grazing. The grazing capacity of the land surrounding the site is 90 acres per animal unit month (Roth, 1985b). A 16-acre residential area constructed for mill workers by the former mill developers exists immediately northwest of the tailings site. Some of the housing units are occasionally occupied by local Navajos. Within two miles of the site are five traditional Navajo hogans and several Navajo camps. Other hogans and camps are scattered along both sides of U.S. Highway 160 between the tailings site and Tuba City. Residential sections of Tuba City have been expanding eastward toward the tailings site, but are still several miles west of the site (FBD, 1983).

The Tuba City tailings site is located within the Bennett Freeze Order Area on lands overseen by the U.S. Department of Interior, Bureau of Indian Affairs (BIA), where an administrative freeze was imposed in 1966. This freeze is the subject of litigation authorized by the Navajo-Hopi Land Settlement Act (PL93-531). Any development on affected lands requires joint approval by both the Navajo Nation and the Hopi Tribe, with the exception of areas known as the Navajo Administered Area, which encompasses areas of Tuba City north of U.S. Highway 160, and the Hopi Administered Area encompassing Moencopi Village (Figure 3.8). Development of lands outside the Navajo and Hopi administered areas has been severely limited by the land dispute (Navajo Nation, 1984). Settlement of the dispute could have impacts (as yet unknown) on land use in the Tuba City/Moencopi Village area and surrounding areas.

Although vegetation is limited, approximately 424,649 acres of land are used for the grazing of livestock. The remaining 17 percent is used for dry land and irrigated farming, homesites, and for the communities of Tuba City and Moencopi Village (Navajo Nation, 1984; Shingoitewa, 1986).

The Greasewood Lake, Shadow Mountain, and Pediment Gravel borrow sites are used occasionally for livestock grazing. One residence is located approximately 0.5 mile southwest of the Greasewood Lake borrow site. Three residences are located approximately 0.5 mile east of the Shadow Mountain borrow site. The Shadow Mountain borrow site has been used previously as a source of borrow materials by the Arizona Department of Transportation (Rosenberg, 1985). Some of the housing units adjacent to the Pediment Gravel borrow site are occasionally occupied by local Navajos.

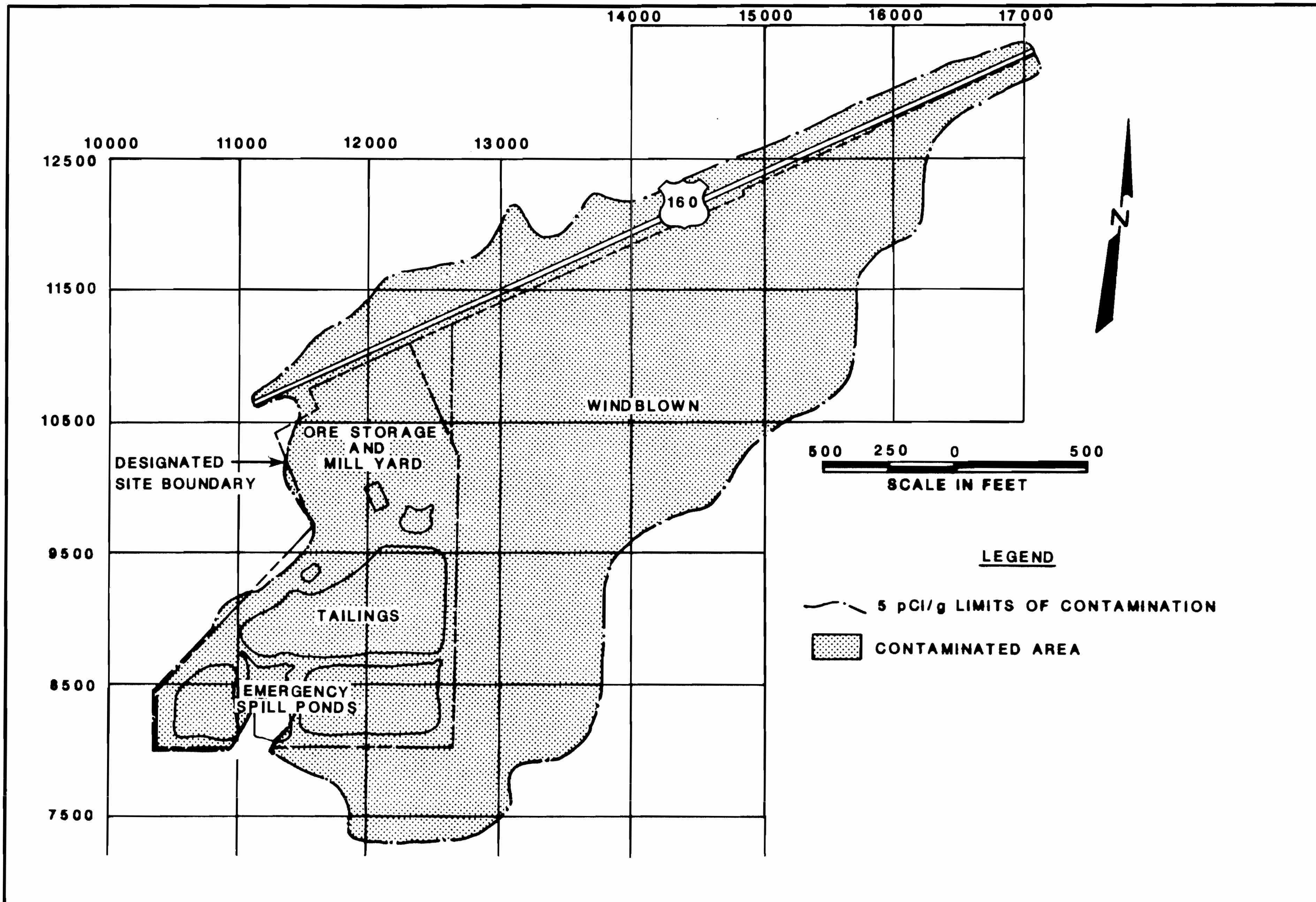


FIGURE 3.7
LIMITS OF CONTAMINATION, TUBA CITY SITE

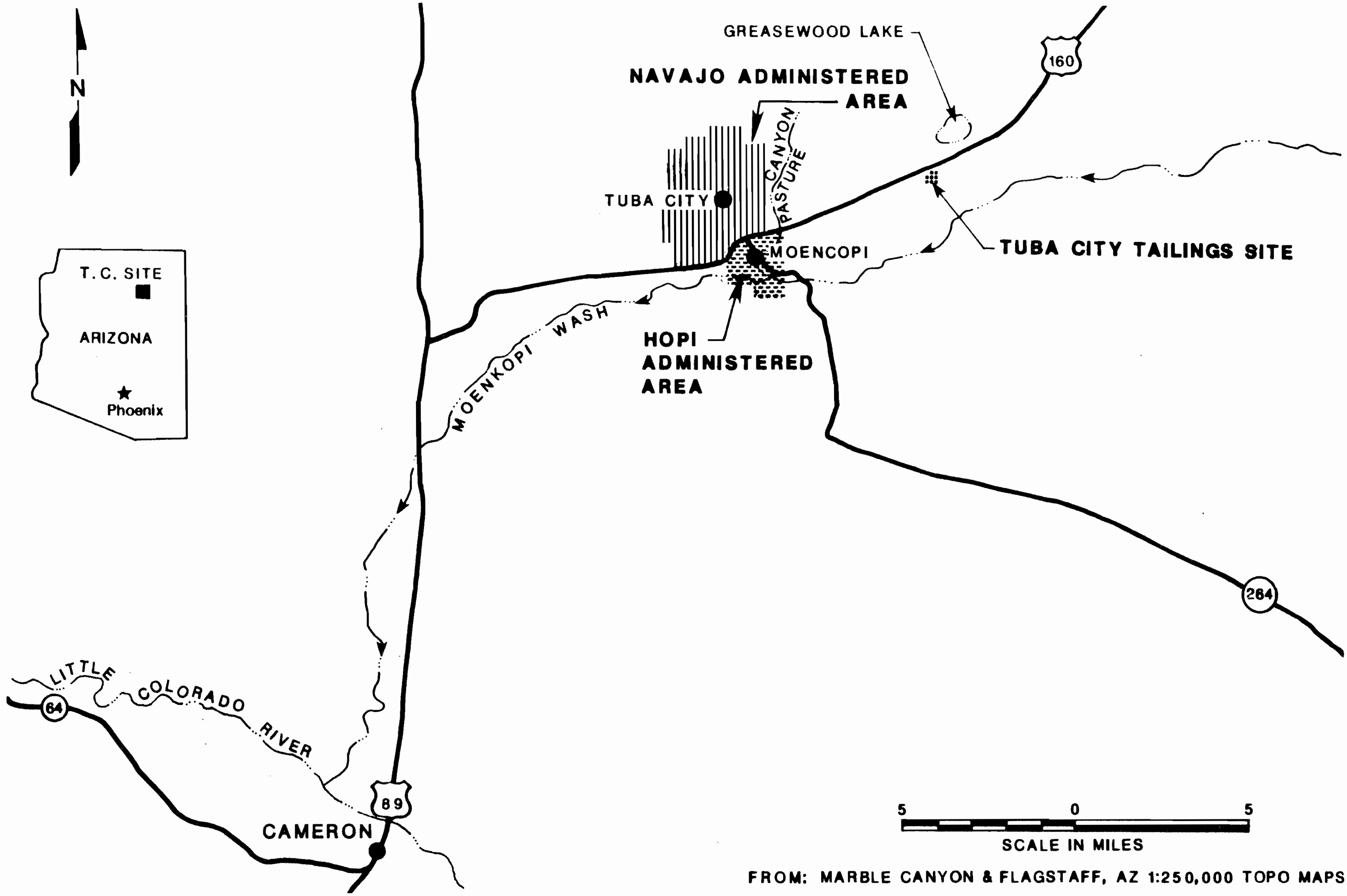


FIGURE 3.8
NAVAJO AND HOPI ADMINISTERED AREAS

3.9 NOISE LEVELS

A background noise survey was performed at the Tuba City tailings site in 1982 (FBD, 1983). Noise levels recorded at and around the tailings pile ranged from 57.1 to 66.6 decibels (dBA) as recorded on the A-weighted scale which most closely approximates the human ear. The highest noise level (66.6 dBA) was recorded north of the tailings pile adjacent to the abandoned mill building. A noise level of 57.1 dBA was recorded at a location northwest of the tailings pile in the residential area. Recordings at both locations included noise generated by wind, traffic on U.S. Highway 160, and jet aircraft.

Noise measurements were not taken at the Greasewood Lake and Shadow Mountain borrow sites. Based on the National Academy of Sciences' method of relating noise levels to population densities, noise levels at the Greasewood Lake and Shadow Mountain borrow sites (undeveloped rural areas) would be equivalent to an average day-night noise level (L_{dn}) of 35 dBA (Table 3.5) (NAS, 1977). The L_{dn} is a noise rating system which assigns a 10 dBA penalty to the nighttime period to account for the heightened perception to noise during that time. The Greasewood Lake borrow site is located approximately 0.5 mile from U.S. Highway 160, and peak noise levels associated with passing traffic are estimated to range as high as 60 dBA. Noise levels at the Pediment Gravel borrow site are the same as those described above for the Tuba City site (57.1 to 67.6 dBA).

Table 3.5 Typical values of day-night noise levels

Land use description	Population density (persons per square mile)	Day-night noise levels (L_{dn}) decibels (dBA)
Rural, undeveloped	20	35
Rural, partially developed	60	40
Quiet suburban	200	45
Normal suburban	600	50
Urban	2000	55
Noisy urban	6000	60
Very noisy urban	20,000	65

Ref. NAS, 1977.

3.10 SCENIC, HISTORIC, AND CULTURAL RESOURCES

Scenic resources

The scenic resources of the Tuba City tailings site are characterized by views of sand-covered hills and distant mesas. The abandoned industrial structures of the designated site contrast markedly with the surrounding terrain. The mill buildings, tailings, and adjacent residential area are not visible from Tuba City, but can be seen for several miles by travelers on U.S. Highway 160. Near the site, foreground views are dominated by scrub vegetation, large deciduous trees near the residential area, and sand dunes. Alluvial terraces and canyons along Moenkopi Wash are visible to the south of the tailings site. Distant mesas of the Painted Desert seen to the south and west form a variety of color and textural changes on the horizon.

The Greasewood Lake borrow site is in a scenic setting very similar to the Tuba City tailings site. Because the Greasewood Lake borrow site is primarily unvegetated, the red and tan sandy soils are the prominent foreground features. The scenic resources of the Shadow Mountain borrow site are characterized by foreground views of rugged, dark colored terrain with limited vegetation. The horizontal strata of the Echo Cliffs are visible to the east, and the San Francisco Peaks are visible in the distance to the southwest. The scenic resources of the Pediment Gravel borrow site are the same as those described above for the Tuba City site.

Historic resources

The Navajo and Hopi Indians have been the dominant ethnic groups in the history of the Tuba City area. The Hopi village of Moencopi two miles south of Tuba City became a permanent settlement in the 1870s, subsequent to seasonal farming use in the 1700s. In 1870, the Hopi leader, Tuve, gave permission to Mormons to settle in the region (McNitt, 1962). As a result, the Mormons established and named the community of Tuba City after the Hopi Leader in 1875. In 1902 and 1903, all Mormon holdings were purchased by the Federal Government (McNitt, 1962).

The Hopi Tribe and Navajo Nation are currently engaged in litigation over the area designated by the Act of June, 1934 (48 Stat. 960), which encompasses the Tuba City/Moencopi Village area. In 1966, an administrative freeze (Bennett Freeze) on development was imposed on portions of this land. Exclusive Navajo and Hopi administered areas were set up in the Bennett Freeze area with U.S. Highway 164 as the dividing line in 1972 (see Figure 3.8) (Navajo and Hopi Indian Relocation Commission, 1981).

Tuba City/Moencopi Village is a center for trading, education, and government for the Hopi Tribe and the Navajo Nation today.

No historic sites are known to exist at the tailings site or the borrow sites.

Cultural resources

The Tuba City area has been occupied by man since as early as 9500 BC; however, relatively few archaeological sites have been studied in the area. Paleo-Indian sites (9500 to 6000 BC) are rare in the region and consist primarily of isolated finds of types of projectile points. The subsequent Archaic period (5500 to 700 BC) has been studied at Black Mesa (approximately 50 air miles northeast of Tuba City) on the basis of projectile points and radio carbon dates. A transition from a hunting and gathering subsistence pattern to establishment of permanent settlements and horticulture marked the beginning of the Anasazi Period (700 BC to 1300 AD).

A Class III (100-percent coverage pedestrian) cultural resource survey of the area surrounding the Tuba City tailings site was conducted in the fall of 1983; however, no archaeological sites were identified in the approximately 325 acres which were surveyed (CASA, 1983).

No archaeological sites or cultural resources are known to occur at the Greasewood Lake, Shadow Mountain, or Pediment Gravel borrow sites. In 1984, archaeological resource surveys were conducted prior to excavation of soil test pits at the Greasewood Lake borrow site (CASA, 1984). These surveys revealed no archaeological sites. An archaeological survey of the Shadow Mountain borrow site was conducted by the Arizona Department of Transportation prior to their use of the site as a source of borrow materials. No archaeological sites were identified (Rosenberg, 1985). The Class III (100-percent coverage pedestrian) cultural resource survey conducted for the Tuba City site (discussed above) also included the Pediment Gravel borrow site and no archeological resources were found (CASA, 1983).

3.11 SOCIOECONOMIC CHARACTERISTICS

Population

The 1983 populations of Tuba City/Moencopi Village and the Tuba City Chapter were 5195 and 5822, respectively (DOC, 1984; Navajo Nation, 1984). These populations represent an average annual increase of 2.8 (Tuba City/Moencopi Village) and 2.5 (Tuba City Chapter) percent since 1980 when they had populations of 4787 and 5416, respectively. However, between 1970 and 1980, the city/village and chapter grew at a much more rapid rate; Tuba City/Moencopi Village's population increased from 4787 in 1971 during this period, reflecting Tuba City's designation by the Navajo Nation as a growth center. Growth of the Tuba City/Moencopi Village area and surrounding areas could be greatly affected by settlement of the Navajo-Hopi land dispute (see Section 3.8).

Housing

In 1980, the Tuba City/Moencopi Village housing stock included 1455 units and 40 motel rooms with a vacancy rate of 16.0 percent for rental units and 18.2 percent for owner units. Of the 1210 occupied units in 1980, 743 were renter occupied and 467 were owner occupied (DOC, 1980a,b). Most of the housing in Tuba City is controlled by one of four organizations--the Navajo Housing Authority, the U.S. Public Health Service, the Tuba City Unified School District, and the Bureau of Indian Affairs (BIA).

Employment and economic base

The Tuba City labor force averaged 2000 people in 1984. The average town unemployment rate for 1984 was 5.5 percent, with per capita income and mean household income of $4158 and $16,769, respectively. The town's largest employment sectors in 1984 were services and public administration which were principally funded by the Navajo Nation and the Federal Government. The principal employers in 1984 were the BIA, the U.S. Public Health Service, and the Tuba City Unified School District. Only 13 percent of the employed individuals worked in the private sector with two percent self-employed (DOC, 1980a). These employment statistics may not accurately represent individuals employed in traditional, non-wage occupations (e.g., artisans, shepherds). In addition, tourism, particularly during the summer travel season, is an important economic factor in this region. Recent labor force and employment trends for Tuba City are presented in Table 3.6.

Table 3.6 Recent labor force and employment trends in Tuba City

Item	1980[a]	1982[b]	1983[b]	1984[b]
Civilian labor force	1866	1965	1989	1999
Employment	1756	1802	1827	1889
Unemployment	110	163	162	110
Unemployment rate	5.9%	8.3%	8.1%	5.5%

[a]Ref. DOC, 1980a.
[b]Ref. ADES, 1985.

Public finance

Tuba City services are funded primarily by the Federal Government and through royalties on minerals extracted from Indian lands. The funds are administered by the Navajo Nation in Window Rock, Arizona, and are distributed according to tribal policies (Faich, 1985).

State and local governments are not allowed to tax Hopi and Navajo-owned land and other property on the Navajo Reservation or the Bennet Freeze Order Area, and Hopi and Navajo incomes derived wholly from Reservation sources are also not taxed. However, non-Indian possessions and income on the Reservation may be taxed. The Navajo Nation currently has two types of taxes and is proposing a third. The first tax is a business activity tax on all nonretail business on the Reservation with gross receipts exceeding $500,000 per year. The second tax is a possessory interest tax on oil, gas, and mineral leases. The newly proposed severance tax on oil and gas would replace the business activity tax for the oil and gas industry, but the business activity tax would remain in effect for all other businesses currently affected. Tax revenues account for approximately 15 percent of the Navajo Nation's total revenues, while royalties on minerals and oil and gas production account for another 30 percent. Funds received from the Federal Government account for nearly 55 percent of the revenues (Francis, 1985).

Community services

Law enforcement in Tuba City is provided by the Navajo Tribal Police, Hopi Tribal Police in Moencopi Village, the BIA, and the Arizona Department of Public Safety. The Navajo Tribal Police and the BIA Police are stationed at Tuba City, and the Arizona Department of Public Safety officers who patrol U.S. Highways 89 and 160 are stationed at Flagstaff, approximately 85 miles to the south. A total of 45 officers provide full or partial police protection. Fire protection is provided by a staff of 17 volunteers from two fire stations (Economic Planning and Development, 1984).

Education in Tuba City is funded by the State of Arizona and the BIA. Public education through grade 12 is administered by the Tuba City Unified School District and the BIA. Total 1983 enrollment in the Tuba City Unified School District for grades kindergarten through 12 was 3338 students (Dennie, 1985). Schools for grades kindergarten through eight were filled to capacity, while the Tuba City High School (grades nine through 12) could provide education for an additional 500 students without expanding (FBD, 1983). A total of 870 students attended the BIA's boarding school in 1983. College extension courses are offered at Tuba City through Navajo Community College, Yavapai Junior College, and Northern Arizona University (Navajo Nation, 1984).

Tuba City has a 109-bed U.S. Public Health Service hospital, which includes surgery, pediatrics, obstetrics/gynecology, psychiatry, and dialysis units. In cases where emergency services cannot be provided locally, patients are flown to other facilities in Arizona, Utah, or New Mexico. The hospital maintained an average occupancy rate of 62.1 percent during the year ending September 30, 1983 (American Hospital Association, 1984).

Tuba City obtains its water supply from six wells located north of the town and has water storage facilities with a total capacity of 5.3 million gallons. Moencopi Village obtains its water supply from two wells located within the boundaries of the village (Shingoitewa, 1986). Total demand in 1984 was approximately 250 million gallons, well below the system's maximum capacity of approximately 600 million gallons (Scarborough, 1985; Navajo Nation, 1984). Families in rural areas surrounding the town haul water from nearby shallow wells and windmills for domestic use. The city's sewer system consists of 60 acres of open treatment lagoons and was designed for a population of 8000; the system is currently operating well below design capacity (Navajo Nation, 1984).

Major transportation routes consist of U.S. Highway 160 and State Highway 264 (Figure 3.1). U.S. Highway 89 is located 11 miles west-southwest of Tuba City at the end of U.S. Highway 160. In 1983, the average daily traffic volumes on the segments of U.S. Highways 89 and 160 that would be affected by the remedial action were 3900 and 3800 vehicles per day, respectively (ADOT, 1984). During the summer tourist season, traffic volumes are somewhat above average; at other times of the year, traffic volumes may decrease somewhat below the average. Access to the tailings site is by an access road leaving to the south from U.S. Highway 160 approximately six miles east of the intersection of U.S. Highway 160 and State Highway 264. Transportation services consist of the Navajo Transit System with bus service between Tuba City and Window Rock, and a Continental Trailways bus stop at the junction of U.S. Highways 89 and 160 (Navajo Nation, 1984).

Tuba City offers a variety of recreational, cultural, and community activities and services. Community facilities include the Tuba City Chapter House, a day care center, a community center (including a gymnasium), three public parks, a swimming pool, a library, and a Navajo-Hopi cultural museum. Numerous Navajo Tribal and National Parks are located within a three-hour drive of Tuba City, including Grand Canyon National Park, Navajo National Park, Sunset Crater National Monument, Wupatki National Monument, Glen Canyon National Recreational Area, Monument Valley Navajo Tribal Park, and Rainbow Bridge National Monument (Economic Planning and Development, 1984).

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4.0 ENVIRONMENTAL IMPACTS

4.1 RADIATION

The environmental impacts of each of the remedial action alternatives are discussed in this section. Both of the action alternatives include remedial action at the estimated six vicinity properties; however, the impacts of remedial action at these vicinity properties were previously assessed in a programmatic environmental report (DOE, 1985a) and are therefore not considered in this section.

The following sections discuss radiation exposure pathways and the excess health effects that would result during and after remedial action and the health effects of construction-related accidents that might occur. Exposure to gamma radiation may cause genetic health effects in addition to somatic health effects (e.g., cancer). The genetic risk is approximately two-thirds of the somatic risk for gamma radiation, and a genetic health effect in general may be considered less severe. Measures taken to reduce the somatic health effects would also reduce the genetic effects. The discussions on health effects in the following sections and the excess health effects calculations in Appendix D, Radiation, reflect only the somatic health effects.

4.1.1 Exposure pathways

There are five principal radiological pathways by which individuals could be exposed during the remedial action (Figure 4.1). These are: (1) inhalation of radon and radon daughters; (2) direct exposure to gamma radiation emitted; (3) inhalation and ingestion of airborne radioactive particulates; (4) ingestion of ground and surface waters contaminated with radioactive materials; and (5) ingestion of contaminated foods produced in areas contaminated by tailings. For the calculation of health effects, only those pathways which would result in the largest radiation doses to the general public were considered in detail: inhalation of radon and radon daughters and direct exposure to gamma radiation. Appendix D, Radiation, also contains estimates of the radiation exposures and health effects to the general public and remedial action workers from the airborne radioactive particulates pathway and to the general public from the ground-water ingestion pathway.

Radon is an inert gas (i.e., does not react chemically with other elements) produced from the radioactive decay of radium-226 (Ra-226) in the uranium-238 (U-238) decay series. As a gas, radon can diffuse through the tailings and into the atmosphere where it is transported by atmospheric winds over a large area. In the atmosphere, radon decays into its solid daughter products which attach to airborne dust particles and can be inhaled by humans. These dust particles, with the radon daughter products attached, may adhere to the lining of the lungs and decay with the release of alpha radiation directly to the lungs.

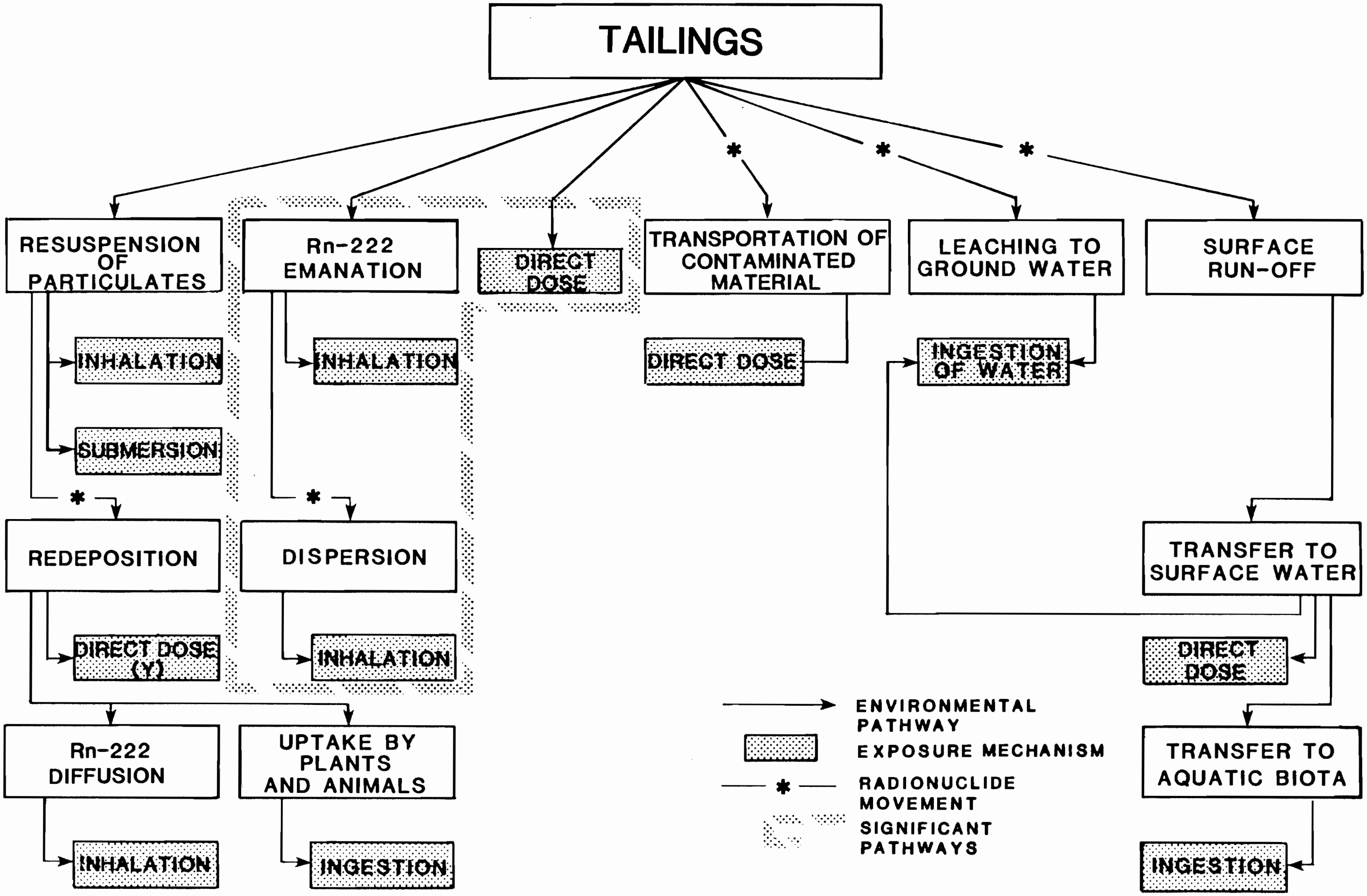

FIGURE 4.1

POTENTIAL RADIATION EXPOSURE PATHWAYS

TO THE GENERAL PUBLIC AND REMEDIAL ACTION WORKERS

Gamma radiation is also emitted by many members of the U-238 decay series. Gamma radiation behaves independently of atmospheric conditions and travels in a straight line until it impacts with matter. Gamma radiation emitted from the tailings delivers an external exposure to the whole body. Gamma radiation levels emitted from the tailings become negligible beyond approximately 0.3 mile from the perimeter of the tailings due to the interaction of the gamma rays with matter in the air.

The general public is presently being exposed to radon daughters and direct gamma radiation from the tailings pile. Radon is diffusing into the atmosphere where it is being dispersed by winds over a large area (i.e., inhalation pathway). Gamma radiation is being emitted and is exposing any person living or working within 0.3 mile of the tailings (i.e., direct gamma exposure pathway). Currently, there are no effective barriers to prevent continued dispersion and unauthorized removal and use of the tailings which could increase the general public's and nearby worker's exposures to radon daughter and gamma radiation.

During remedial action radon daughter and gamma radiation exposure to the general public would increase and exposure to remedial action workers to these pathways would occur as the tailings are disturbed. Following remedial action, there would be no exposure to direct gamma radiation since the tailings would be covered with earthen material which gamma radiation could not penetrate. However, there would be a small public exposure to radon and radon daughters following remedial action because the earthen cover would substantially reduce the release of radon to levels at or below the U.S. Environmental Protection Agency (EPA) standards. The earthen cover would have a very low permeability and most of the radon would decay into its solid daughter products before it could diffuse through the cover and enter the atmosphere.

4.1.2 Health effects during remedial action

The estimates of excess health effects (i.e., fatal cancers) in this section are based on the procedures discussed in Appendix D, Radiation. These procedures are based on realistic but conservative assumptions to estimate the level of excess health effects. Table 4.1 lists the estimated excess health effects that would occur for stabilization in place.

The percentage increase in radon released from the tailings during remedial action would be small relative to the radon released prior to remedial action because there is a large radon flux from the existing tailings pile under present conditions. During remedial action, increases in gamma exposure rates and airborne radioactive particulate concentrations would be larger than the radon concentration increase compared to levels prior to remedial action. These increased exposure rates would be due to disturbance of the tailings.

Table 4.1 Excess health effects during stabilization in place[a]

General public radon daughter health effects	General public gamma health effects	Remedial action worker radon daughter health effects	Remedial action worker gamma health effects	Total excess health effects
0.015	0.0000095	0.0023	0.0022	0.02

[a]The no action alternative would result in 0.02 total excess health effects per year. Tailings relocation to the Fivemile Wash alternate site would result in a total number of excess health effects approximately equal to the number for stabilization in place.

The elevated gamma exposure rates during disturbance of the tailings would increase the excess health effects primarily to the remedial action workers. The maximum risk to remedial action workers from the inhalation of airborne radioactive particulates would be a small percent of the risk from exposure to radon daughters and gamma radiation, and the airborne particulate exposure to the general public would be even less. Inhalation of radon daughters would be the dominant exposure pathway in the excess health effects calculations for the general public.

The excess health effects to the general public during remedial action are principally dependent on the amount of tailings and contaminated materials to be moved and the number of people who live nearby. The estimated excess health effects are very small in comparison to the natural incidence of cancer. For example, the excess radon daughter health effects to an individual in the general public during stabilization in place was estimated to be 0.00021 percent (based on 0.015 excess health effects and an exposed population of 7020) or one chance in 475,000 of contracting fatal cancer from exposure to radon daughters. This is a very small fraction of the normal cancer incidence rate. In the United States, an individual has a 16 percent chance or approximately one chance in six of contracting cancer (NAS, 1980).

Stabilization in place would result in a total of 0.02 excess health effects during the 12-month disturbance of the tailings, based on the present population distribution in the vicinity of the Tuba City tailings site.

The no action alternative would result in 0.02 total excess health effects per year. This number is not directly correlated to the total excess health effects listed in Table 4.1 because the health effects associated with stabilization in place are for the duration of tailings disturbance (12 months) and account for increased radon levels due to tailings disturbance. In addition, the total excess health effects for the no action alternative do not consider factors such as dispersion or unauthorized removal and misuse of the tailings which could lead to greater excess health effects than those calculated.

Tailings relocation to the Fivemile Wash alternate site would result in a total number of excess health effects approximately equal to the number for stabilization in place. An increased health effect to remedial action workers would be due to a greater construction period and a greater number of remedial action workers. The transportation gamma health effects to the general public for the Fivemile Wash alternative would be negligible.

4.1.3 Hypothetical accidents

The Tuba City tailings emit low levels of radiation which over a long period of time could produce excess health effects. Any spillage of tailings resulting from a traffic accident involving a truck loaded with tailings would be cleaned up immediately and would therefore cause only a short exposure time to persons living or working near the spill. Contractors working for the DOE would be required to establish approved procedures for cleaning up spills.

The only spill which could not be completely cleaned up would be one that occurs as a truck crosses a river or flowing watercourse. The probability of such an accident would be extremely low. Relocation of the tailings to the alternate disposal site would have the possibility of this occurring since the transportation route would cross Moenkopi Wash. In this case much of the tailings could not be recovered; however, studies of similar hypothetical accidents at other Uranium Mill Tailings Remedial Action (UMTRA) Project sites (DOE, 1985b) have shown that the concentration of radioactive elements would be rapidly diluted by the flowing waters and little or no excess health effects would occur. However, the DOE and its contractors would take all reasonable mitigative measures if such an event occurred.

4.1.4 Health effects after remedial action

The procedures used to calculate the excess health effects after remedial action for each of the alternatives are discussed in Appendix D, Radiation. These procedures are based on realistic but conservative assumptions to estimate the level of excess health effects. Table 4.2 lists the estimated yearly excess health effects after remedial action for the stabilization in place and no action alternatives.

Stabilization in place would result in 0.0005 total general public excess health effects per year after remedial action. The no action alternative would result in the greatest yearly excess health effects to the general public (0.02 total excess effects per year) which is at least 34 times greater than for stabilization in place.

Table 4.2 Yearly excess health effects after remedial action[a]

Alternative	General public radon daughter health effects per year	General public gamma health effects per year	Total excess health effects per year
Stabilization in place	0.00049	0.00	0.0005
No action	0.016	0.0000095	0.02

[a]Tailings relocation to the Fivemile Wash alternate site would result in a total number of excess health effects approximately equal to the number for stabilization in place.

The excess health effects calculations for the no action alternative do not consider the dispersal of the tailings by natural erosion or by man because there is no way to accurately predict the level or rate of dispersion. However, without remedial action, dispersion would occur over time, and the actual total excess health effects might be greater than 0.02 per year.

The Fivemile Wash alternative would result in a total number of excess health effects approximately equal to the number for stabilization in place. The alternate disposal site is relatively remote and located in a sparsely populated area, resulting in minimum excess health effects following remedial action.

Table 4.3 lists the estimated total excess health effects for the stabilization in place and the action alternatives that would occur over five, 10, 100, 200, and 1000 years following remedial action. These excess health effects are the sum of the excess health effects that would occur during remedial action and the integrated yearly excess health effects that would occur after remedial action. The data in Table 4.3 reflect a stable population; the total excess health effects would increase if the nearby population increased.

4.2 AIR QUALITY

Air quality impacts were estimated for the stabilization in place and no action alternatives by calculating a detailed emissions inventory and translation of these emissions into ambient air pollution concentrations with the use of computer simulation techniques. The modeling is conservative in nature and thus overpredicts potential impacts. Air quality impacts from disposal of the tailings at the Fivemile Wash site are discussed in comparison to impacts from stabilization in place.

Table 4.3 Total excess health effects 5, 10, 100, 200, and 1000 years after remedial action

	Number of years after remedial action[a]				
Alternative[b]	5 years	10 years	100 years	200 years	1000 years
Stabilization in place	0.02	0.03	0.07	0.1	0.5
No action[c]	0.08	0.2	2.0	3.0	20.0

[a]Tailings relocation to the Fivemile Wash alternate site would result in a total number of excess health effects approximately equal to the number for stabilization in place.

[b]These estimates assume that the population in the vicinity of each site remains constant and include the total excess health effects during remedial action.

[c]The calculations for no action assume that the tailings would not be dispersed by natural forces or by man because there is no way to accurately predict the level or rate of dispersion. However, if the dispersion could be predicted and were factored into the above estimates, the total excess health effects for the no action alternative would greatly increase.

Air emissions inventory

The emissions inventory includes estimates of combustion emissions from construction equipment and fugitive dust emissions. Emissions were calculated for hydrocarbons (HC), nitrogen oxides (NO_x), sulfur oxides (SO_x), carbon monoxide (CO), and total suspended particulates (TSP). The estimates include emissions from activities occurring at the Tuba City tailings site and the adjacent Pediment Gravel borrow site, from vehicles traveling on paved and graveled haul roads, from equipment operating at the Greasewood Lake and Shadow Mountain borrow sites, and from wind erosion of the tailings. Combustion and fugitive dust emissions for heavy-duty construction equipment were calculated based on the emission factors for heavy-duty construction equipment shown in Table 4.4. Total emissions from remedial action were based on fuel consumption rates, vehicle-miles traveled, vehicle speed, soil composition, the size of the area of disturbance, and the volumes of materials moved.

Table 4.5 presents total emissions for stabilization in place. Fugitive dust emissions would far exceed combustion emissions. A total of 2221 tons of fugitive dust emissions would result, primarily due to wind erosion and equipment activity at the tailings site and adjacent borrow area and dispersal of road dust by trucks operating on unpaved haul roads. The no action alternative would contribute suspended particulates to the ambient air due to dispersion of the tailings by winds. Total fugitive dust emissions resulting from no action are

Table 4.4 Air pollutant emission factors

Equipment	Fugitive dust[b]	Exhaust emissions[a]				
		HC	NO_x	SO_x	CO	TSP
Compactor	4 lb/hr	24.3	488	31.1	114	24.2
Bulldozer	32 lb/hr	20.7	450	31.2	65.9	14.8
Front-end loader (5 cy)	0.037 lb/cy	32.3	408	31.2	95.4	29.3
Grader	32 lb/hr	17.4	374	31.1	78.0	22.2
Scraper	16 lb/hr	42.2	419	31.2	98.3	27.3
Truck (10 cy)						
unpaved haul	16.44 lb/mile	3.3	23.4	2.8	15.4	1.3
paved haul	1.1 lb/mile	3.3	23.4	2.8	15.4	1.3
dumping	0.04 lb/cy	-	-	-	-	-
Truck (18 cy)						
unpaved haul	29.59 lb/mile	3.3	23.4	2.8	15.4	1.3
paved haul	2.0 lb/mile	3.3	23.4	2.8	15.4	1.3
dumping	0.04 lb/cy	-	-	-	-	-
Water truck	4 lb/hr	30.0	524	31.2	92.2	17.7

[a]Exhaust emission factors are in pounds per thousand gallons of fuel consumed, except those for haul trucks, which are in grams per mile.
[b]Lb/hr - pounds per hour; lb/cy - pounds per cubic yard; lb/mile - pounds per mile; cy - cubic yards.

Ref. EPA, 1983a; CDH, 1984.

estimated to be 217 tons. This estimate is based on the application of the universal soil-loss equation which includes components for soil erodibility, local climate, the size of the area exposed to wind erosion, and the amount of vegetative cover.

As shown on Table 4.5, the emissions of NO_x would be the highest of the combustion emissions followed by CO; HC and SO_x emissions would be similar in magnitude and TSP would be the lowest of the combustion emissions. The no action alternative would not create emissions of hydrocarbons, nitrogen oxides, sulfur oxides, carbon monoxide, and combustion TSP.

Table 4.5 Total emissions during stabilization in place[a]

Activity	Combustion emissions (tons) HC	NO_x	SO_x	CO	TSP	Fugitive dust emissions (tons) TSP
Construction activities at existing tailings site	5.8	81.9	5.7	16.5	4.1	1246.7
Construction activities at Greasewood Lake borrow site	0.2	2.8	0.2	0.6	0.2	8.3[b]
Construction activities at Shadow Mountain borrow site	0.1	1.1	0.1	0.2	0.1	3.1[b]
Truck haulage along transportation routes to borrow sites	0.9	5.7	0.7	3.7	0.3	962.7
Total	7.0	91.5	6.7	21.0	4.7	2220.8

[a]The no action alternative would not create emissions of hydrocarbons, nitrogen oxides, sulfur oxides, and carbon monoxide; however, it would contribute suspended particulates to the ambient atmosphere due to dispersion of the tailings by winds. A total of 217 tons per year of fugitive dust emissions were estimated to occur under existing conditions (no action) at the Tuba City tailings site.

[b]The increase in wind erosion resulting from construction activities at the borrow sites was assumed to be negligible.

Air pollutant concentrations

Ambient air pollutant concentrations were estimated through the use of an EPA-approved computer simulation model, assuming conservative meteorological conditions. Emphasis was placed upon modeling of TSP emissions because TSP emissions would be much higher than gaseous combustion emissions (Table 4.5). Impacts resulting from gaseous combustion emissions would be small, and easily within all applicable air quality standards.

Modeling of project-related, 24-hour TSP increments was based on the use of the Industrial Source Complex Dispersion Model for short-term applications (ISCST) (EPA, 1983b). The ISCST model is particularly appropriate for an application of this type since it considers particulate deposition and can also accomodate large area emissions sources and line emissions sources such as trucks traveling on haul roads. The emissions used as inputs to the model for the tailings site and surrounding area are shown in Table 4.6, and correspond to the project phase in which the maximum emission rates would occur (month five).

Table 4.6 Fugitive particulate emissions inputs for the ISCST model for the tailings site and surrounding area

Source	Emissions (pounds per hour)
Compactor	8
Bulldozer	288
Grader	32
Scraper	192
Water truck	8
Truck loading and dumping	10
Truck hauling	150
Wind erosion	164
Total uncontrolled	852
Total controlled	426[a]

[a]Assumes 50 percent effectiveness of dust control measures.

Modeling for stabilization in place was performed for the following: (1) activities at the tailings site and adjacent Pediment Gravel borrow area; and (2) truck transportation along the graveled haul road between the Greasewood Lake borrow site and the tailings site. For modeling purposes, dust erosion emissions were conservatively assumed to be constant throughout the remedial action, and dust control measures were assumed to be 50 percent effective. Emissions from the tailings site and surrounding area were assumed to be emitted from a single 224-acre (9,760,000 square feet) source area. Receptors were located downwind of the tailings site at 820-foot intervals to a distance of 4920 feet. For truck transport along the graveled haul road between the Greasewood Lake borrow site and the tailings site, emissions from a 2950-foot length of haul road were modeled at receptors located downwind of the haul road at distances of 330, 980, 1640, and 2300 feet. Conservative meteorological conditions were used to estimate maximum 24-hour particulate concentrations. Light winds (5.6 miles per hour) were assumed to blow persistently from a single direction under stable meteorological conditions (Pasquil-Gifford category F). These meteorological conditions were assumed to persist for the first six hours of the 24-hour modeling period.

Table 4.7 presents the maximum, project-related, 24-hour TSP increments, as well as the predicted total 24-hour TSP levels for stabilization in place. The modeled 24-hour TSP air pollutant concentrations associated with the project were added to the maximum 24-hour TSP level (193 micrograms per cubic meter) measured in the region to determine the maximum possible TSP concentrations. Stabilization in place would result in an increase over ambient particulate concentrations of 218 micrograms per cubic meter (microg/m^3) and 89 microg/m^3 at the Tuba City tailings site and the transportation route to the Greasewood Lake borrow site, respectively. Total predicted 24-hour TSP levels would be 411 microg/m^3 at the Tuba City site and 282 microg/m^3 along the transportation route. Both levels would exceed the Federal primary standard of 260 microg/m^3. The Federal primary standard defines the level of air quality deemed necessary, with an adequate margin of safety, to protect the public health (EPA, 1982).

Table 4.7 Predicted incremental and total 24-hour TSP concentrations for stabilization in place[a,b]

Location	24-hour TSP increment (microg/m^3)	Total 24-hour TSP level[c] (microg/m^3)	Federal secondary 24-hour standard[d] (microg/m^3)	Federal primary 24-hour standard[d] (microg/m^3)
Tuba City tailings site	218	411	150	260
Transportation route between Greasewood Lake borrow site and tailings site	89	282	150	260

[a]The no action alternative would not create emissions of hydrocarbons, nitrogen oxides, sulfur oxides, and carbon monoxide; however, it would contribute suspended particulates to the ambient atmosphere due to dispersion of the tailings by winds. This contribution of particulates is estimated to total 217 tons per year.
[b]Microg/m^3 - micrograms per cubic meter.
[c]Based on the addition of 24-hour TSP increments to the maximum recorded level at the air quality monitoring stations near the Tuba City site (193 microg/m^3 at Flagstaff, Arizona) for the most recent available one-year period of record (1983).
[d]Ref. EPA, 1982. State ambient air quality standards for Arizona are the same as the Federal ambient air quality standards (Arizona Ambient Air Quality Standards, 1983).

The modeled emission rates for stabilization in place are such that the remedial action could also cause Federal annual TSP standards to be exceeded. The Federal secondary annual standard is 60 microg/m^3, and the Federal primary annual standard is 75 microg/m^3 (EPA, 1982). It should be noted that the 24-hour modeling uses a conservative approach which assumes uninterrupted simultaneous occurrence of average wind and maximum equipment-generated emissions rates and conservative meteorological conditions (i.e., light winds blowing persistently from a single direction under stable mixing conditions). The actual occurrence of such conditions during the remedial action is highly unlikely. All predicted maximum increments are localized, occurring at or near the source area.

The estimated combustion emissions from stabilization in place would not exceed the EPA significance levels of 100, 40, 40, and 25 tons per year for carbon monoxide, hydrocarbons, sulfur dioxide, and particulates (TSP), respectively (EPA, 1982). The total NO_x emission would exceed the EPA significance level of 40 tons per year; however, Prevention of Significant Deterioration regulations are not applicable for temporary emission sources such as those from remedial action. The total combustion emissions shown in Table 4.5 are relatively small and would occur over an extended period of time (18 months). Furthermore, some emissions would be from haulage trucks, most of which would operate over wide areas between the tailings site and either the Greasewood Lake, Shadow Mountain, or Pediment Gravel borrow sites.

Total emissions from the Greasewood Lake and Shadow Mountain borrow sites for stabilization in place are substantially lower than at the tailings site (see Table 4.5) because of much lower equipment activity levels, amounts of materials handled, and acreage disturbed. Emissions at either of these borrow sites would be expected to result in similar, minor impacts to air quality in the area. For truck haul routes other than the one between the tailings site and the Greasewood Lake borrow site, many fewer truck trips would result in substantially lower impacts along these routes.

Disposal of the tailings at Fivemile Wash would result in reduced pollutant emissions rates at the Tuba City tailings site relative to stabilization in place due to lower equipment activity levels and consequently lower maximum pollutant concentrations; however, emissions would occur over a longer period (24 months for disposal at Fivemile Wash rather than 18 months for stabilization in place). Emission rates and resultant maximum pollutant concentrations at the Fivemile Wash site would be expected to be similar in magnitude to levels estimated for the Tuba City tailings site for stabilization in place. Graveled haul road dust emissions and resultant concentrations would be much greater because of the much larger number of truck trips for hauling tailings and borrow materials. It is therefore expected that relocation of the tailings to Fivemile Wash would result in substantially greater overall impacts to air quality than the impacts from stabilization in place.

4.3 SOILS

Each of the action alternatives would result in both the temporary disturbance and permanent loss of soils. These impacts would result from surface disturbances caused by: (1) the excavation of contaminated soils, borrow materials, and the alternate tailings disposal site; (2) upgrading of access roads; and (3) construction of staging and stockpile areas.

Stabilization in place would result in the disturbance of 408 acres of soils including 105 acres at the Tuba City site, 11 acres for access roads, 222 acres contaminated by windblown tailings, and 70 acres at the Greasewood Lake, Shadow Mountain, and Pediment Gravel borrow sites. Following remedial action 327 acres of these disturbed soils would be reestablished. The areas where the soils would not be reestablished include 60 acres of stabilized tailings, 11 acres of access roads, and 10 acres at the Shadow Mountain borrow site.

No action alternative

The no action alternative would not involve remedial action; therefore, no new disturbance or loss of soils would occur. Contamination (with Ra-226) of soils adjacent to the tailings site due to dispersion of the tailings by wind and water erosion would continue. The rate of this continuing contamination cannot be accurately quantified, but 273 acres of soil have been contaminated to date.

Disposal at the Fivemile Wash site

Disposal of the tailings and contaminated materials at the Fivemile Wash site would result in a similar level of disturbance to soils at the existing tailings site as stabilization in place. Earthen materials excavated from the Fivemile Wash site for partially below-grade disposal of the tailings would be used for covering the consolidated tailings and contaminated materials. Earthen materials excavated from the Greasewood Lake borrow site would be used for restoration of the existing tailings site. Both disposal at Fivemile Wash and stabilization in place would involve a similar amount of disturbance at the Shadow Mountain borrow site. Soils present in the area that would be occupied by the stabilized tailings embankment at the Fivemile Wash site would be permanently lost.

4.4 MINERAL RESOURCES

All of the alternatives, except no action, would result in the consumption of borrow materials (earth and rock). The consumption of borrow materials from the proposed local sources would have a negligible impact on the availability of these resources in the area as all of these materials are available in large quantities throughout the Tuba City area. None of the alternatives would have an impact on other mineral resources in the area. The existing tailings site, the Fivemile Wash alternate disposal site, and the Greasewood Lake and Shadow Mountain borrow sites are underlain by geologic formations that are not known to contain economic mineral reserves.

Stabilization in place

The in-place volumes of uncontaminated borrow materials that would be required for stabilization in place are 288,900 cubic yards (cy) of earth and rock for construction of the radon cover, erosion protection, and restoration. These borrow materials would be obtained from the Greasewood Lake borrow site (earth), the Shadow Mountain borrow site (large rock), and the Pediment Gravel borrow site (gravel-size rock). Access to any sand and gravel deposits beneath and around the stabilized tailings pile would be restricted; however, this would not be expected to affect the availability of these resources in the area.

No action

The no action alternative would not require the consumption of borrow materials because there would be no remedial action. As with stabilization in place, access to any sand and gravel deposits beneath the existing tailings pile would be restricted, but this would not be expected to affect the availability of these resources in the area.

Disposal at the Fivemile Wash site

The in-place volumes of uncontaminated borrow materials that would be required for construction of the stabilized tailings embankment at the Fivemile Wash site would be similar to those required for stabilization in place; however, an additional amount of earthen borrow materials would be required for restoration of the existing tailings site. These borrow materials would be obtained from excavation of the partially below-grade disposal site (earth and rock), the Greasewood Lake borrow site (earth), and the Shadow Mountain borrow site (rock). Relocating the tailings to the Fivemile Wash site would allow access to any sand and gravel deposits beneath the existing tailings site, but would preclude access to any borrow materials beneath and around the alternate disposal site.

Borrow sites

Development of mineral resources at the borrow sites is the subject of authorization under the Navajo-Hopi Land Settlement Act (PL93-531). Temporary borrow activities would not permanently preclude future development of mineral resources because the areas disturbed by the borrow activities would be restored in accordance with the sand and gravel permit issued by the Bureau of Indian Affairs (Appendix E, Permits, Licenses, Approvals).

4.5 WATER

4.5.1 Surface water

Section 4.5.1 describes the potential surface-water impacts from each remedial action alternative and summarizes water use during each remedial action alternative. Additional details are provided in Section B.1 of Appendix B, Water.

Stabilization in place

During remedial action, the cleanup and consolidation of the tailings and other contaminated materials would result in surface disturbance, and runoff from these disturbed areas could be contaminated. Also, contaminated waste water would be generated by activities such as equipment washing. The remedial action design includes the construction of drainage controls and a waste-water retention pond(s) during site preparation to prevent the discharge of contaminated water from the site. The drainage controls and waste-water retention pond(s) would be constructed according to applicable regulations (Appendix E, Permits, Licenses, Approvals). The contaminated water would be retained for evaporation or use in the compaction of the tailings and contaminated materials and any sediments from the pond(s) would be consolidated with the tailings during the final reshaping of the tailings pile.

After remedial action, surface runoff created by excessive rainfall could cause erosion of the stabilized tailings pile which could result in the transport of contaminants into local surface water. Several control features were incorporated into the remedial action design to prevent erosion of the stabilized pile and subsequent contamination of adjacent surface water. The side-slopes of the pile would be limited to five horizontal to one vertical (20 percent) and the top of the pile would be gently sloped (two to three percent) to promote drainage from the pile with non-erosive flow velocities. A combination of ditches and other hydraulic facilities would be constructed to direct surface runoff around and away from the pile. These design features would prevent impacts to surface waters by contact with the tailings after remedial action.

A rock erosion protection barrier would be placed on the top and sideslopes (one foot thick) of the pile to withstand the erosive forces of severe rainfall events such as a Probable Maximum Precipitation (PMP). The drainage ditch and south slope of the pile would be lined with large rock (two feet thick) to withstand a PMP event occurring on the drainage area above the site.

<u>No action</u>

The no action alternative would result in the continued exposure of the tailings pile to erosion from surface runoff. Since abandonment of the site, water and wind erosion have altered the configuration of the pile (SHB, 1984). Eventual erosion of the tailings would result in the transport of contaminants into Moenkopi Wash by surface runoff which could result in an increase in the concentration of contaminants in the wash.

<u>Disposal at the Fivemile Wash site</u>

During remedial action, the Fivemile Wash alternative would incorporate erosion protection measures similar to stabilization in place to prevent the release of contaminants from the sites and to assure the long-term stability of the pile. These measures would include construction of drainage controls and a waste-water retention pond(s) at both the tailings and disposal sites, placement of a rock erosion protection barrier over the stabilized pile, and construction of a permanent ditch lined with erosion protection material around the stabilized pile to divert surface runoff around and away from the pile. Surface waters near the Fivemile Wash site would not be impacted after remedial action because features incorporated into the design would prevent surface waters from contacting the tailings.

Borrow sites

During remedial action, appropriate drainage controls would be used at both borrow sites to minimize or prevent erosion and any corresponding surface-water impacts. After remedial action, the site would be restored according to the sand and gravel permit issued by the Bureau of Indian Affairs (Appendix E, Permits, Licenses, Approvals). Generally, these requirements consist of grading and revegetation measures to control erosion and return the site to a condition compatible with its original use and the surrounding terrain.

4.5.2 Ground water

This section summarizes the predicted impacts on ground water of stabilization in place, no action, and disposal of the tailings at the Fivemile Wash site. Also, water use during remedial action and protection of aquifer users are discussed. The data and data analyses on which these predictions are based are presented in detail in Section B.2 of Appendix B, Water.

Stabilization in place

Stabilization in place would reduce the amount of precipitation which percolates through the pile. The stabilized pile would be covered with 1.5 feet of low-permeability materials which would present a barrier to infiltration. In addition, the pile would be sloped so that precipitation would run off instead of collecting in depressions. Therefore, stabilization in place would reduce the long-term amount of ground-water contamination produced by the pile.

Stabilization in place would have no effect on the existing contaminant plume. The contaminants would continue to move downgradient toward Moenkopi Wash.

No action

If no action is taken there would be no reduction in the amount of ground-water contamination produced by the pile. Contaminant production would continue at its present rate for an indefinite period of time.

Disposal at Fivemile Wash

Stabilization of the tailings at the Fivemile Wash site would probably not adversely affect any usable ground-water supplies. There are no known withdrawals of ground water within four miles of the site. The site is also favorable from the geological point of view. The pile would rest on the Owl Creek Member of the Chinle Formation, which consists of five to 10 feet of limestone covered by up to five feet of eolian sands. The Owl Creek Member is underlain by 500 feet or more of the Petrified Forest Member of the Chinle Formation. The Petrified Forest Member is primarily comprised of siltstones, mudstones, and clays. Because of its composition, the Petrified Forest Member probably does not transmit usable quantities of ground water.

Tailings relocation to the Fivemile Wash site would have no impact on the existing contaminant plume. Contaminants would continue to move downgradient toward Moenkopi Wash.

Water use

The anticipated water consumption for stabilization in place would be 8,500,000 gallons. The basis for this estimated water consumption is contained in Section A.2.5, Appendix A, Engineering Summary. Water would be needed for compaction of the tailings, cover, and other materials, washdown of the haul trucks, and dust control. Tailings relocation to the Fivemile Wash site would require more than twice the amount of water as stabilization in place because this alternative requires a greater amount of earth moving and use of unpaved roads. The sources of the water would be determined by the Remedial Action Contractor, and the water would be obtained according to the applicable laws and regulations (Appendix E, Permits, Licenses, Approvals).

Protection of aquifer users

There is no risk of human exposure to contaminated ground water at this time because there are no withdrawals of ground water downgradient of the pile, either in the area that is presently contaminated or the area that is likely to become contaminated as the plume moves toward Moenkopi Wash. However, there is a possibility that contaminated ground water will be withdrawn in the future. This could be prevented by removing the contaminated water through an aquifer restoration program, or by administrative prohibitions against ground-water withdrawals downgradient of the pile.

A ground-water restoration program would be very expensive. Compared to aquifer restoration, administrative prohibitions are inexpensive because there are no capital or operating costs. The objective of protecting public health and safety could be achieved most cost-effectively by imposing administrative controls to restrict access to the contaminated ground water until natural flushing restores the affected portion of the aquifer.

DOE will mitigate contaminated ground water by applying institutional controls on water development around the site. When EPA issues revisions to the water protection standards (40 CFR 192.20(a)(2)-(3)) that were remanded by the U.S. Tenth Circuit Court of Appeals, DOE will re-evaluate the ground-water issues at the Tuba City site to assure that the revised standards are met. Performing remedial actions to stabilize the tailings prior to EPA issuing new standards will not affect the measures that are ultimately required to meet the revised water protection EPA standards.

4.6 FLORA AND FAUNA

The temporary and permanent losses of vegetation, wildlife habitat, and potential livestock grazing acreage would be the primary impact to plants and animals from remedial action. These impacts would result from surface disturbances caused by: (1) the excavation of contaminated soils, borrow materials, and the alternate tailings disposal site; (2) upgrading of haul roads; and (3) construction of staging and stockpile areas.

Stabilization in place

Stabilization in place would result in the disturbance of 327 acres at and around the tailings site and, consequently, the loss of the vegetation on that acreage.

The remedial action activities would result in the loss of most of the wildlife (mammals, birds, reptiles, and amphibians) inhabiting the disturbed areas at and around the tailings site. Transient, mobile species could relocate to surrounding areas.

Following remedial action, 267 of the 327 acres disturbed would be recontoured to a level compatible with the surrounding terrain and revegetated, reestablishing diverse habitat. The 60 acres containing the stabilized tailings pile would not be revegetated and would not be suitable for wildlife habitat.

No listed, proposed, or candidate threatened or endangered plant or animal species would be affected by remedial action at the tailings site (Metz, 1984).

No action

The no action alternative would not involve any remedial action and therefore would not create any surface disturbance. There would not be any impacts on vegetation, wildlife, or wildlife habitat.

Disposal at the Fivemile Wash site

Relocating the tailings and contaminated materials to the Fivemile Wash site would result in the disturbance of a greater amount of acreage than stabilization in place. The surface disturbance at and around the tailings site and the resulting impacts would be the same as stabilization in place.

The surface-disturbing activities at the Fivemile Wash site would result in displacement of wildlife species inhabiting the site. Most of those species would relocate to suitable habitat in the surrounding area, but a few individuals unable to relocate would not survive.

Following remedial action, areas surrounding the stabilized tailings pile at the disposal site and the existing tailings site would be restored to a level compatible with the surrounding terrain and revegetated. The revegetated areas would be suitable for wildlife habitat. The acreage containing the rock-covered stabilized tailings pile, surveillance and maintenance and access roads, and a drainage ditch would not be revegetated and would not be suitable for wildlife habitat.

Borrow sites

Stabilization in place would require the disturbance of approximately 70 acres at the borrow sites by the excavation of borrow materials. An additional 11 acres would be disturbed by the upgrading of existing roads to the borrow sites.

The borrow activities would result in the displacement of any wildlife species inhabiting the borrow sites. While there is habitat for the displaced species in the surrounding area, some individuals would not survive. Truck transportation of the borrow materials from the borrow site could cause a limited, temporary increase in wildlife mortality along the transportation routes. Areas revegetated following remedial action (60 acres) would reestablish suitable habitat for any displaced wildlife.

The peregrine falcon, a Federally-listed endangered species, may be present in the vicinity of the Shadow Mountain borrow site (Baucom, 1985). This species generally nests in areas of steep cliffs, usually near water. Any cliffs adjacent to the borrow sites would be examined prior to use of the area to verify the presence or absence of the peregrine falcon. Should nesting peregrine falcons be identified, further consultation with the USFWS will occur.

4.7 LAND USE

Stabilization in place

The final restricted area containing the stabilized tailings pile would encompass 60 acres, and other use of these 60 acres at the Tuba City site would be permanently precluded. The stabilized tailings site would be under the direct control of the Federal Government and would be permanently restricted from any development. However, the remaining disturbed acreage at and around the site would be decontaminated, restored, and released for any use consistent with local land use plans.

Stabilization in place would involve the temporary disturbance of 327 acres at and adjacent to the tailings site for cleanup of contaminated areas within the designated site boundary and the areas contaminated by windblown tailings. Residents living adjacent to the area of decontamination activity would not be required to relocate during remedial action. Of the acreage disturbed, 267 acres would be restored and released for unrestricted use.

Disturbance at the Greasewood Lake, Shadow Mountain, and Pediment Gravel borrow sites would consist of 30, 10, and 30 acres, respectively. An additional 11 acres would be disturbed during the construction of access roads. The acreage disturbed at the borrow sites (except at the Shadow Mountain borrow site) would be reclaimed according to the requirements of the sand and gravel permit issued by the Bureau of Indian Affairs (Appendix E, Permits, Licenses, Approvals).

Activities during remedial action would have little impact on land use in the surrounding area. Impacts to sheep grazing would be negligible because of the large areas nearby which are available for grazing. The existing pattern of occasional occupancy of some of the housing units at the residential area adjacent to the tailings site could be temporarily impacted during remedial action because of the increase in noise levels and dust emissions, but would return to current levels after the cleanup is complete. After remedial action, use of lands in the area adjacent to the stabilized tailings pile for sheep grazing would not be impacted. The potential for future development of areas surrounding the stabilized tailings pile would be improved by decontamination and reclamation of the existing tailings pile and adjacent areas.

No action

The no action alternative would allow the tailings pile to continue to affect existing land use patterns. The acreage presently occupied by the tailings site (105 acres) would not be available for alternative uses. In addition, dispersion of the tailings by wind and water erosion would continue to contaminate lands adjacent to the pile. The rate of this continuing contamination cannot be accurately quantified, but 222 acres have been contaminated to date.

Disposal at the Fivemile Wash site

The final restricted area containing the stabilized tailings pile at the Fivemile Wash site would be approximately the same size as stabilization in place, and other uses of this acreage at the Fivemile Wash site would be permanently precluded. This acreage represents a very small portion of the lands available for grazing in the general area (approximately 350,000 acres in the Tuba City Chapter). Relocation of the tailings to the Fivemile Wash site would allow release of the existing tailings site for unrestricted use.

The Fivemile Wash alternative would involve the temporary disturbance of approximately half the area at the Greasewood Lake borrow site and an equal area at the Shadow Mountain borrow site as stabilization in place. As with stabilization in place, the borrow sites would be reclaimed in accordance with the sand and gravel permit issued by the Bureau of Indian Affairs (Appendix E, Permits, Licenses, Approvals). A limited area at the Fivemile Wash disposal site would be temporarily disturbed for use as a construction staging area and for stockpiling of surface materials. This disturbed land would be restored to a level compatible with the surrounding terrain and revegetated.

4.8 NOISE LEVELS

Noise impacts were estimated for the remedial action alternatives. The major noise-producing sources would be the construction equipment used at the sites and the trucks used to haul tailings and borrow materials. Typical sound levels generated by the types of equipment used in the alternatives are presented in Table 4.8.

Table 4.8 Noise levels for equipment used for remedial action

Equipment	Maximum noise level at 50 feet (decibels)
D-8 bulldozer	88
Front-end loader	85
Scraper	87
Water truck	89
Haul truck	86
Compactor	87
Grader	83

Ref. Kessler et al., 1978.

For the stabilization in place alternative, a noise prediction model (Kessler et al., 1978) was used to estimate the maximum A-weighted noise levels in decibels (dBA) from each of the sites during the remedial action. The model is based on the numbers and types of equipment operating on the site, usage factors for operation in the noisiest modes, and the distance from the activity to the nearest noise-sensitive receptors (residences). The model tends to overpredict noise levels since it assumes a clustering of equipment. In reality, the equipment would be located over a number of acres.

The maximum noise level predicted for stabilization in place is approximately 95 dBA at locations 100 feet from the center of activity. The nearest residences to the center of activity are at the 26-dwelling residential area, approximately 1500 feet away. Project noise levels would be attenuated approximately 23 dBA over this distance, resulting in a 72-dBA noise level at the residences. Activities associated with cleanup of the mill building and ore storage areas would be centered approximately 500 feet from the residential area. This could result in brief periods of noise levels at the residential area of up to 100 dBA. The predicted maximum noise level is greater than the EPA-recommended level established for the protection of hearing of 70 dBA (EPA, 1974). It should be noted that the residential area is only occasionally occupied; therefore, the potential for annoyance and hearing impacts is limited. This noise level would occur only during normal daytime work hours. Noise levels from remedial action will drop below 60 decibels at approximately one mile from the tailings site.

Projected maximum noise levels from activities at the Greasewood Lake and Shadow Mountain borrow sites at a distance of 100 feet from the center of activity are approximately 86 decibels. There is one residence located approximately 0.5 mile from the Greasewood Lake borrow site, and three residences approximately 0.5 mile from the Shadow Mountain borrow site. Project noise levels would be attenuated by 29 dBA over this distance, resulting in approximately a 57-dBA noise level at the residences. This noise level is greater than the EPA recommended upper level for annoyance from outdoor activity of 55 dBA but less than the 70 dBA level established for the protection of hearing (EPA, 1974). This noise level would occur only during normal daytime work hours. The Shadow Mountain borrow site has been used previously as a source of borrow materials by the Arizona Department of Transportation (Rosenberg, 1985).

Finally, there would also be noise produced by the haul trucks traveling between the various sites. Noise produced by the trucks could be expected to be approximately 79 dBA at a location 100 feet from the haulage route. Such levels would prove annoying to residents along the transportation routes, but the elevated noise levels would be extremely brief in duration at any single location as the trucks passed by and would occur only during normal daytime work hours.

Disposal of the tailings at Fivemile Wash would result in somewhat reduced noise impacts at the existing tailings site than would stabilization in place because of lower equipment activity levels; however, substantially greater noise impacts along transportation routes would occur because of the large number of truck trips required to relocate the tailings and associated contaminated materials. Noise levels at the Fivemile Wash disposal site would be similar to those described for the existing tailings site for stabilization in place; however, impacts would be less because of the greater distance from the Fivemile Wash site to the nearest residence (approximately two miles at the Fivemile Wash site rather than 1500 feet at the existing tailings site).

4.9 SCENIC, HISTORIC, AND CULTURAL RESOURCES

Scenic resources

Stabilization in place would have a minor impact on scenic resources. The new shape and height of the stabilized pile and the demolition of the existing mill structures would cause a permanent but slight change in the immediate viewshed around the tailings pile. The stabilized pile would be an average of 33 feet above the surrounding terrain; however, it would not be visible from Tuba City. During the decontamination activities, the removal of vegetation and surficial materials would temporarily alter the foreground views around the pile. Cleanup of the areas of windblown tailings would result in a large area devoid of vegetation that would be clearly visible in the foreground and middleground to people traveling along U.S. Highway 160. The excavated area would be in the view of approximately 7600 people per day assuming an average daily traffic count of 3800 vehicles (ADOT, 1984) and two people per vehicle. After remedial action, restoration of the excavated areas surrounding the stabilized tailings pile to a level compatible with the surrounding terrain would reduce the impacts to the viewshed. Once vegetation is reestablished, the excavated areas would not be noticeable. Both the permanent and temporary changes in the views would be subordinate to the regional view.

During stabilization in place, the removal of vegetation and borrow materials at the Greasewood Lake, Shadow Mountain, and Pediment Gravel borrow sites would temporarily alter the elements of color, texture, and contrast at the sites. Borrow activities at Greasewood Lake would not be visible from any major roads or highways; however, excavations at the Shadow Mountain borrow site would be visible in the distance from several segments of U.S. Highway 89. Alteration in color and texture due to borrow activities at the Shadow Mountain borrow site would be evident in the middleground when viewed from the nearest residences approximately 0.5 mile east of the site. Excavation at the Pediment Gravel borrow site would occur at the same time and adjacent to remedial action at the tailings pile and would only slightly alter the visual impacts of remedial action. The Greasewood Lake borrow site would be restored according to the reclamation requirements specified in the sand and gravel permit issued by the BIA (Appendix E, Permits, Licenses, Approvals). These requirements would include returning the site to a condition compatible with the surrounding terrain. The Shadow Mountain borrow site would not be reclaimed since this site is located on a rock surface.

The no action alternative would not involve any remedial action and, therefore, would have no impact on existing scenic resources.

Disposal of the tailings at the Fivemile Wash site would result in fewer long-term impacts to scenic resources than stabilization in place because the site is not visible from any residences or major roads or highways. The height and shape of the stabilized tailings pile would cause a permanent change in the visual landscape of the area because of the height of the embankment above the surrounding terrain. Relocation of the tailings would improve the viewshed at the existing tailings site by the removal of the abandoned mill structures and the tailings and subsequent restoration.

Historic and cultural resources

No sites currently listed on the National Register of Historic Places (NRHP) would be affected by any of the remedial action alternatives.

An intensive cultural resource inventory was conducted at the existing tailings site and part of the adjacent area of windblown contamination

(CASA, 1983). No historic or cultural resources were identified in the survey. Based on previous archaeological surveys (CASA, 1983, 1984), the probability is very low that archaeological sites are present in the unsurveyed area.

Based on the results of previous cultural resource surveys at the Greasewood Lake, Shadow Mountain, and Pediment Gravel borrow sites (Rosenberg, 1985; CASA, 1984), no cultural resources would be affected by borrow activities associated with any of the remedial action alternatives. These areas would be completely surveyed prior to remedial action.

No cultural resources are known to exist at the Fivemile Wash site and, therefore, no cultural resources would be expected to be affected by relocation of the tailings to the Fivemile Wash disposal site. An intensive cultural resource survey would be conducted at the Fivemile Wash site prior to initiating surface disturbance activities if the tailings relocation alternative were to be selected.

4.10 POPULATION AND EMPLOYMENT

This section describes the impacts of the remedial action alternatives on the Tuba City population and work force.

Stabilization in place

Stabilization in place would involve an overall average work force of 48 workers over an 18-month period. During the fifth month of the construction period when activities would be at their highest levels, a total of 77 workers would be employed. Of this total, 60 workers would be from the general work force category and 17 would be from the supervisory-field services category. The general work force category is comprised of truck drivers, heavy equipment operators, operator supervisors, and laborers, and the supervisory-field services category is comprised of the project manager, project engineer, health physics personnel, surveyors, security guards, and secretaries. For estimation of population and employment impacts, the local work force was assumed to be adequate to meet the requirements for the general work force. It is anticipated that half of the supervisory-field services personnel would be obtained from outside the local area because of the specialized nature of certain skills. In accordance with the Cooperative Agreement with the Hopi Tribe and Navajo Nation, the DOE requires that the Remedial Action Contractor or subcontractor make full use of any qualified Indian tribal members residing in the vicinity of the tailings site.

The overall average work force of 48 workers would involve 31 general workers and 17 supervisory-field services personnel. Forty of the 48 workers would be hired from the local work force (31 general and nine supervisory-field services workers); the remaining eight workers would be obtained from outside the local area. Based on historical patterns of construction employment in the western U.S. (e.g., married versus single, relocate with families or without), approximately

60 percent of the inmigrant construction workers would bring families to the local area (Mountain West Research, 1979). Using this percentage and the Tuba City average family size of five persons (DOC, 1980), the eight inmigrant workers would result in an addition of five families and a total inmigration of 28 persons. After the project is completed, it is anticipated that the inmigrant workers would only be able to find employment outside the Tuba City area; therefore, they would leave the area taking their families with them.

Direct project employment would create induced employment as project labor dollars circulate through the local economy. Research on employment multipliers for projects similar to the proposed action resulted in an employment multiplier of 1.44 (Gibson and Stephenson, 1983) for areas with demographic characteristics similar to Tuba City. Applying this multiplier to the overall average of 48 direct project employment, an estimated 21 additional induced jobs would be generated. It is expected that all induced jobs would be taken by current local residents.

In summary, over the 18-month period of remedial action, stabilization in place would create a total of 69 new jobs (48 direct and 21 induced), 61 of which would be obtained by current local residents. This would result in a 3.2 percent increase in total Tuba City employment over the 1984 levels. A total population increase of 24 would be expected, representing less than a 0.5 percent increase in the local population.

No action alternative

The no action alternative would have no impacts on the size of the local population or the area's employment base.

Disposal at the Fivemile Wash site

Disposal of the tailings and associated contaminated materials to the Fivemile Wash site would result in moderately greater impacts to the local work force than stabilization in place. Somewhat greater labor and nonlabor expenditures would be required for tailings relocation to the Fivemile Wash site as stabilization in place, and the duration of the remedial action would be longer (24 months for tailings relocation rather than 18 months for stabilization in place) resulting in greater overall impacts to the local work force. The number of supervisory field services personnel required for either remedial action alternative would be the same; therefore, impacts to the local population from inmigration would be the same for disposal at the Fivemile Wash site as stabilization in place.

4.11 HOUSING, SOCIAL STRUCTURE, AND COMMUNITY SERVICES

Either remedial action alternative would involve the relocation of eight inmigrant workers to Tuba City. Because of the limited supply of available housing, the inmigrants could have some difficulty in finding housing in Tuba City, and might locate in communities more distant from the project site. There would be no impact on the local housing situation from the no action alternative.

Because of the low level of population inmigration (28 persons), neither action alternative would have an appreciable effect on the local social structure. The no action alternative would have no impact on the local social structure.

The project-related inmigrant population would be expected to include 11 school-age children for either action alternative. Assuming all inmigrants were able to locate housing locally, this would result in an additional enrollment of 11 students in Tuba City public schools. Although primary schools have been filled to capacity in recent years, given that the 1984-85 school year enrollment in Tuba City Unified School District was 64 students less than it had been in the previous year, no impacts would be expected from the addition of 11 pupils of varying ages to the Tuba City public school system which had a total enrollment in 1983 of over 3300.

Project-related population water consumption would be expected to be 2800 gallons per day (using a 100-gallon per day per capita consumption factor) for either action alternative. Direct project uses (mostly non-potable water for compaction, dust suppression, and the like) would be 8,500,000 gallons for stabilization in place. Adequate sources of water are available to provide the required quantities without impacting local water supplies.

Project sewer demand would be 2800 gallons per day (gpd) for either action alternative, using a per capita sewage generation factor of 100 gpd. The Tuba City sewer system was designed for a population of 8000 (Navajo Nation, 1984), and is currently operating well below capacity. Thus, no impacts would be expected from the inmigration of 28 persons.

Because of the low levels of population increase associated with either action alternative, no adverse impacts would be expected on local public safety, health care, or recreational facilities. The no action alternative would have no impacts on local community services.

4.12 ECONOMIC STRUCTURE

Implementation of any of the action alternatives would impact the local economy through wages and salaries paid to direct and indirect employees; through the project's local spending for materials, equipment, and supplies; and through indirect expenditures as project dollars spent locally are respent locally on other goods and services.

The total direct input to the local economy for stabilization in place is estimated at $1.7 million in employee wages and salaries and $3.1 million in local expenditures for materials and equipment. Using a multiplier of 1.23 for local expenditures (every dollar in wages and salaries would generate an additional $0.23 in indirect spending)

(Mountain West Research, 1979), an additional $1.1 million of local expenditures would be generated. Thus, the total impact of the stabilization in place alternative on the local economy is estimated to be $5.9 million.

The no action alternative would have no impact on the local economy.

Tailings relocation to the Fivemile Wash site is estimated to increase the cost of remedial action by almost three times relative to stabilization in place. Consequently, project-related expenditures for wages, salaries, materials, and equipment would be substantially greater for disposal at Fivemile Wash than for stabilization in place, as would be impacts to the local economy.

4.13 TRANSPORTATION NETWORKS

The roadways primarily affected by the remedial action alternatives would include U.S. Highways 160 and 89. Average daily traffic volumes on these routes in 1983 were estimated at 3800 vehicles per day on U.S. Highway 160 and 3900 vehicles per day on U.S. Highway 89 (ADOT, 1984).

Stabilization in place

Stabilization in place would primarily affect segments of U.S. Highways 89 and 160 between the existing tailings site and the Greasewood Lake and Shadow Mountain borrow sites. Incremental project traffic would stem from worker commuting, site preparation, the hauling of borrow materials, and from miscellaneous trips.

Maximum traffic impacts would occur during months two through 13 of the 18-month schedule for stabilization in place. During these months, in addition to worker commuting, the transport of borrow materials would be ongoing. An estimated 27 haul-truck round-trips per day would be made on the two-mile route between the Greasewood Lake borrow site and the tailings site during the period of greatest activity. The unimproved dirt road between the sites would be upgraded for use during the project. The route includes a crossing on U.S. Highway 160 where traffic control measures would be implemented.

U.S. Highways 89 and 160, and an unimproved dirt road between U.S. Highway 89 and the Shadow Mountain borrow site, would be used to transport borrow materials approximately 25 road miles from the Shadow Mountain borrow site to the Tuba City tailings site. The 4.9-mile-long unimproved dirt road between U.S. Highway 89 and the Shadow Mountain borrow site would be upgraded for use during the project. An increase in traffic volume of 1.6 percent would occur on affected portions of U.S. Highways 160 and 89, as a result of up to 31 daily haul-truck round-trips between the tailings site and the Shadow Mountain borrow site during the period of greatest activity.

Traffic impacts would be minor because substantial excess roadway capacity exists, and short term (i.e., for the duration of the remedial action); no long-term impacts would occur. All project vehicular traffic would occur during normal weekday working hours.

No action alternative

The no action alternative would have no impacts on local transportation networks.

Disposal at the Fivemile Wash site

Disposal of the tailings at the Fivemile Wash site would primarily involve U.S. Highways 89 and 160, the unimproved road between U.S. Highway 160 and the Fivemile Wash site, the unimproved road between the Greasewood Lake borrow site and the Tuba City tailings site, the unimproved road between the Shadow Mountain borrow site and U.S. Highway 89, and the unimproved road between U.S. Highway 89 and the Fivemile Wash site. Relocation of the tailings and associated contaminated materials would require the use of the 15.8-mile route between the sites over a 16-month period for an average of 281 truck trips per day. The transport of erosion protection borrow materials from the Shadow Mountain borrow site would involve many more truck trips than for stabilization in place; however the route to the Fivemile Wash site from the Shadow Mountain site is shorter (9.4 miles total and only one mile on U.S. Highway 89 for disposal at Fivemile Wash, rather than 24.9 miles total for stabilization in place). Tailings relocation to the Fivemile Wash site would also involve approximately three times as many truck trips between the Greasewood Lake borrow site and the Tuba City tailings site (for site restoration).

As for stabilization in place, traffic impacts from disposal at the Fivemile Wash site would be short term in nature (i.e., only during the remedial action itself); no long-term impacts would occur.

4.14 ENERGY AND WATER CONSUMPTION

Both stabilization in place and disposal at the Fivemile Wash site would require the expenditure of energy to operate equipment and for on-site operations. In addition, water would be used by remedial action workers for consumption, compaction of the tailings, cover, and other materials, for washdown of equipment, and for dust control.

For stabilization in place, total fuel consumption is estimated to be 468,000 gallons. The sources of the fuel would be determined by the Remedial Action Contractor (RAC). The anticipated water consumption would be 8,500,000 gallons. Not included in this estimate is water consumed by inmigrant workers and their families (2800 gallons per day for an 18-month extended peak period). Inmigrant water consumption is addressed in Section 4.11. Potable water is available from municipal sources. No impacts on the availability of water to other users would result from the use of water from the Tuba City community water supply, as the capacity of the existing system is adequate to meet the incremental increase in demand caused by the remedial action (Navajo Nation, 1984; Scarborough, 1985). Nonpotable water may be obtained from the former Rare Metals production wells located approximately one mile north of the tailings site. The source of the water would be determined by the RAC, and would be obtained according to applicable laws and regulations (Appendix E, Permits, Licenses, Approvals).

Estimated electricity demands for stabilization in place would total 273,000 kilowatt-hours. Electricity used on the site would be produced by portable generators. Appendix A, Engineering Summary, provides greater detail on energy and water consumption.

Disposal of the tailings at the Fivemile Wash site would require more than twice the amount of energy and water as stabilization in place because this alternative would require a greater amount of earth moving and use of unpaved roads and would occur over a longer period.

4.15 ACCIDENTS NOT INVOLVING RADIATION

The remedial action alternatives would involve the extensive use of heavy construction equipment (e.g., dozers, scrapers, front-end loaders) and many heavy truck trips as tailings, other contaminated materials, and borrow materials are transported. Project workers would also be commuting between their homes and the work site. Because a high proportion of the project work force is expected to be available locally, an average commuting distance of 15 miles (one-way) is assumed for project workers for both remedial action alternatives.

The construction equipment used and transportation activities associated with each alternative pose the risk of accidents and resulting injuries and fatalities. Based on nationwide data from the mining and construction industries, an estimated 0.042 non-fatal accidents leading to loss of work time and 0.0005 fatal accidents would occur per man-year (DOC, 1983).

The average total accident rate for the potentially affected segments of U.S. Highways 89 and 160 from 1981 through 1984 was 1.01 accidents per million vehicle-miles traveled. This composite rate included a fatal accident rate of 0.04 fatal accidents per million vehicle-miles traveled, an injury accident rate of 0.34 injury accidents per million vehicle-miles traveled, and a property damage rate of 0.63 property damage accidents per million vehicle-miles traveled (ADOT, 1984, 1985). The analyses presented below express expected transportation fatalities and injuries in terms of the above accident rate factors.

Non-radiological accident impacts associated with the remedial action alternatives are estimated below based on the vehicle-miles traveled and man-years of labor associated with each alternative. It should be noted that the equipment use accident data include truck use, and thus appear to be partly redundant with the purely transportation accident data.

Stabilization in place

Stabilization in place would have less off-site vehicular travel than disposal at the Fivemile Wash site because there would be no off-site transportation of the tailings. A total of 653,000 vehicle-miles of off-site vehicular travel would be required, including 221,000 vehicle-miles of truck travel to and from the borrow sites and 432,000 vehicle-miles of workers commuting. Based on the historical accident rate data for the affected segments of U.S. Highways 89 and 160 presented above, 0.03 fatal accidents, 0.22 injury accidents, and 0.41 property damage accidents would occur.

Stabilization in place would involve an estimated 72 man-years of labor. Assuming a fatal accident factor of 0.0005 fatal accidents per man-year of labor, 0.04 fatalities would be expected. Assuming a non-fatal accident factor of 0.042 injury accidents per man-year of labor, 3.0 injury accidents leading to loss of work time would be expected.

No action alternative

The no action alternative would have no impacts in terms of construction or transportation accidents.

Disposal at the Fivemile Wash site

Relocation of the tailings and associated contaminated materials would require much greater off-site vehicular traffic than stabilization in place because the tailings would be transported 15.8 road-miles from the existing tailings site to the Fivemile Wash site. In addition, the Fivemile Wash alternative would involve greater manpower and borrow material requirements. Consequently, approximately three times as many project-related injuries, fatalities, and property damage accidents would be expected to result from tailings disposal at Fivemile Wash as stabilization in place.

4.16 MITIGATIVE MEASURES

As stated in Section 2.3, the engineering design for the Fivemile Wash alternative is based on existing, published data. If this alternative were selected, additional site-specific data would be obtained before the final engineering design is made. This could necessitate the incorporation of mitigative measures that are not discussed in this document.

The following mitigative measures were incorporated into the design and approach for each of the remedial action alternatives in order to reduce the environmental impacts:

- Establishment of a site security system at each site to control traffic entering and leaving each site.

- o Construction of drainage controls to direct surface runoff away from the stabilized tailings and prevent long-term erosion.
- o Removal of all contaminated soils (consistent with EPA standards) adjacent to the tailings pile and consolidation of the contaminated soils with the tailings.
- o Application of water and chemical dust suppressants to dirt and graveled haul roads to inhibit dust emissions.
- o Covering of haulage trucks to prevent dispersion of tailings during relocation.
- o Immediate cleanup of any off-site spills of contaminated materials in compliance with applicable regulations.
- o Selection of borrow sites which are as close to the disposal sites as possible to reduce costs and eliminate the impacts of long haulage distances.
- o Reclamation of borrow sites in accordance with requirements of borrow permits.
- o Design of the stabilized tailings to withstand a Design Earthquake.
- o Implementation of complex cover designs to inhibit plant root penetration, burrowing by animals, and inadvertent human intrusion after remedial action.
- o Construction of a rock cover on the stabilized tailings pile to assure that the stabilized pile would withstand the erosive effects of a Probable Maximum Precipitation (PMP).
- o Construction of compacted, earthen tailings covers to inhibit radon emanation (consistent with EPA standards) and surface-water infiltration.
- o Construction of drainage controls and a waste-water retention pond(s) at each site to prevent contaminated waste-water and surface-water runoff from leaving the site during remedial action.
- o Cleanup of equipment used before release to prevent the spread of contaminated materials.
- o Construction of concrete posts with warning signs to discourage human intrusion to the stabilized tailings pile.
- o Use of local labor whenever possible to reduce the sociological impacts to the local communities and to provide economic benefits.

- o Conducting operations only during normal work hours to minimize noise impacts.

- o Maintaining close communications with the local population through an established public information program.

The following mitigative measures were incorporated into the individual alternatives:

<u>Stabilization in place</u>

- o Recontouring and revegetating the areas surrounding the stabilized tailings pile disturbed during the cleanup and consolidation of the tailings and contaminated materials after remedial action.

<u>Fivemile Wash alternative</u>

- o Recontouring and revegetating the areas disturbed at the Tuba City tailings site by the removal of tailings and contaminated materials.

- o Recontouring and revegetating areas disturbed at the Fivemile Wash disposal site for the construction staging area and the surface materials stockpile.

- o Release of the Tuba City tailings site for unrestricted use after remedial action.

Mitigative measures taken to ensure remedial action worker protection and long-term stability of the tailings are described in the Uranium Mill Tailings Remedial Action (UMTRA) Project Health and Safety Plan (DOE, 1983), the draft Remedial Action Plan (DOE, 1985c), and the UMTRA Project Surveillance and Maintenance Plan (DOE, 1985d).

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GLOSSARY

alluvium	Sediment deposited by a flowing river.
alpha particle	A positively charged particle emitted from certain radionuclides. It is composed of two protons and two neutrons, and is identical to the helium nucleus.
ambient	Surrounding on all sides, encompassing.
animal unit month	The amount of feed or forage required by one mature cow and calf for one month.
anticline	A fold in rocks that is convex upward or had such an attitude at some stage of development.
aquifer	A subsurface formation containing sufficiently saturated permeable material to yield usable quantities of water.
attenuate	To reduce the level of radiation emitted from a source.
A-weighted scale	Sound pressure level scale which most closely matches the response of the human ear. This scale is most commonly used to measure environmental noise and is often supplemented by the time and duration of the noise to determine the total quantity of sound affecting people.
background radiation	Radiation arising from radioactive material other than that under consideration. Background radiation due to cosmic rays and natural radioactivity is always present, and there is always background radiation due to the presence of radioactive substances in building materials, and the like.
bioassay	A method for quantitatively determining the concentration of radionuclides in a body by measuring the quantities of those radionuclides that are eliminated from the body, usually in the urine or the feces.
Class III archaeological surveys	Relates to an archaeological investigation of probable occurrence of cultural resources within a given locale. A Class III survey is an in-depth inspection of an area to determine the presence of archaeological materials where the likelihood of their occurrence is high, based on the history of the area.
confined aquifer	An aquifer bounded above and possibly below, by continuous beds or strata of much lower permeability. In general, a confined aquifer contains water under pressure that is significantly greater, or less than, the normal hydrostatic pressure gradient of water created by the force of gravity.

curie (Ci)	The unit of radioactivity of any nuclide, defined as precisely equal to 3.7×10^{10} disintegrations per second.
daughter product(s)	A nuclide resulting from radioactive disintegration of a radionuclide, formed either directly or as a result of successive transformations in a radioactive series; it may be either radioactive or stable.
decay, radioactive	Disintegration of the nucleus of an unstable nuclide by spontaneous emission of charged particles, photons, or both.
decibels (dB)	A unit used to express power or intensity ratios in electrical or acoustical technology.
decontamination	The reduction of radioactive contamination from an area to a predetermined level set by a standards-setting body such as the EPA, by removing the contaminated material.
disposal	The planned, safe, permanent placement of radioactive waste.
dose	A general term denoting the quantity of radiation or energy absorbed, usually by a person; for special purposes, it must be qualified; if unqualified, it refers to absorbed dose.
dose, absorbed	The amount of energy imparted to matter by ionizing radiation per unit mass of irradiated material at the point of interest; given in units of rads.
dosimetry	The measurement of radiation doses.
eolian	Deposited after transport by wind.
excess health effects	Adverse physiological response from radiation exposure (in this report, one health effect is defined as one cancer death from exposure to radioactivity in addition to the normal occurrence of fatal cancer).
exposure	The presence of gamma radiation that may deposit energy in an individual; given in units of roentgens.
external dose	The absorbed dose that is due to a radioactive source external to the individual as opposed to radiation emitted by inhaled or ingested sources.
floodplain	Lowland or relatively flat areas that are subject to flooding. A 100-year floodplain has a one percent or greater probability of flooding in any given year.

flux, radon	The emission of radon gas from the earth or other material, usually measured in units of picocuries per square meter per second.
fugitive dust	Dust particles which are dispersed from a construction site or from trucks during hauling.
gamma	A high energy and deep penetrating form of radiation.
gamma ray	High energy electromagnetic radiation emitted from some radiation radionuclides. The energy levels are specified for different radionuclides.
grazing capacity	The maximum number of livestock which can graze each year on a given area of range for a specific number of days without inducing a downward trend in forage production, forage quality, or soil.
ground water	Subsurface water that occurs beneath the water table in soils and geologic formations that are fully saturated.
half-life	The time required for 50 percent of the quantity of a radionuclide to decay into its daughters.
hydraulic conductivity	Ratio of flow velocity to driving force (for viscous flow under saturated conditions of a specified liquid in a porous medium).
hydraulic gradient	Pressure gradient; rate of change of pressure head per unit of distance of flow at a given point.
inmigrant	A person that moves into an area from outside the local area.
inert gas	One of the chemically unreactive gases: helium, neon, argon, krypton, xenon, and radon.
interbedded	Occurring between beds, or lying in a bed parallel to other beds of a different material.
licensing	In this report, the process by which the NRC will, after the remedial actions are completed, approve the final disposition and controls over a disposal site. It will include a finding that the site does not and will not constitute a danger to the public health and safety.
maintenance, custodial (passive)	The repair of fencing, the repair or replacement of monitoring equipment, revegetation, minor additions to soil cover, and general upkeep of the stabilized tailings pile.
micro	A prefix meaning one millionth (x 1/1,000,000 or 10^{-6}).
milli	A prefix meaning one thousandth (x 1/1000 or 10^{-3}).

Modified Mercalli (scale)	A standard scale for the evaluation of the local intensity of earthquakes based on observed phenomena such as the resulting level of damage. Not to be confused with magnitude, such as measured by the Richter scale, which is a measure of the comparative strength of earthquakes at their sources.
monitor	To observe and make measurements to provide data for evaluating the performance and characteristics of the stabilized tailings pile.
National Register of Historic Places	Established by the Historic Preservation Act of 1966. The Register is a listing of archaeological, historical, and architectural sites nominated for their local, state, or national significance by state and Federal agencies and approved by the Register staff.
permeability	A measure of the relative ease with which a porous medium can transmit a liquid under a potential gradient.
physiographic province	A region of similar structure and climate that has a common geomorphic history.
pico	A prefix meaning one trillionth (1 x 1/1,000,000,000,000 or 10^{-12}).
picocurie	A unit of radioactivity defined as 0.037 disintegrations per second.
radioactivity (radioactive decay)	The property of some nuclides of spontaneously emitting particles or gamma radiation or of spontaneous fission.
radioisotope	A radioactive isotope of an element with which it shares almost identical chemical properties.
radionuclide	A radioactive nuclide.
radium-226	A radioactive daughter product of uranium-238. Radium is present in all uranium-bearing ores; it has a half-life of 1620 years.
radon-daughter product	One of several short-lived radioactive daughter products of radon-222. All are solids.
recharge	The entry into the saturated zone of water made available at the water-table surface, together with the associated flow away from the water table within the saturated zone.
Richter scale	A logarithmic scale ranging from one to 10 used to express the magnitude or total energy of an earthquake.

roentgen	A unit of measure of ionizing radiation in air; one roentgen in air is approximately equal to one rad and one rem in tissue.
sedimentary	Descriptive term for rock formed of sediment, especially: (1) clastic rocks (e.g., conglomerate, sandstone, shale) formed of fragments of other rock transported from their sources and deposited by water or wind, and (2) rocks formed by precipitation from solution (e.g., gypsum) or from secretions of organisms (e.g., limestone).
seismic	Pertaining to an earthquake or earth vibration.
somatic	Radiation health effects to the body of an individual, as opposed to genetic health effects to future generations.
stabilization	The reduction of radioactive contamination in an area to a predetermined level by a standards-setting board such as the EPA, by encapsulating or covering the contaminated material.
surveillance	The observation of the stabilized tailings pile for purposes of visual detection of need for custodial care, evidence of intrusion, and compliance with other license and regulatory requirements.
syncline	A fold in rocks in which the strata dip inward from both sides toward the axis.
tailings, uranium-mill	The wastes remaining after most of the uranium has been extracted from uranium ore.
thorium-230	A radioactive daughter product of uranium-238; it has a half-life of 80,000 years and is the parent of radium-226.
transmissivity	A measure of the ability of an aquifer to transmit water. The value of transmissivity is equal to the product of the hydraulic conductivity and the thickness of the aquifer.
UMTRA Project	Uranium Mill Tailings Remedial Action Project of the Department of Energy.
unconfined aquifer	An aquifer in which the water table forms the upper boundary.
uranium-238	A naturally occurring radioisotope with a half-life of 4.5 billion years; it is the parent of uranium-234, thorium-230, radium-226, radon-222, and others.

vicinity property	A property in the vicinity of the Tuba City site that is determined by the DOE, in consultation with the NRC, to be contaminated with residual radioactive material derived from the Tuba City site, and which is determined by the DOE to require remedial action.
water table	The surface of a body of unconfined ground water on which the fluid pressure in the pores of a porous medium is exactly atmospheric.
windblown	Off-pile tailings transported by wind or water erosion.

ABBREVIATIONS AND ACRONYMS

AD	Anno Domini
BC	Before Christ
BIA	Bureau of Indian Affairs
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
Ci	Curie
cm	Centimenter
cfs	Cubic feet per second
cfs/ft	Cubic feet per second per foot
CO	Carbon monoxide
COE	U.S. Army Corps of Engineers
cy	Cubic yard
dBA	Decibels on the A scale; a logarithmically based unit of sound intensity weighted to account for human auditory responses
DOE	U.S. Department of Energy
EA	Environmental Assessment
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
°F	Degrees Farenheit
g	The force of gravity which is an acceleration of 32 feet per second per second
GECR	Geochemistry and Environmental Chemistry Research, Inc.
gpd	Gallons per day
HC	Hydrocarbon
ISCST	Industrial Source Complex Dispersion Model for Short-Term Application

L_{dn}	Day-night sound level, measured in decibels
lb/cy	Pounds per cubic yard
lb/hr	Pounds per hour
lb/mile	Pounds per mile
MCE	Maximum Credible Earthquake
mg/m^3	Milligram per cubic meter
microg	Microgram; a millionth of a gram
mph	Miles per hour
$microg/m^3$	Microgram per cubic meter
microR/hr	Microroentgens per hour
NA	Not available
NEPA	National Environmental Policy Act of 1969 (PL91-190)
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
NRC	U.S. Nuclear Regulatory Commission
NRHP	National Register of Historic Places
O_3	Ozone
OSHA	Occupational Safety and Health Administration
pCi/g	Picocuries per gram
pCi/l	Picocuries per liter
pCi/m^2s	Picocuries per square meter per second
PL	Public Law
PMP	Probable Maximum Precipitation
ppm	Parts per million
RAC	Remedial Action Contractor

ABBREVIATIONS AND ACRONYMS (Concluded)

RAECOM	Radon Attenuation Effectiveness and Cover Optimization with Moisture
Ra-226	Radium-226
SO_x	Any oxide of sulfur
TAC	Technical Assistance Contractor
Th-230	Thorium-230
TLD	Thermoluminescent dosimeter
TSP	Total suspended particulates
U-238	Uranium-238
UMTRA	Uranium Mill Tailings Remedial Action
UMTRCA	Uranium Mill Tailings Radiation Control Act of 1978 (PL95-604)
USGS	U.S. Geological Survey
WL	Working level (a measure of radon-daughter-product concentration)

Agencies, organizations, and persons consulted

Agency/Organization	Person	Subject
Arizona Department of Economic Security Flagstaff, Arizona	Tom Mauge	Socioeconomics
Arizona Department of Transportation Phoenix, Arizona	Ron Krohn Betina Rosenberg	Engineering, scenic resources
Arizona State Department Water Resources Division Phoenix, Arizona	Beverly Stripling	Surface-water uses
Arizona State Land Department Flagstaff, Arizona	Mike Milne	Surface-water uses
Bureau of Indian Affairs Navajo Area Office Window Rock, Arizona	James Analla Terry DelBene Mark Henderson Edward Olson Loretta Tsosie	Scenic resources, air quality, archaeology, biology, EA production guidelines
Bureau of Indian Affairs Western Navajo Agency Tuba City, Arizona	George Abe Della Jimmie Melinda Roth Edmund Store	Land use, socioeconomics, archaeology, biology, water
Hopi Tribe Kykotsmovi, Arizona	Donald Ami	Water, land use
Hopi Tribe Tuba City (Moencopi Village), Arizona	Leroy Shingoitewa	Socioeconomics
Navajo Housing Authority Tuba City, Arizona	Hanley Begay	Socioeconomics
Navajo Nation Division of Chapter Development Tuba City, Arizona	Chester Claw	Socioeconomics
Navajo Nation Division of Community Development Window Rock, Arizona	Ronald Faich Ben Curley	Socioeconomics, weather, biology

Agencies, organizations, and persons consulted (Continued)

Agency/Organization	Person	Subject
Navajo Nation Division of Economic Development Saint Michaels, Arizona	Stella Saunders	Socioeconomics
Navajo Nation Division of Economic Development Window Rock, Arizona	Adrian Hansen	Geology, minerals
Navajo Nation Division of Resources Window Rock, Arizona	Samuel Diswood	Biology
Navajo Nation Division of Water Resources Fort Defiance, Arizona	Carol Lowery	Surface water uses, water
Navajo Nation Tax Commission Window Rock, Arizona	Emmitt Francis	Socioeconomics
Navajo Tribal Utility Authority Fort Defiance, Arizona	John Scarborough	Water
Nuclear Regulatory Commission Silver Spring, Maryland	Ted Johnson	Engineering, surface water
Tuba City Unified School District Tuba City, Arizona	Hubert Dennie Alberta Talayumpkwa	Education, school enrollment, statistics
U.S. Army Corps of Engineers Los Angeles, California	J. P. Fast Carl F. Enson Wanda Kiebala Vernon Harrell	Wetlands, floodplains
U.S. Department of Agriculture Soil Conservation Service Tuba City, Arizona	Larry Martinez	Soils

Agencies, organizations, and persons consulted (Concluded)

Agency/Organization	Person	Subject
U.S. Fish and Wildlife Service Phoenix, Arizona	Gilbert D. Metz Frank M. Baucom	Wetlands, threatened and endangered species
U.S. Geological Survey Albuquerque, New Mexico	Linda Beal	Surface water
U.S. Geological Survey Flagstaff, Arizona	George Billingsley Paula Helm	Geology, weather
U.S. Geological Survey Tucson, Arizona	Natalie White	Surface water
U.S. Public Health Service Indian Health Service Division Tuba City, Arizona	Angela Maloney	Socioeconomics

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Meunier, Gary	Jacobs	Noise/Weather/ Transportation
Meyer, Carol	Jacobs-Weston	Technical editor
Nelson, Marc	Jacobs-Weston	Project management
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Pingle, Mark	Jacobs	Land use/ Socioeconomics/ Transportation/ Accidents/Energy and water consumption
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Stepp, Leon	Jacobs-Weston	Quality review
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APPENDIX A

ENGINEERING SUMMARY

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A.1 INTRODUCTION

A.1.1 PURPOSE

This appendix provides the information needed to understand the conceptual design, evaluate the feasibility, and assess the environmental impacts of each remedial action alternative addressed in this environmental assessment. However, this appendix is not intended to provide the detailed engineering necessary to implement the remedial action.

The conceptual details (e.g., cover thickness, soil characteristics) of the proposed action are based upon field studies, laboratory testing, and various modeling techniques. Details of these data and calculations are available in the draft Remedial Action Plan (RAP) (DOE, 1985). In addition, the Technical Approach Document (DOE, 1986) describes the general approaches and design criteria that are adopted by the DOE in order to implement the RAP and final designs that comply with EPA standards. For the alternative design, assumptions regarding various factors leading to the proposed action concept (e.g., soil type and availability) have been made based upon the data and calculations applicable to the proposed action.

A.1.2 CONCEPT OBJECTIVES

The purpose of the remedial action is to stabilize and control the uranium mill tailings and other contaminated materials in a manner which complies with the U.S. Environmental Protection Agency (EPA) standards (40 CFR Part 192). Consistent with this purpose, the following major concept objectives have been established:

- o Reduce the average radon flux from the site to 20 picocuries per square meter per second (pCi/m^2s) or 0.5 picocuries per liter (pCi/l) at the boundaries of the disposal site.
- o Design controls to remain effective for up to 1000 years, to the extent reasonably achievable, and, in any case, for at least 200 years.
- o Prevent inadvertent human intrusion into the stabilized tailings.
- o Minimize burrowing by animals and plant root penetration into the stabilized tailings.
- o Ensure that existing or anticipated beneficial uses of surface and ground waters are not adversely affected.
- o Reduce contaminant levels of Ra-226 in areas released for unrestricted use to five picocuries per gram (pCi/g) averaged in the first 15 centimeters (cm) of soil below the surface and 15 pCi/g averaged in 15-cm-thick layers of soil more than 15 cm below the surface.

- Make a reasonable effort to achieve, in any occupied or habitable building, an annual average (or equivalent) radon decay product concentration (including background) not to exceed 0.02 working level (WL). In any case, the radon decay product concentration (including background) shall not exceed 0.03 WL, and the level of gamma radiation shall not exceed the background level by more than 20 microroentgens per hour.

- Minimize the land area to be occupied by the stabilized tailings.

- Protect against releases of contaminants from the site during construction.

- Minimize the areas disturbed during construction, and minimize human exposure to contaminated materials.

A.2 THE PROPOSED ACTION - STABILIZATION IN PLACE

A.2.1 SITE DESCRIPTION

The Tuba City tailings site is located on the Navajo Reservation in Coconino County, Arizona, approximately six air miles east of Tuba City (Figure A.2.1). The 105-acre designated site consists of the tailings pile, three former emergency spill ponds, the mill yard and ore storage area, an emergency dump pit, and a sewage lagoon (Figure A.2.2). Two of the original mill buildings, concrete foundations, and buried conduits remain at the site. Wind and water erosion have spread the tailings over approximately 222 acres outside of the designated site boundary. The limits of contamination at the Tuba City site are shown in Figure A.2.3.

A.2.2 DESCRIPTION OF FINAL CONDITIONS

The stabilized tailings pile would be roughly triangular in shape with a maximum side of 1940 feet in length and a minimum side of 1585 feet (Figure A.2.4). The consolidated tailings and contaminated materials would be covered with a 1.5-foot-thick, compacted earthen cover, and the top and sides would be covered with a one-foot-thick layer of rock for erosion protection. The stabilized pile would have maximum sideslopes of 20 percent (five horizontal to one vertical) and topslopes of two to three percent. The final stabilized pile would be an average of approximately 33 feet and a maximum of approximately 44 feet above the surrounding terrain.

The rock erosion barrier would tie into rock armor channels or rock toe-of-slope protection around the toe of the stabilized pile. A drainage ditch would be constructed around the pile on the north, northwest, and east sides to direct surface runoff around and away from the pile to the south (Figure A.2.5). Concrete posts with warning signs would be placed around the pile and drainage ditch. A 1200-foot-long access road would be constructed to the site from U.S. Highway 160. The final restricted area, including concrete posts with warning signs, roads, and drainage ditch, would cover approximately 60 acres.

The remaining area (45 acres) at the Tuba City site would be restored to a level compatible with the surrounding terrain, recontoured to promote surface drainage, and revegetated as required.

The conceptual design provided is for a comparative analysis of remedial actions at the Tuba City site. The final design will refine the concept presented, but will not significantly alter the proposed action.

A.2.3 MAJOR CONSTRUCTION ACTIVITIES

The principal feature of the design concept is the consolidation of all of the tailings and other contaminated materials into a gently contoured pile conforming to the shape of the existing tailings pile

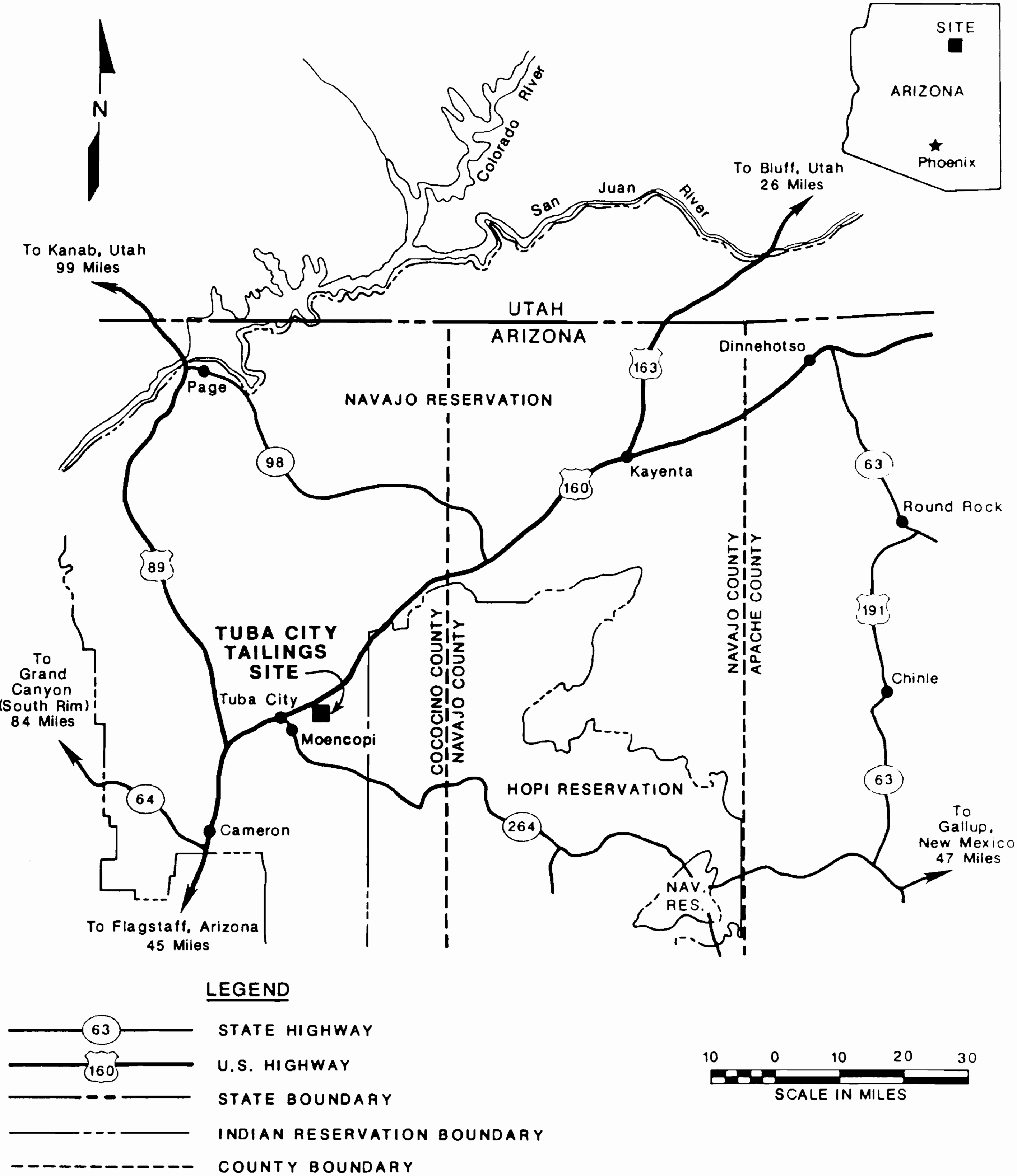


FIGURE A.2.1
TUBA CITY SITE LOCATION

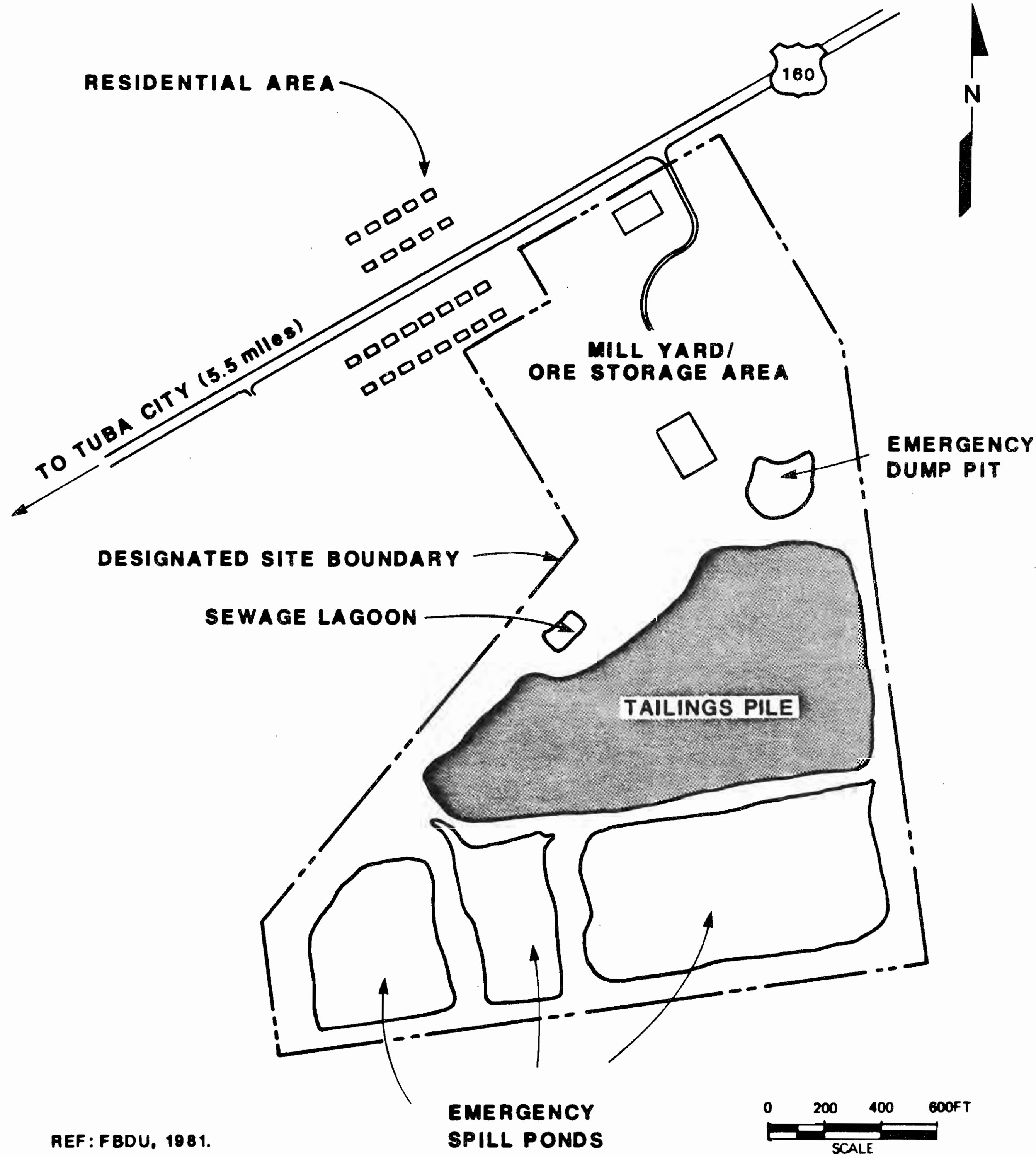


FIGURE A.2.2 TUBA CITY TAILINGS SITE

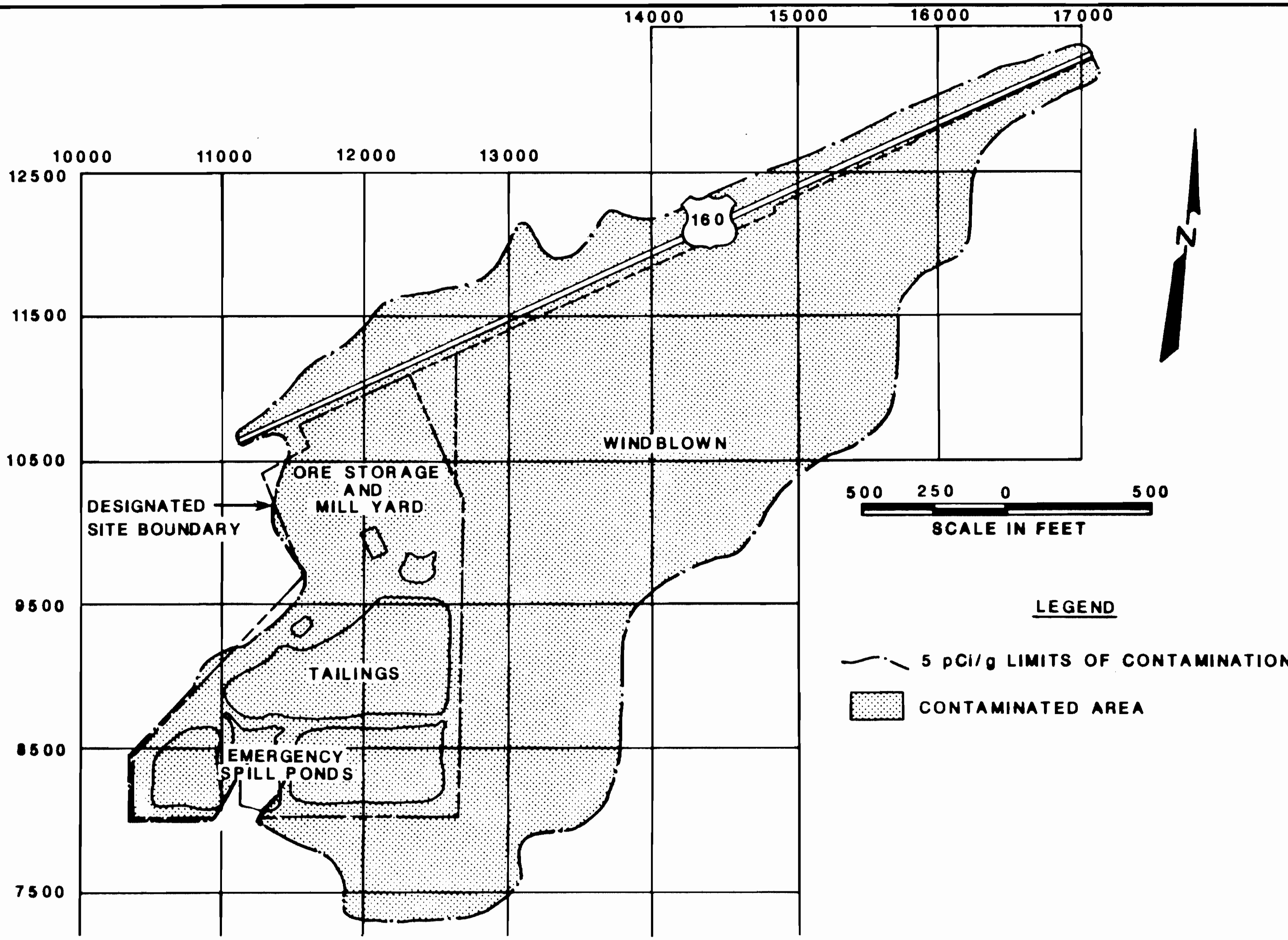


FIGURE A.2.3
LIMITS OF CONTAMINATION, TUBA CITY SITE

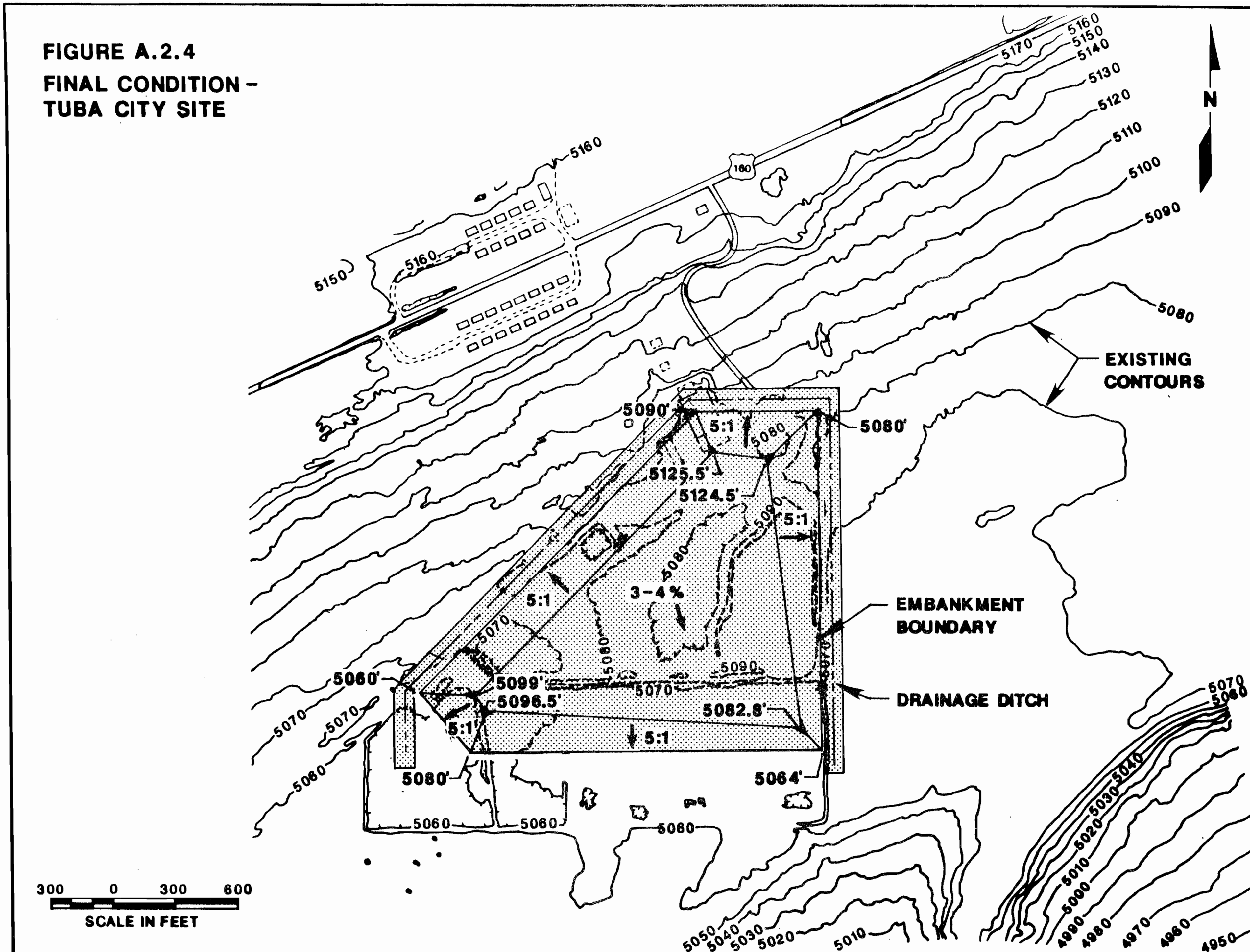


FIGURE A.2.4
FINAL CONDITION - TUBA CITY SITE
N
EXISTING CONTOURS
EMBANKMENT BOUNDARY
DRAINAGE DITCH
5090'
5080'
5125.5'
5124.5'
5:1
3-4%
5060'
5099'
5096.5'
5082.8'
5080'
5064'
300 0 300 600
SCALE IN FEET

A-7

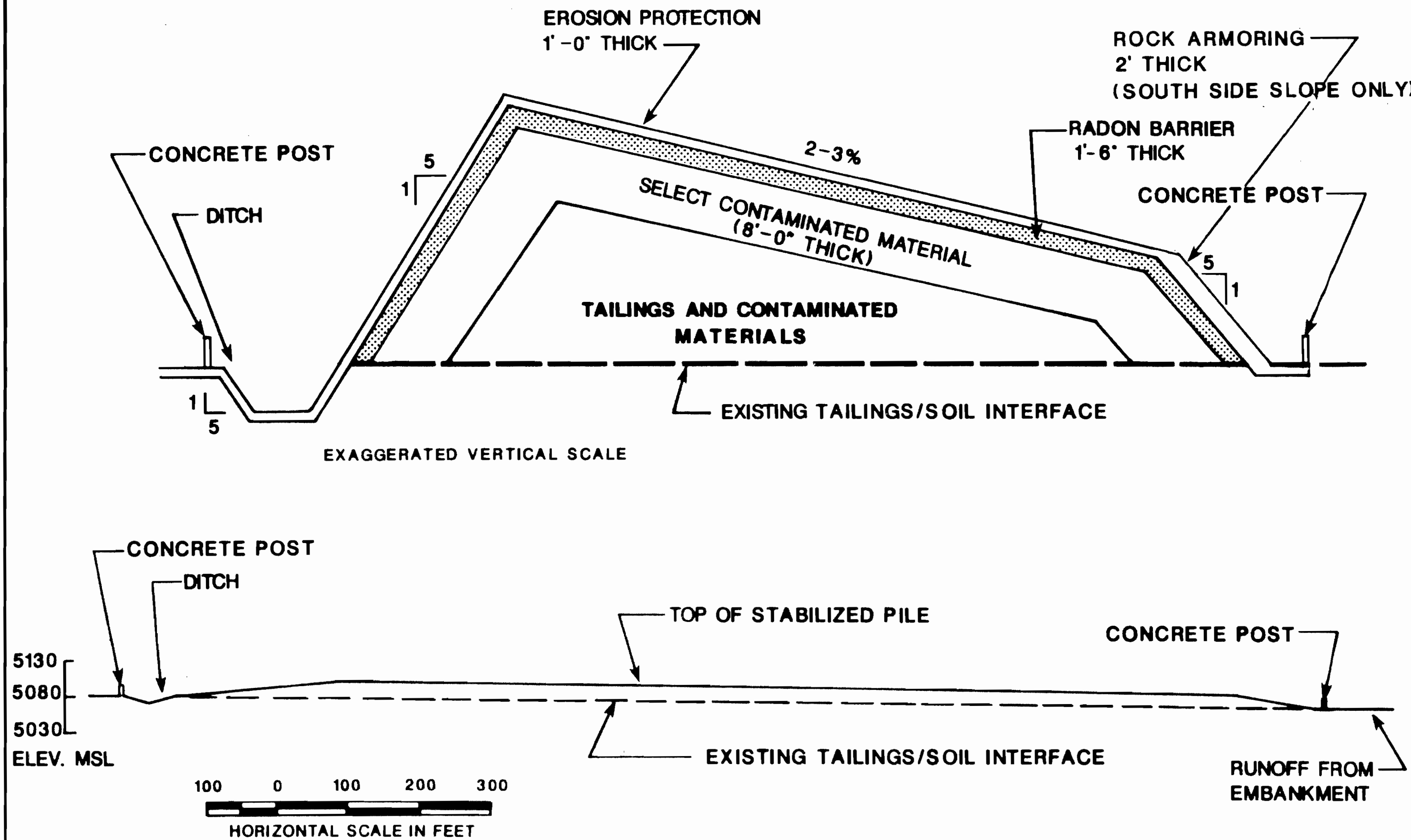


FIGURE A.2.5

STABILIZATION IN PLACE
TYPICAL CROSS-SECTION

(see Figures A.2.2 and A.2.3). The consolidated tailings and contaminated materials would be covered with a compacted layer of earth to control radon emanation and inhibit water infiltration. This radon barrier would consist of earthen materials excavated from the Greasewood Lake borrow site located approximately two road miles northeast of the tailings site and from local sands excavated as part of the construction process (Figure A.2.6). The radon barrier would be covered with rock to protect against wind and water erosion and penetration by burrowing animals. The rock for this erosion protection barrier would be excavated from the pediment gravel source adjacent to the northwest side of the tailings pile and from the Shadow Mountain borrow site located approximately 25 road miles southwest of the tailings site (Figures A.2.7 and A.2.8). An additional pediment gravel has been identified northeast of the tailings site, and would be used only if the Pediment Gravel borrow site does not contain sufficient volume. Details of the engineering properties of the borrow materials are available in the draft Remedial Action Plan (DOE, 1985).

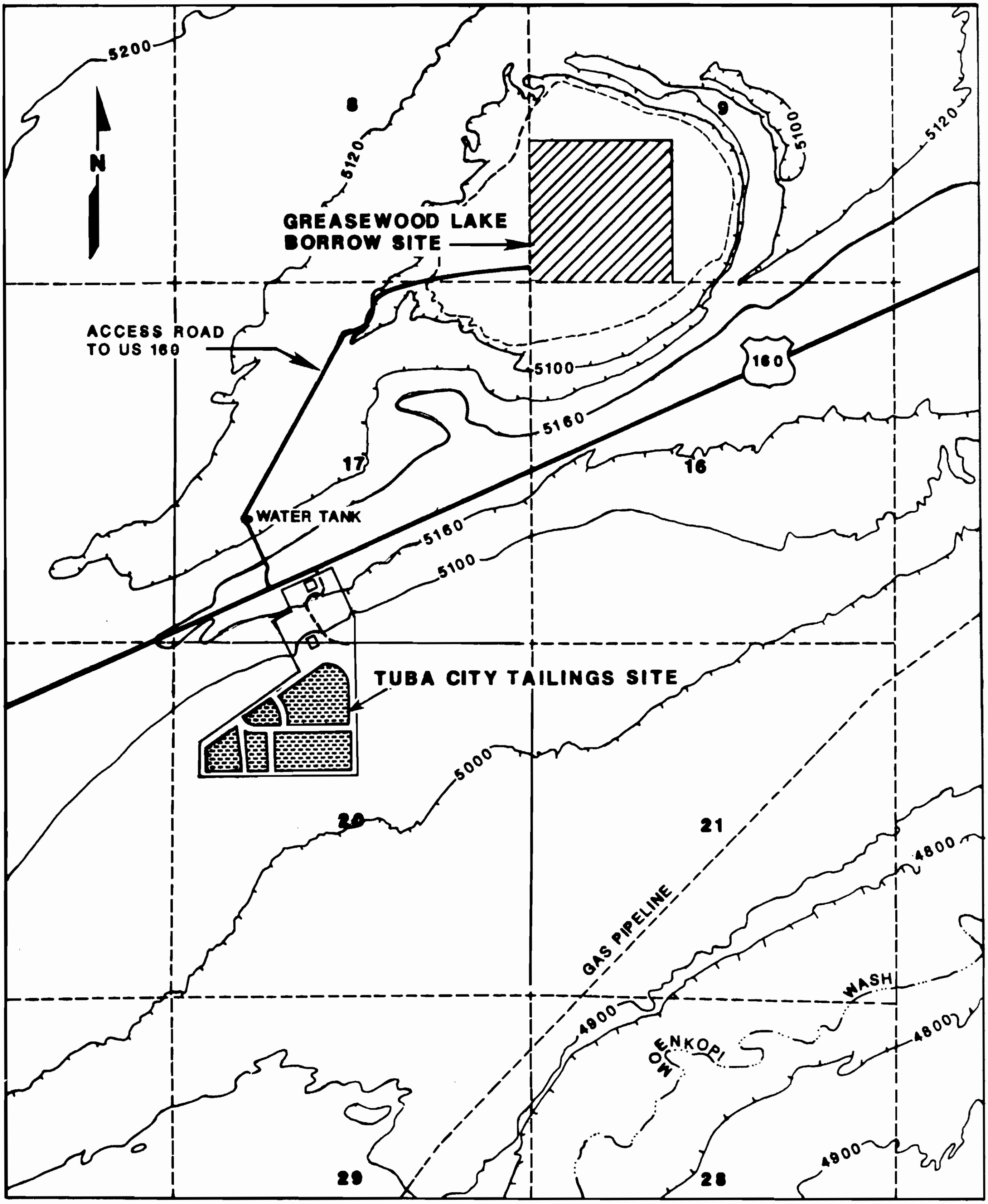
This design would require the following major construction activities:

<u>Site preparation</u>

- o Grubbing and clearing (as necessary) and erection of a temporary security fence.
- o Upgrading 6.4 miles of existing dirt roads between the Tuba City tailings site and the Greasewood Lake and Shadow Mountain borrow sites (Figures A.2.6 and A.2.7).
- o Construction of a 1200-foot-long access road.
- o Construction of a waste-water retention pond(s) to protect against the release of contaminants from the site during construction.
- o Construction of temporary drainage control measures to direct all generated waste-water and storm-water runoff to the waste-water retention pond(s) during remedial action.
- o Installation of measures to control erosion and sediment from all disturbed areas during construction.
- o Construction of a vehicle washdown station.

<u>Tailings pile construction</u>

- o Grading the sideslopes of the pile for the five to one slopes (20 percent).
- o Consolidation of all contaminated materials from the mill buildings, ore pad, and windblown areas onto the existing tailings pile.



REF: TUBA CITY & TUBA CITY NE, ARIZ. USGS 7 1/2 MIN. QUADS

1000 0 1000 2000

SCALE IN FEET

FIGURE A.2.6
GREASEWOOD LAKE BORROW SITE

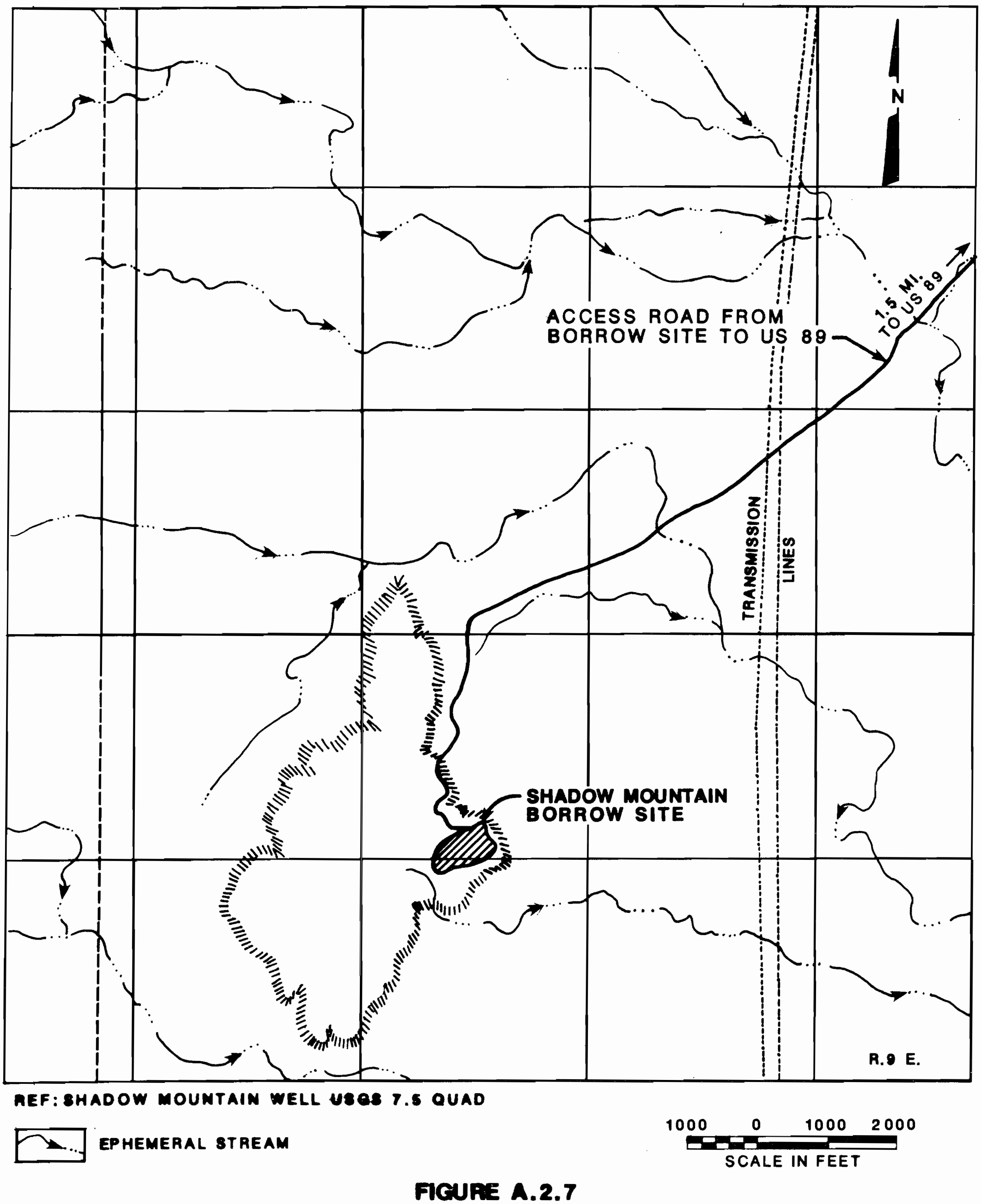


FIGURE A.2.7

SHADOW MOUNTAIN BORROW SITE

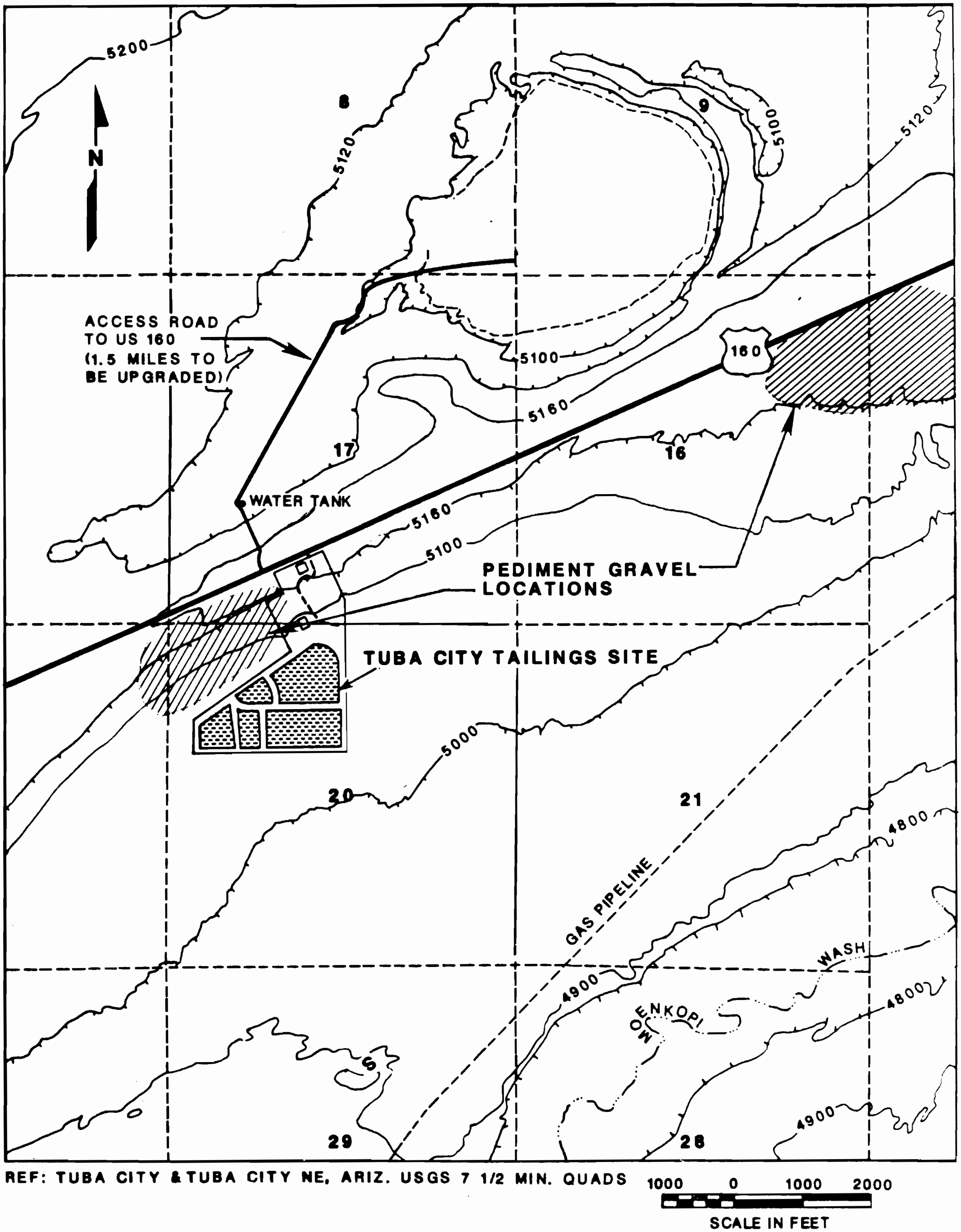


FIGURE A.2.8
PEDIMENT GRAVEL BORROW SITES

- o Grading of the top of the embankment to have a two to three percent slope.

Radon barrier

- o Placement of lesser contaminated materials as the upper eight feet of the contaminated materials.
- o Placement of a 1.5-foot-thick, compacted earthen cover over the consolidated tailings and contaminated materials to inhibit radon emanation, water infiltration, and plant root penetration.

Erosion protection

- o Placement of gravel-sized rock, one foot thick, over the compacted earthen cover to protect against erosion and penetration by burrowing animals.
- o Placement of large rock, two feet thick, over the southern slope of the pile to protect against erosion.

Site restoration

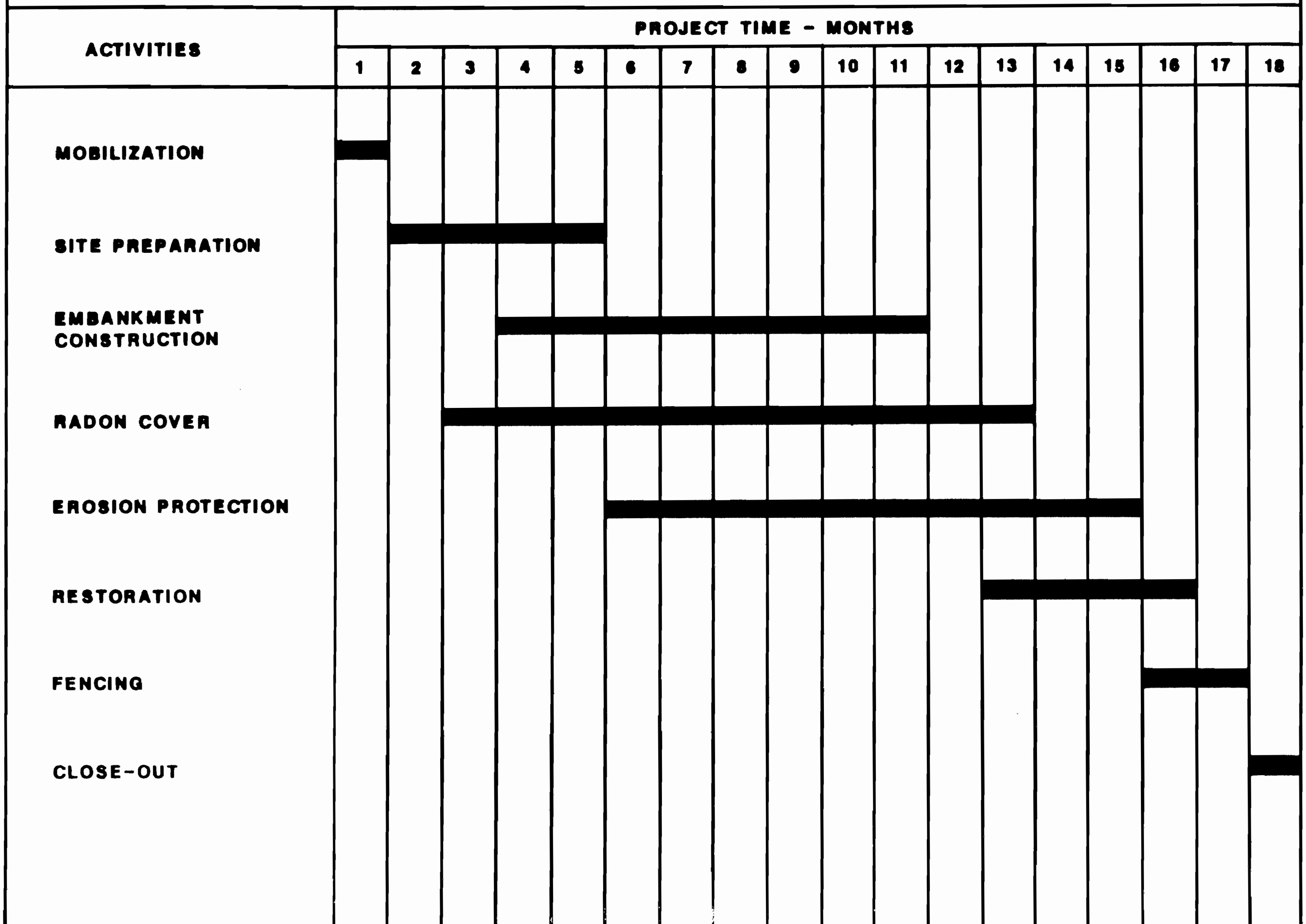
- o Final grading for drainage control and revegetation (as required) of all areas disturbed, including the borrow sites, during remedial action.
- o Construction of a drainage ditch around the north, northwest, and east sides of the stabilized pile.
- o Installation of permanent concrete posts with warning signs to discourage human intrusion.

Figure A.2.9 shows the remedial action schedule for stabilization in place.

A.2.4 MAJOR CONCEPT CONSIDERATIONS

Major factors considered in the concept for stabilization in place include erosion of the stabilized tailings pile by wind and water, resistance of the stabilized pile to deformations caused by a seismic event, and continued but diminishing ground-water contamination from the pile. These and other factors are discussed in the following subsections.

FIGURE A.2.9 REMEDIAL ACTION SCHEDULE: STABILIZATION IN PLACE



A.2.4.1 Siting and configuration

The siting and configuration for stabilization in place were dictated by the site boundary and existing pile shape. Results of a geomorphic evaluation (SHB, 1984) indicated that a pile configuration which included a low west-facing slope would conform with the prevailing westerly winds and minimize the potential for wind erosion. Subsequently, it was determined that the low west-facing slope was not practical because portions of the tailings near the western site boundary contain a higher level of radioactivity and would require a thicker radon barrier than other areas of the tailings pile. To minimize the radon cover thickness, the design was modified so that less contaminated materials (e.g., windblown tailings) could be spread in layers of even thickness over the tailings. The off-pile contaminated materials would be placed as the upper eight feet of contaminated materials in two layers: (1) on-site, off-pile (mill building and pond areas) contaminated materials on top of the tailings, and (2) off-site (windblown) contaminated materials.

The selected design included a low profile to minimize the effects of wind erosion, and the pile sideslopes were limited to five to one (20 percent) to ensure stability. To minimize the size of the drainage ditches required to direct surface water away from the pile, the top of the pile was gently sloped to allow sheet flow off the pile toward the south.

The benefit of consolidating tailings and contaminated materials to a smaller area to minimize required cover materials was also analyzed. It was decided that increased tailings handling (particularly saturated slimes) would offset the savings of smaller cover volumes.

A.2.4.2 Radon control

Data on the distribution of radium in the tailings on and off the site and the properties of the Greasewood Lake borrow materials were input to the RAECOM model (NRC, 1984) which was then used to estimate the cover thickness and the post-remedial action radon flux of the stabilized tailings pile. Considering several alternatives to optimize radon control from a cost-effectiveness and constructibility perspective, control of radon emissions from the stabilized tailings pile would be accomplished through a combination of techniques including the following:

o Decontamination of a large portion of the present site by excavating and placing contaminated materials on the tailings pile.

- Placing windblown tailings and lesser contaminated materials over the reshaped tailings.

- Placing a 1.5-foot-thick, compacted earthen cover at optimum moisture content over the tailings and contaminated materials.

Using these techniques, the post-remedial action radon flux was estimated to be 20 pCi/m^2s.

A.2.4.3 Long-term stability

The stabilized tailings pile has been designed to withstand the forces of nature in compliance with the EPA standard for up to 1000 years and in any case for at least 200 years. Natural phenomena that may affect the stabilized tailings pile have been investigated and are discussed below.

Water and wind erosion

To reduce the potential for water erosion by surface runoff, several control features were incorporated into the design. These features were included to protect the stabilized pile from the effects of a Probable Maximum Precipitation (PMP). A PMP is defined as the maximum precipitation that could occur from the most severe combination of meteorological conditions that would be reasonably possible in a region. Flow rates resulting from a PMP event were calculated based on approved methods (COE, 1970; Haan and Barfield, 1978; Johnson, 1985; NOAA, 1977; Rawls and Brakensiek, 1983; Stubchaer, 1975). To promote drainage and protect the stabilized tailings pile from the impact of an unlikely PMP, the pile sideslopes would be limited to five horizontal to one vertical (20 percent), and the topslope would be two to three percent. The stabilized pile and drainage ditches would be covered with a layer of rock one to two feet thick. The rock would be sized to withstand sheet erosion on the pile topslopes and sideslopes and concentrated flows in ditches during a PMP event.

The same rock layer used to protect against water erosion would protect against wind erosion because the erosive forces caused by severe winds would be much lower than those caused by a PMP.

Details of the PMP analysis and erosion protection requirements are contained in the draft Remedial Action Plan (DOE, 1985).

Flood protection and geomorphology

The Tuba City tailings site is located on a gently sloping terrace surface approximately 6000 feet away from and 300 feet above Moenkopi Wash, the closest established watercourse. No other intermittent or ephemeral streams exist in the vicinity of the site. Because of the distance between the tailings site and Moenkopi Wash and the lack of evidence of arroyo headcutting, stream channel migration and flooding were not considered to be critical issues in the design of the remedial action.

To protect the stabilized tailings pile from a flood resulting from a PMP over the 71-acre drainage area above the site, drainage ditches would be constructed to concentrate floodflows and to direct these flows away from the stabilized pile. The ditches would direct flows along the northern, western, and eastern edges of the pile and would discharge to the south (Figure A.2.4). The ditches would be lined with a layer of graded rock one to two feet thick to prevent erosion of the ditch foundation during periods of high flow.

Slope stability/seismic risk

Slope failure due to slope instability under static and seismic loading is another phenomenon that could affect the integrity of the stabilized tailings pile. Several standard methods of stability analysis were performed for each loading condition to estimate factors of safety against slope failure. In particular, the seismic loading conditions were evaluated by applying the horizontal ground acceleration resulting from a site-specific design earthquake. The evaluation estimated that a floating earthquake for the Colorado Plateau located 15 kilometers (9.3 miles) from the site would produce a magnitude 6.2 (Richter scale) earthquake which would generate an on-site peak horizontal free field acceleration of 0.21g. Details of the seismic study are contained in the draft Remedial Action Plan (DOE, 1985).

The principal seismic hazard to the stabilized tailings pile is the potential for slope failure due to seismically induced liquefaction of the tailings or underlying soils. In order for liquefaction to occur, a soil must be loose, noncohesive, and saturated, such as saturated sand. The Tuba City tailings contain some nearly saturated slimes which are cohesive, and some sand-slime mixtures and sands which are cohesionless but nonsaturated. The coarse-grained eolian and alluvial deposits underlying the Tuba City tailings site are also nonsaturated as the water table is well below the tailings and foundation soils. With the use of relatively flat (five horizontal to one vertical) sideslopes and the lack of loose, noncohesive, saturated tailings and subpile soils, the potential for seismically induced liquefaction is negligible and the pile would be stable under all loading conditions.

Settlement and cover cracking

Differential settlement of the stabilized tailings pile has the potential of cracking the cover due to horizontal strains and could increase the potential for gullying due to concentrations of surface runoff.

Due to the difficulty in controlling differential settlement of the recontoured tailings pile, settlement monitoring devices would be installed to measure the change in elevation of the pile caused by placement of the tailings and other contaminated materials. Upon the completion of a majority of all of the settlement, the earthen cover would be placed over the tailings pile, and the settlement would be monitored again. Final grading and compaction of the earthen cover would be performed only after sufficient settlement had occurred to prevent cracking of the earthen cover and concentration of surface runoff flows.

Frost heave and solifluction

Frost heave is the expansion toward the surface from the freeze-thaw cycle. Solifluction is the action of slow flow rate in saturated soils in periglacial regions (Ritter, 1978). Climatic conditions at Tuba City are such that damage to the stabilized tailings pile from frost heave is highly unlikely and solifluction of the surface layer of the stabilized pile would not occur. However, the remedial action design includes the use of sufficiently impermeable earthen materials to restrict ice lens formation and a sufficiently porous rock layer to restrict water buildup over the earthen cover to mitigate potential damage from frost heave.

A.2.4.4 Ground-water protection

An unconfined aquifer (N-aquifer) has been identified beneath the Tuba City tailings pile. Ground-water flows from the site southeast toward Moenkopi Wash have been contaminated primarily by percolating leachate generated through natural dewatering of the tailings during and immediately after the uranium milling. Lesser contamination continues due to precipitation and standing water collecting in depressions on the pile surface. After remedial action, percolation of precipitation through the pile will be minimized by the compacted, earthen cover, thereby greatly reducing the amount of contamination entering the aquifer. The natural flow of ground water toward the wash is expected to eventually reduce the existing contamination by dilution and adsorption. The existing geohydrologic environment and the impacts of remedial action on ground water are discussed in Section B.2 of Appendix B, Water.

A.2.5 CONSTRUCTION ESTIMATES

Estimates of equipment and personnel requirements; fuel, energy, and water consumptions; major earthwork volumes; and construction costs for the proposed action are summarized in Tables A.2.1 through A.2.7.

Table A.2.1 Equipment use - stabilization in place

Type of equipment	Pieces of equipment per month of project time 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Total equipment months per type of equipment
Compactor	0	1	1	2	2	2	2	2	2	2	2	1	1	0	0	0	1	0	21
Crane	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	4
D8 dozer	0	5	5	8	9	5	5	5	5	5	4	1	2	1	1	1	3	0	65
Front-end loader	0	1	1	1	2	2	2	2	2	2	2	2	2	1	1	0	2	0	25
Grader	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	0	13
Scraper	0	4	4	11	12	8	8	8	8	8	8	1	1	0	0	0	1	0	82
Seeder	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	0	0	8
10-cy[a] truck	0	1	1	1	5	4	4	4	4	4	4	4	4	0	0	0	0	0	40
10-cy truck with 8-cy pup	0	6	6	6	7	3	3	3	3	3	3	3	3	2	5	4	4	0	64
Water truck	0	1	1	2	2	2	2	2	2	2	2	1	1	0	0	0	1	0	21
Total pieces of equipment per month of project time	0	21	21	33	41	27	27	27	27	27	26	14	17	6	9	7	13	0	343

[a]cy - cubic yard.

Average = 343 total equipment-months/18 months = 20 pieces of equipment per month.

Table A.2.2 Personnel requirements – stabilization in place[a]

Type of personnel	Number of personnel per month of project time																		Total man-months per type of personnel
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Truck drivers	0	8	8	9	14	9	9	9	9	9	9	8	8	2	5	4	5	0	125
Equipment operators	0	13	13	24	27	18	18	18	18	18	17	6	9	4	4	3	8	0	218
General supervision and field services	19	19	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	310
Operator supervisors	0	3	3	4	5	3	3	3	3	3	3	2	2	1	1	1	2	0	42
Mechanics[b]	1	10	10	12	14	11	11	11	11	11	11	8	9	7	7	7	8	5	164
Total man-months per month of project time	20	53	51	66	77	58	58	58	58	58	57	41	45	31	34	32	40	22	859

[a]Peak employment = 77 people; average employment = 859 total man-months/18 months = 48 people; personnel requirements based on an eight-hour shift per day, 16.7 days per month.
[b]Also includes shipping and receiving personnel and welders.

Table A.2.3 Fuel consumption - stabilization in place

Type of equipment	Fuel consumption (gallons)
Compactor	39,312
Crane	4,288
D8 dozer	95,568
5-cy[a] front-end loader	30,096
Grader	10,416
Scraper	142,376
Seeder	6,432
10-cy truck	42,752
10-cy truck with 8-cy pup	85,520
Water truck	11,232
Totals	467,992

[a]cy - cubic yard.

Table A.2.4 Water consumption - stabilization in place

Water use	Gallons x 1000
Compaction	
o Site preparation	890
o Tailings pile construction	0
o Radon cover	2,250
o Restoration	0
Compaction total	3,140
Decontamination	530
Dust control	4,450
Potable (laundry, showers, consumption)	380
Total consumption	8,500

Table A.2.5 Energy consumption - stabilization in place

Facility	Kilowatt-hours x 1000
Field office(s)	83
Change/shower trailer(s)	127
Laundry	63
Totals	273

Table A.2.6 Summary of major earthwork volumes - stabilization in place

Activity	Estimated in-place volumes (cubic yards)
Site preparation	
o Excavate and spoil waste-water retention pond(s)	17,200
o Excavate and spoil temporary ditches	7,500
o Permanent ditch	
- Excavate and spoil	170,200
- Excavate, haul, and place rock	31,000
- Excavate, haul, and place sand filter	7,500
Pile construction	
o Excavate, haul, spread, and compact contaminated materials	785,400
Radon cover	
o Excavate, haul, spread, and compact earth	112,500
Erosion protection	
o Excavate, stockpile, haul, and place rock	91,300
o Excavate, haul, and place sand filter	38,900
Restoration	
o Recontour with spoil	
- Waste-water retention pond(s)	17,200
- Temporary ditches	7,500

Table A.2.7 Summary of construction costs - stabilization in place

Activity	Cost x $1000
Site preparation	258
Demolition	520
Tailings excavation/ relocation	2,460
Radon cover	410
Erosion protection	3,914
Decontamination	108
Total	7,678

These estimates do not include the costs of:

- o Property acquisition.
- o Engineering design.
- o Construction management and field supervision.
- o Overall project management.
- o Long-term surveillance and maintenance.
- o Vicinity properties cleanup.

The $7.678 million cost was rounded to $7.5 million for use in calculating impacts in this document.

A.3 DISPOSAL AT THE FIVEMILE WASH SITE

A.3.1 SITE DESCRIPTION

The Fivemile Wash alternate disposal site is located approximately 16 road miles southwest of the Tuba City tailings site (Figure A.3.1). The site is on level, sparsely vegetated terrain approximately 0.5 mile west of Fivemile Wash. The principal land use of the area is low-density grazing. The closest residence is approximately two miles away.

A.3.2 DESCRIPTION OF FINAL CONDITIONS

The stabilized tailings pile would cover approximately 55 acres of the disposal site, and the entire restricted area (including concrete posts, roads, and drainage ditch) would cover approximately 68 acres (Figure A.3.2).

The top of the stabilized tailings pile (with cover) would be sloped three to four percent to promote drainage and would average approximately 27 feet above the surrounding terrain. The sideslopes of the pile would be a maximum of five horizontal to one vertical (20 percent).

The below-grade excavation of the disposal area would extend to an average depth of five feet. The tailings and contaminated materials would be covered with a 4.5-foot-thick compacted, earthen cover obtained from the surficial materials excavated from the disposal area. The tailings and contaminated materials would be covered with a two-foot-thick layer of rock for erosion protection (Figure A.3.3).

The rock erosion barrier would tie into an unpaved surveillance and maintenance road which would loop the toe of the stabilized tailings pile. A drainage ditch constructed adjacent to the roadway on three sides of the pile would divert surface runoff around and away from the pile.

After completion of the remedial action, the disturbed areas at the Tuba City tailings site would be backfilled as required with borrow materials from the Greasewood Lake borrow site to a level compatible with the surrounding terrain, recontoured for surface drainage, and revegetated. Disturbed areas adjacent to the stabilized pile at the Fivemile Wash site would be recontoured to promote surface drainage and revegetated, as required.

A.3.3 MAJOR CONSTRUCTION ACTIVITIES

For tailings disposal at the Fivemile Wash site, surficial materials would be excavated to an average depth of five feet and would be stockpiled for use as the earthen cover.

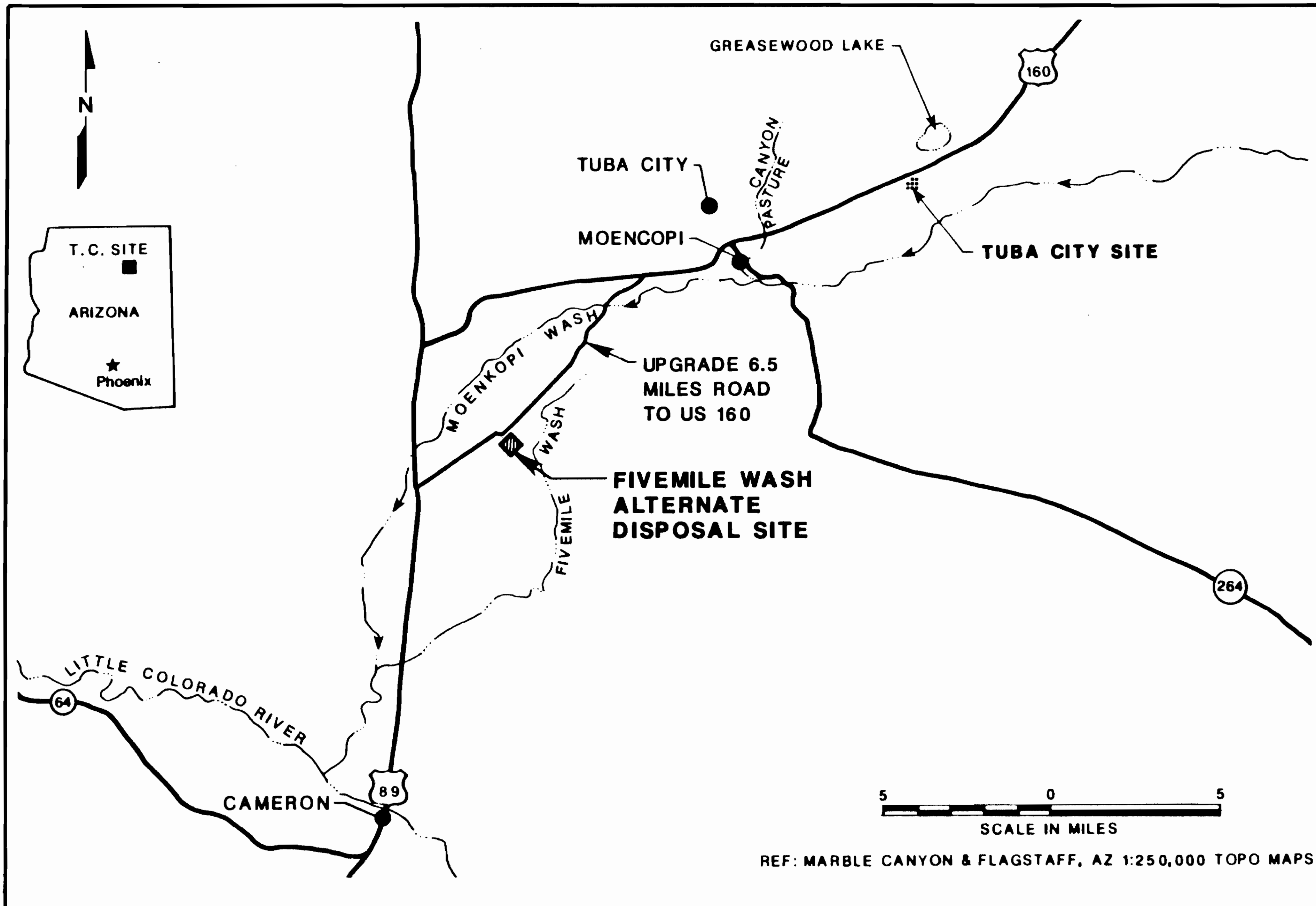


FIGURE A.3.1
ALTERNATE DISPOSAL SITE LOCATION

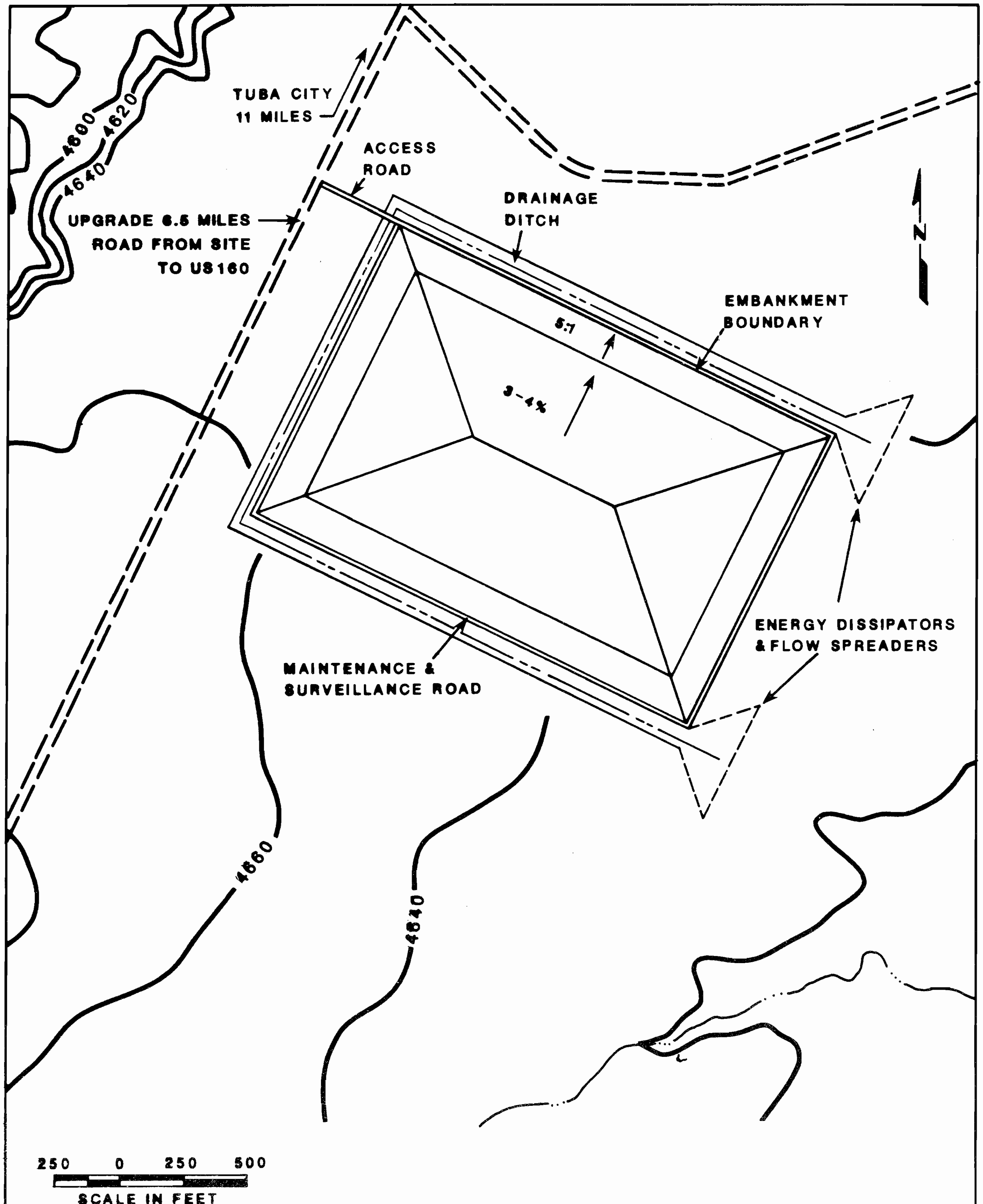


FIGURE A.3.2
FINAL CONDITION - FIVEMILE WASH ALTERNATE DISPOSAL SITE

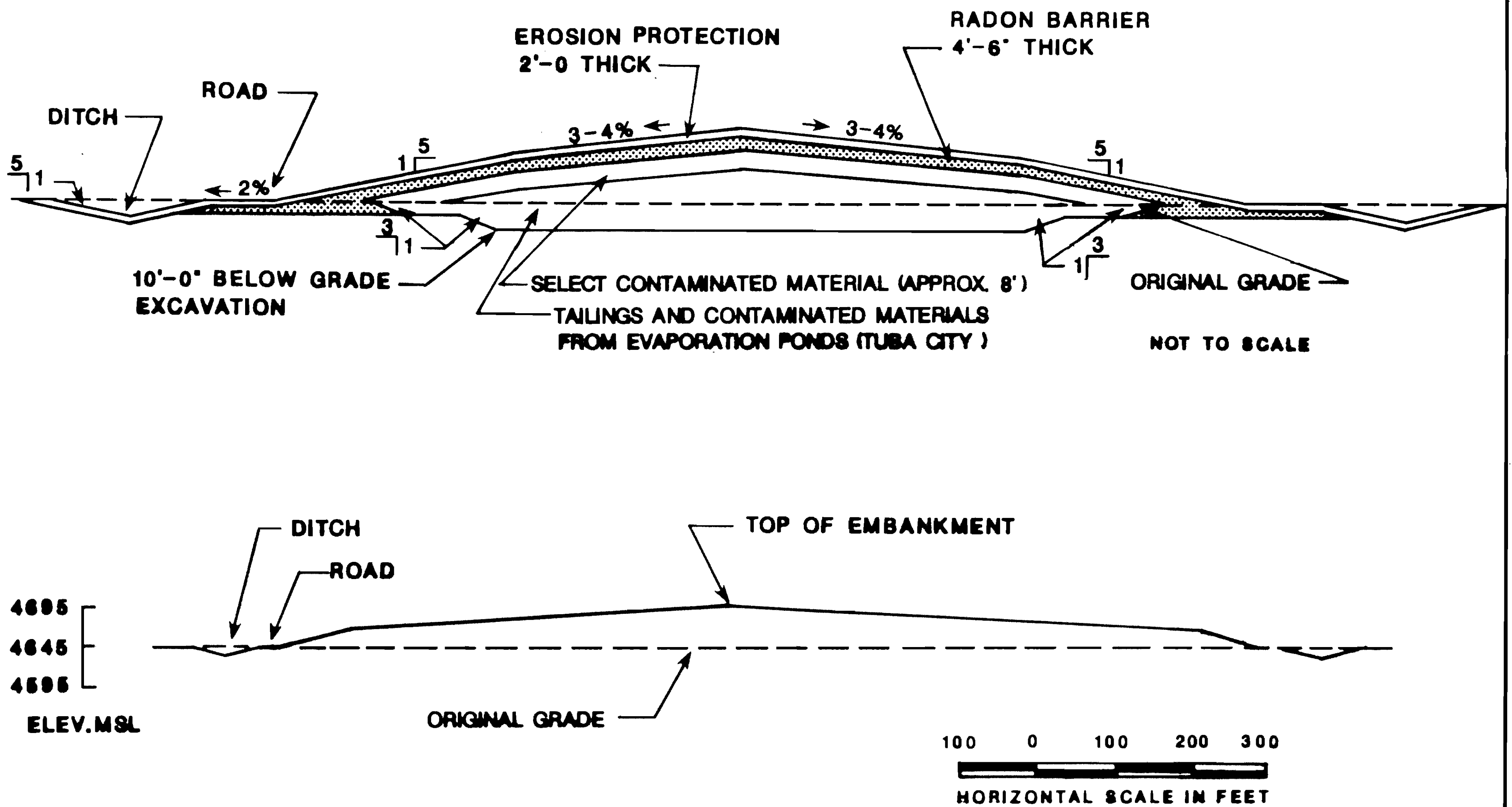


FIGURE A.3.3
FIVEMILE WASH SITE
TYPICAL CROSS-SECTION

The tailings and other contaminated materials would be transported by truck from the existing tailings site and consolidated into a gently contoured, partially below grade pile. The pile would then be covered with a compacted, earthen radon barrier and rock erosion protection layer similar to stabilization in place at the existing tailings site. Figure A.3.4 shows the remedial action schedule for disposal at the Fivemile Wash site.

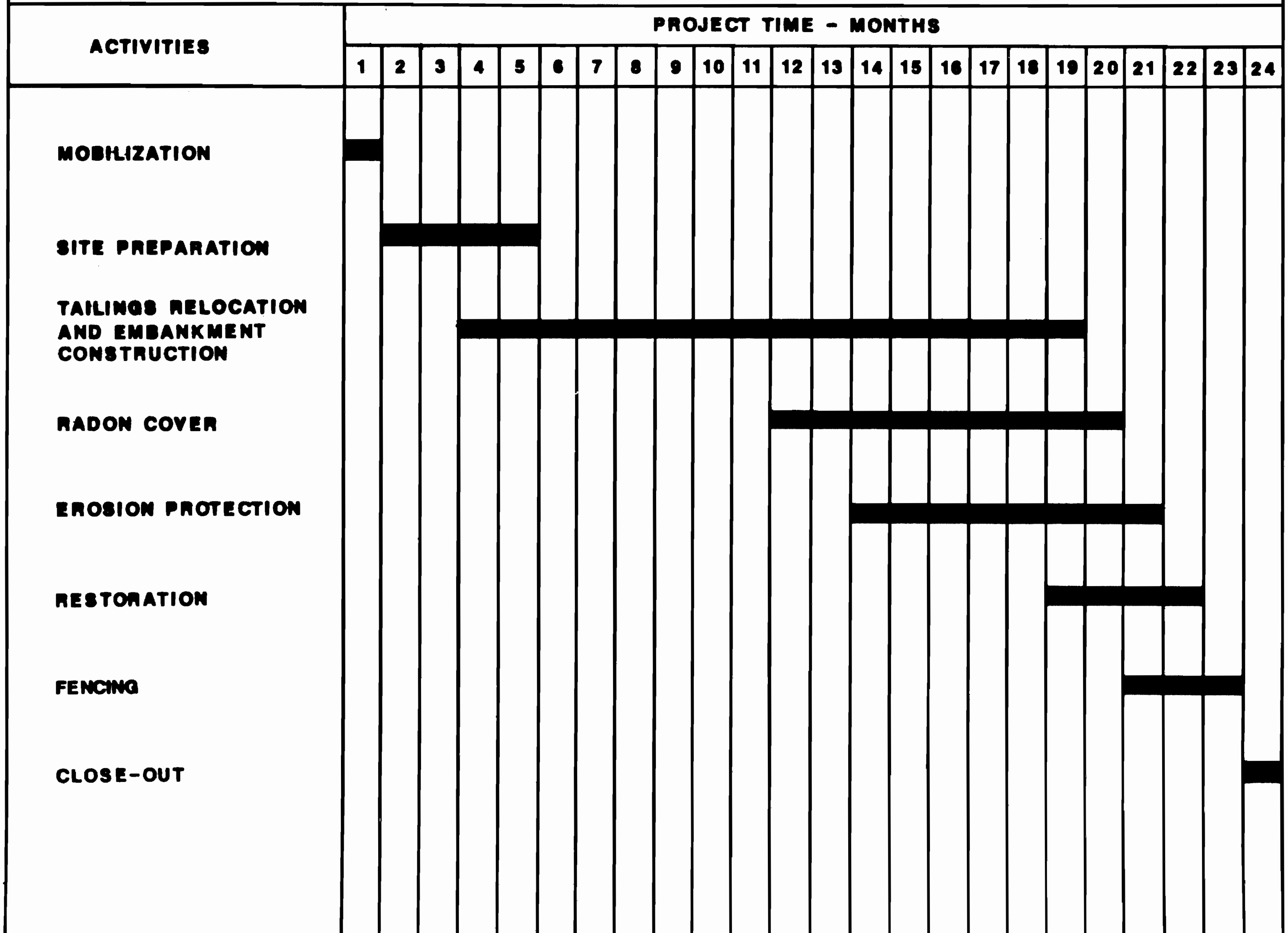
A.3.4 MAJOR DESIGN CONSIDERATIONS

A.3.4.1 Assumptions

The conceptual design for relocation of the tailings to the Fivemile Wash site was based on the following assumptions:

- o Approximately 1.3 million cubic yards of tailings and contaminated materials would be relocated.
- o The cover on the tailings and contaminated materials would consist of 4.5 feet of radon barrier (earthen materials) and two feet of erosion protection (rock).
- o All fine-grained earthen materials for the radon barrier would be obtained from excavation of the partially below-grade disposal area.
- o Surficial materials at the Fivemile Wash site have the same characteristics as borrow materials at the Greasewood Lake borrow site.
- o All earthen borrow materials would shrink 15 percent during compaction.
- o Rock materials (for the erosion protection) would be obtained from the Shadow Mountain borrow site.
- o Erosion protection requirements for the Fivemile Wash alternative would be the same as stabilization in place.
- o Rock borrow materials at the Shadow Mountain borrow site could be excavated by normal means.
- o All rock borrow materials would swell 20 percent during excavation from the borrow site.
- o An adequate supply of water would be available from the former Tuba City production wells for compaction, dust control, and equipment washing.

FIGURE A.3.4 REMEDIAL ACTION SCHEDULE: DISPOSAL AT THE FIVEMILE WASH SITE



- All disturbed areas would be restored to a level compatible with the surrounding terrain by recontouring to promote surface runoff and revegetating for erosion control, as required.
- Earthen materials for restoration of the existing tailings site would be obtained from the Greasewood Lake borrow site.

A.3.4.2 Siting and configuration

Factors which contributed to the selection of the Fivemile Wash site during the alternate site selection process were as follows:

- The site is located on a geologically stable, level surface.
- The site is located at the head of a small watershed.
- Surficial materials at the Fivemile Wash site are suitable for the radon barrier.
- The thickness of surficial materials at the Fivemile Wash site would enable partial below grade disposal of the tailings and other contaminated materials.

The quantity of earthen materials required for the radon barrier and the depth of surficial deposits at the Fivemile Wash site dictated the pile configuraton.

A.3.4.3 Radon control

Control of radon emanation from the stabilized tailings at the disposal site would be accomplished in the same manner as stabilization in place except that the tailings and contaminated materials would be placed partially below grade to an average depth of five feet at the alternate disposal site. Cover thickness and construction sequencing would be the same for either alternative.

A.3.4.4 Long-term stability

The Fivemile Wash site alternative would incorporate the same measures to assure long-term stability against water and wind erosion, slope failure and seismic risk, differential settlement and cover cracking, and frost heave as discussed for the proposed action (see Section A.2.3).

No floodflows would be expected to impact the Fivemile Wash site because of its distance from and elevation above the closest stream channel. Therefore, flood protection and stream meander would not be stability considerations for this remedial action alternative.

A.3.4.5 Ground-water protection

Relocation of the tailings and other contaminated materials to the Fivemile Wash site would reduce, but not totally eliminate future ground-water contamination at the Tuba City tailings site. Contaminants presently in the unsaturated zone would continue moving toward the water table. The design of the stabilized tailings pile and the low permeability of the geologic strata underlying the Fivemile Wash make it unlikely that ground-water resources beneath the site would be affected.

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APPENDIX B

WATER

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B.1 SURFACE WATER

B.1.1 SURFACE-WATER FEATURES

B.1.1.1 Tuba City tailings site

The Tuba City tailings site is located approximately 6000 feet northwest of Moenkopi Wash, an intermittent stream that drains to the southwest into the Little Colorado River. The wash has a drainage area of about 2500 square miles, with a change in elevation of over 3000 feet from the headwaters to the mouth of the wash.

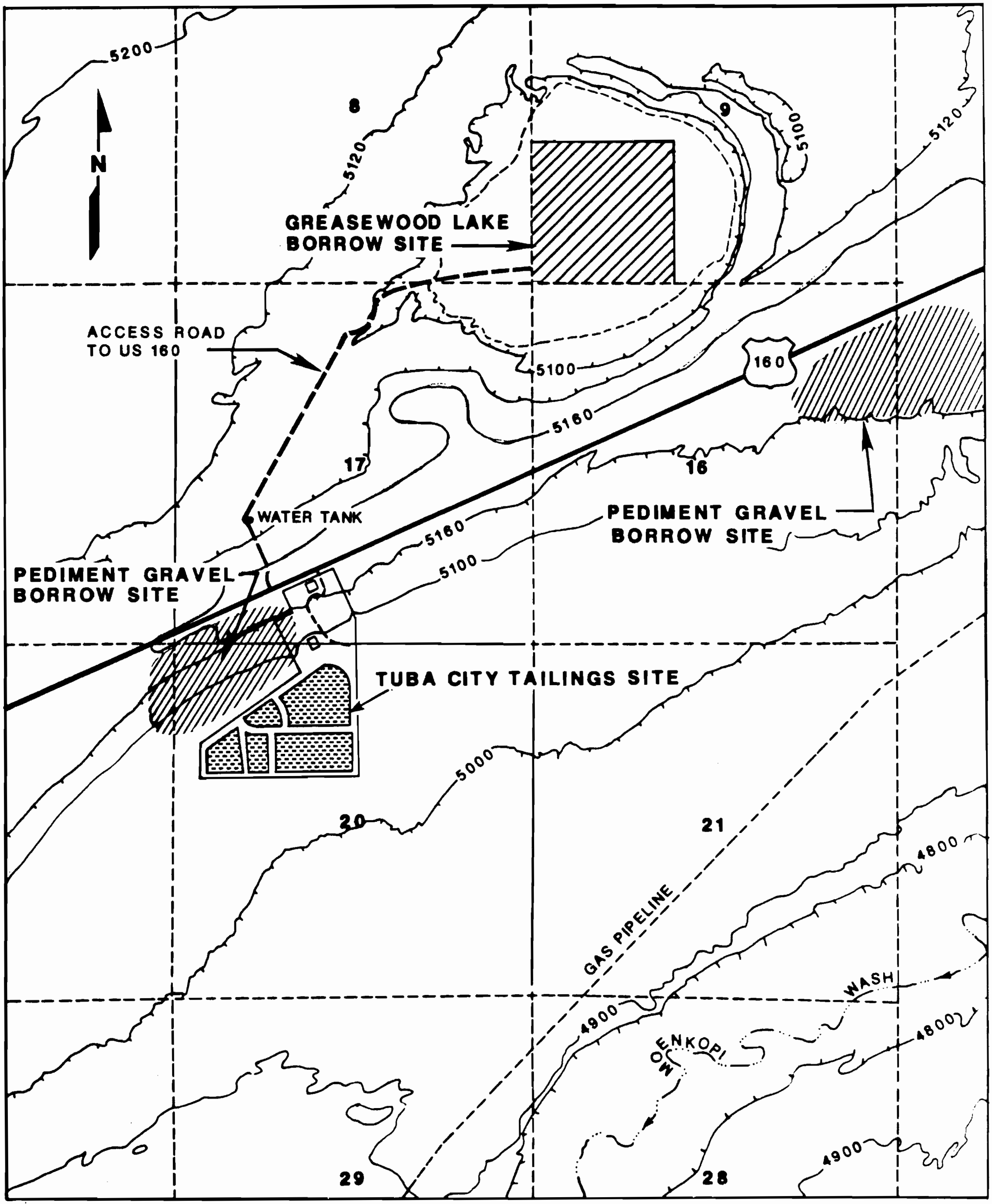
Surface drainage for the tailings site is to the southeast toward Moenkopi Wash. A 71-acre drainage area above the tailings site is bounded by U.S. Highway 160 which runs along a low ridge. All drainage on the north side of the highway flows toward Greasewood Lake, a dry lake approximately 1.5 miles northeast of the tailings site. No established watercourses or other drainage features exist in the vicinity of the tailings site (Figure B.1.1).

There are no U.S. Geological Survey (USGS) gauging stations currently operating on Moenkopi Wash near the tailings site. A former station located at the U.S. Highway 89 bridge over Moenkopi Wash (11 miles southwest of Tuba City) recorded an average annual flow of approximately 10,650 acre-feet for a 15-year period of record from 1926 to 1941. Flow rates varied substantially, ranging from several days of no flow to a peak flow of 14,500 cubic feet per second on August 28, 1934. This peak flow was at a depth of 12.85 feet (Beal, 1985).

B.1.1.2 Borrow sites

The Greasewood Lake borrow site is situated on level terrain in Greasewood Lake, a dry desert basin (Figure B.1.1). The center elevation of the basin is 5087 feet, and the total drainage area is approximately 20,000 acres. Greasewood Lake is at the center of a larger depression and is approximately 279 acres in area. The larger depression has a water storage capacity of approximately 12,500 acre-feet. No data on historical water-surface elevations are available for Greasewood Lake.

The Shadow Mountain borrow site is situated approximately 150 feet north of an ephemeral stream that drains the area southwest of the borrow site toward Moenkopi Wash (Figure B.1.2). The ephemeral stream flows into Moenkopi Wash approximately 3.2 miles south of the site at an average elevation of 440 feet below the site. The borrow site elevation ranges from 30 to 140 feet below the elevation of the headwaters of



REF: TUBA CITY & TUBA CITY NE, ARIZ. USGS 7 1/2 MIN. QUADS

1000 0 1000 2000

SCALE IN FEET

FIGURE B.1.1
TUBA CITY TAILINGS SITE AND GREASEWOOD LAKE BORROW SITE DRAINAGE CHARACTERISTICS

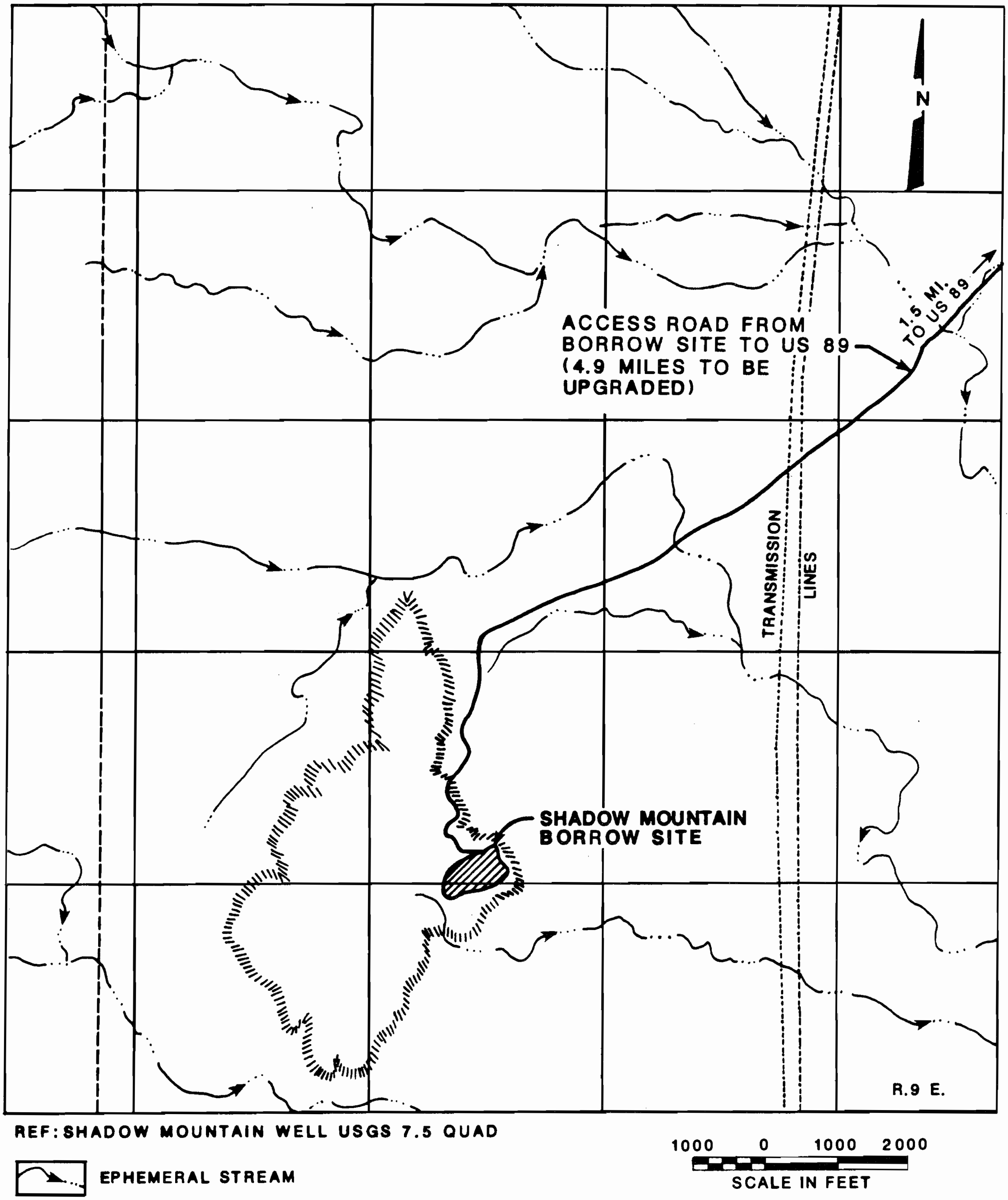


FIGURE B.1.2

SHADOW MOUNTAIN BORROW SITE, DRAINAGE CHARACTERISTICS

the ephemeral stream. No data on historical flows are available for the ephemeral stream. The total drainage area for the borrow site is approximately 19.3 acres.

The Pediment Gravel borrow site is contiguous with the west boundary of the former processing site. This borrow source covers approximately 30 acres and is part of the drainage area above the tailings site (Figure B.1.1). Therefore, the surface-water features of the Pediment Gravel source and the processing site are approximately identical.

If there is insufficient material in the Pediment Gravel source adjacent to the former processing site, one other borrow source for pediment gravels has been selected. It is approximately one mile northeast of the tailings site. This site has nearly identical surface water characteristics as the Greasewood Lake borrow area and the Tuba City site.

B.1.2 FLOOD ANALYSIS

B.1.2.1 Tuba City tailings site

The tailings pile is approximately 8000 feet away from and 300 feet above the streambed of Moenkopi Wash. Because of the difference in elevation between the tailings pile and the wash, the potential for flooding from Moenkopi Wash at the tailings pile is considered negligible. Therefore, a flood analysis for Moenkopi Wash was not performed.

The tailings pile could be subject to flooding from runoff from the 71-acre drainage area above the site. A Probable Maximum Precipitation (PMP) is defined as the maximum precipitation that could occur from the most severe combination of meteorological conditions that would be reasonably possible in a region. Flow rates resulting from a PMP event were calculated based on approved methods (COE, 1970; Haan and Barfield, 1978; Johnson, 1985; NOAA, 1977; Rawls and Brakensiek, 1983; Stubchaer, 1975). The design for the stabilized tailings pile included features to protect the tailings from the erosive forces of an unlikely PMP event (see Appendix A, Engineering Summary).

Details of the PMP analysis are contained in the draft Remedial Action Plan (DOE, 1985).

B.1.2.2 Borrow sites

The Greasewood Lake borrow site may be subject to flooding from surface runoff from the 20,000-acre drainage area surrounding the site. No data on historical floods are available for the Greasewood Lake borrow site; however, a flood at the site would only result in a delay in excavation of borrow materials until floodwaters evaporated or percolated into the ground and debris was removed. A detailed filling frequency analysis for Greasewood Lake is being conducted by the U.S. Army Corps of Engineers, Los Angeles District, to determine the water-surface elevation from a 100-year flood (Harrell, 1985).

Floodflows would not be expected at the Shadow Mountain borrow site due to its height above and distance from the small ephemeral stream south of the site. Because of the small size of the watershed above the site, flows resulting from high intensity rainstorms would not be expected to cause damage.

The flooding characteristics for the Pediment Gravel borrow area are the same as for the tailings site. Since the borrow source is located between the tailings site and the watershed boundary, any major precipitation events would result in minor construction delays.

B.1.3 SURFACE-WATER QUALITY

Surface water-quality monitoring was performed by the DOE at four locations on Moenkopi Wash near the tailings site. Eight samples were collected from locations upstream and downstream of the axis of the ground-water contaminant plume emanating from the tailings pile. These sampling locations are shown on Figure B.1.3 (locations numbered 965, 778, 759, and 969). The water samples were analyzed for common ions, heavy metals, and radionuclides. The results of the water-quality analyses are listed in Table B.1.1. Concentrations of total dissolved solids (TDS) and sulfates (SO_4) exceeded the EPA's National Secondary Drinking Water Standards at each station. Concentrations of iron (Fe) exceeded the EPA's secondary standards at locations 965 and 759. Gross alpha activity exceeded the EPA's National Primary Drinking Water Standards at location 759. The National Drinking Water Standards are presented in Table B.1.2.

Moenkopi Wash has not been affected by the contaminant plume emanating from the pile. If the wash were affected, elevated concentrations of major plume components (Cl, NO_x, and alkalinity; see Secion B.2) would be found at sampling stations 778 and 759. This is because these stations are in the path of the plume (see Figure B.2.9). However, as shown in Figure B.1.4, concentrations of Cl, NO_x, and alkalinity are not elevated at stations 778 and 759. Therefore, it may be concluded that the water quality of the wash is unaffected by the plume.

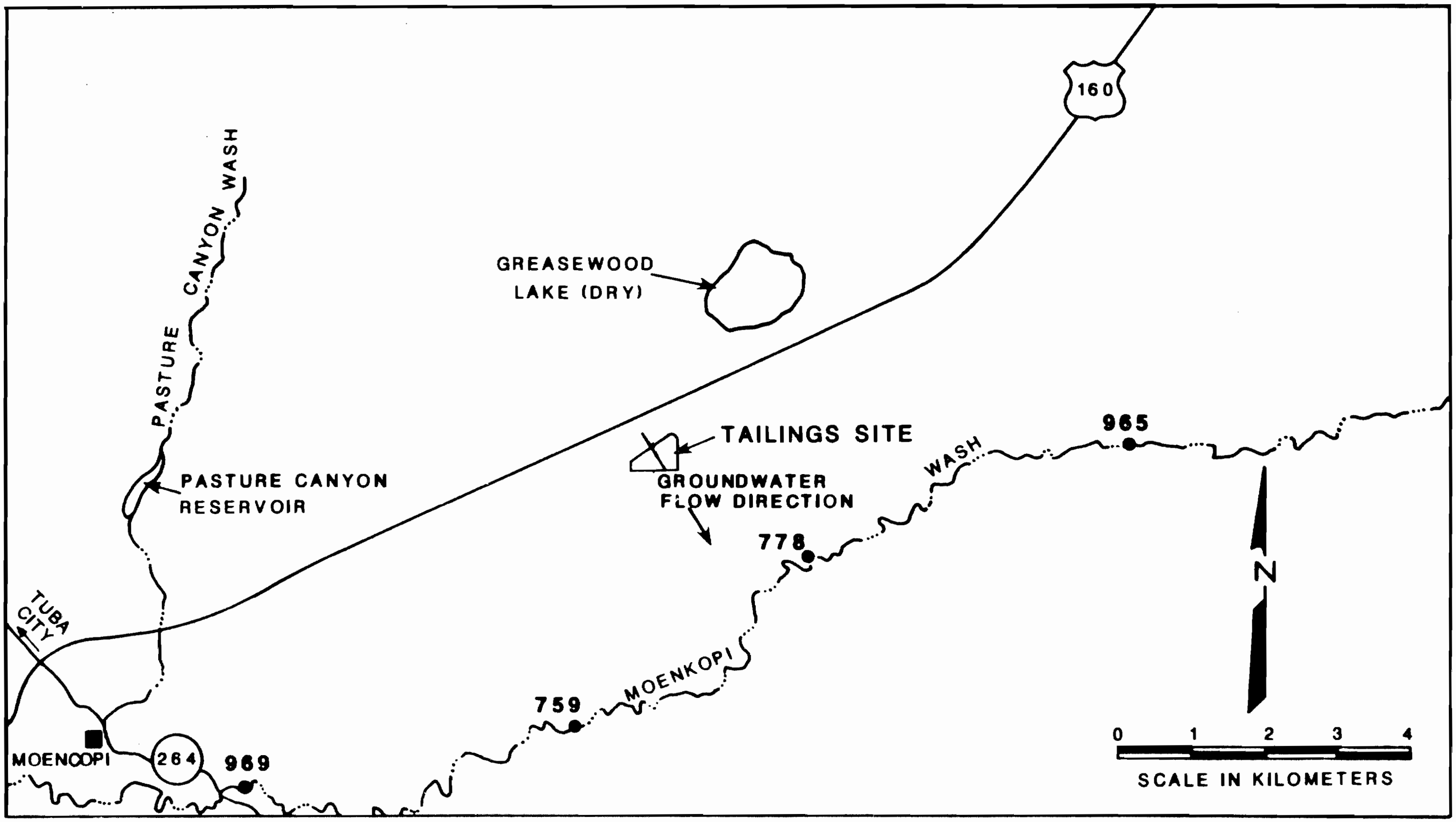


FIGURE B.1.3
SURFACE-WATER MONITORING LOCATIONS

Table B.1.1 Chemical analyses of surface-water samples from Moenkopi Wash

PARAMETER	UNIT OF MEASURE	759-01 12/16/84 PARAMETER VALUE	+/-UNCERTAINTY	759-01 03/26/85 PARAMETER VALUE	+/-UNCERTAINTY	759-S1 04/01/86 PARAMETER VALUE	+/-UNCERTAINTY	778-S1 12/12/84 PARAMETER VALUE	+/-UNCERTAINTY	778-01 03/31/85 PARAMETER VALUE	+/-UNCERTAINTY
ALKALINITY	MG/L CACO3	219.		208.		175.		193.		198.	
ALUMINUM	MG/L	-		< 0.1		-		< 0.1		< 0.1	
AMMONIUM	MG/L	0.2		< 0.1		0.2		0.1		< 0.1	
ANTIMONY	MG/L	< 0.003		< 0.003		-		< 0.003		< 0.003	
ARSENIC	MG/L	< 0.01		< 0.01		-		< 0.01		< 0.01	
BARIUM	MG/L	< 0.1		< 0.1		-		< 0.1		< 0.1	
BORON	MG/L	0.04		0.2		-		0.03		0.2	
CADMIUM	MG/L	0.007		0.009		-		< 0.001		0.007	
CALCIUM	MG/L	119.		110.		64.5		117.		89.	
CHLORIDE	MG/L	10.		15.		13.		9.		10.	
CHROMIUM	MG/L	< 0.01		< 0.01		-		< 0.01		< 0.1	
COBALT	MG/L	< 0.05		< 0.05		-		< 0.05		< 0.05	
COND, IN-SITU	UMHO/CM	-		1100.		-		-		850.	
CONDUCTANCE	UMHO/CM	1100.		-		620.		1060.		-	
COPPER	MG/L	< 0.02		< 0.02		-		< 0.02		< 0.02	
CYANIDE	MG/L	-		< 0.01		-		-		< 0.01	
FLUORIDE	MG/L	0.35		0.5		0.6		0.56		0.4	
GROSS ALPHA	PCI/L	-		< 16. *	3.	5.5	5.1	-		< 14. *	4.
GROSS BETA	PCI/L	-		20.	2.	11.	3	-		< 10.	1.
IRON	MG/L	0.38 **		< 0.03		-		< 0.03		< 0.03	
LEAD	MG/L	< 0.01		< 0.01		-		< 0.01		< 0.01	
MAGNESIUM	MG/L	24.3		38.		16.7		22.7		28.	
MANGANESE	MG/L	0.03		0.01		-		< 0.01		0.02	
MERCURY	MG/L	< 0.0002		< 0.0002		-		< 0.0002		< 0.0002	
MOLYBDENUM	MG/L	< 0.01		0.01		0.23		< 0.01		0.01	
NICKEL	MG/L	< 0.04		0.04		-		< 0.04		< 0.04	
NITRATE	MG/L	1.		< 1.		< 1.		1.		< 1.	
ORG. CARBON	MG/L	5.9		7.		-		4.5		6.	
PB-210	PCI/L	< 1.5		0.4	0.8	-		< 1.5		0.1	0.9
PH	SU	7.8		8.48		8.		8.25		8.27	
PHOSPHATE	MG/L	< 0.15		< 0.1		< 0.1		< 0.15		< 0.1	
PO-210	PCI/L	< 1.		-0.2	0.4	-		< 1.		0.1	0.4
POTASSIUM	MG/L	3.84		5.1		3.73		3.48		4.1	
RA-226	PCI/L	< 1.		0.1	0.3	-		< 1.		0.	0.3
RA-228	PCI/L	-		1.6	0.7	-		< 1.		-0.1	0.9
SELENIUM	MG/L	< 0.005		< 0.005		-		< 0.005		0.005	
SILCON	MG/L	5.		-		-		4.6		-	
SILICA	MG/L	-		11.		-		-		10.	
SILVER	MG/L	-		< 0.01		-		-		< 0.01	
SODIUM	MG/L	101.		130.		106.		95.1		110.	
STRONTIUM	MG/L	1.48		1.6		-		1.45		1.5	
SULFATE	MG/L	450. **		490. **		270. **		350. **		380. **	
SULFIDE	MG/L	-		< 0.1		-		-		< 0.1	
TEMP, IN-SITU	C-DEGREE	-		19.		-		-		18.	
TEMPERATURE	C - DEGREE	-		-		14.		7.3		-	
TH-230	PCI/L	< 1.		0.	0.2	-		< 1.		-0.1	0.2
TIN	MG/L	< 0.005		< 0.005		-		< 0.005		0.007	
TOTAL SOLIDS	MG/L	900.		900.		591.		320.		750.	
TOX	MG/L	-		< 0.1		-		-		< 0.1	
U-234	PCI/L	3.		-		-		3.		-	

Table B.1.1 Chemical analyses of surface-water samples from Moenkopi Wash (continued)

		LOCATION ID - SAMPLE ID AND LOG DATE				
		759-01 12/16/84	759-01 03/26/85	759-S1 04/01/86	778-S1 12/12/84	778-01 03/31/85
PARAMETER	UNIT OF MEASURE	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY
U-238	PCI/L	2.	-	-	2.	-
URANIUM	MG/L	-	0.012	0.0065	-	0.011
VANADIUM	MG/L	< 0.01	< 0.01	-	< 0.01	< 0.01
ZINC	MG/L	0.031	0.008	-	0.021	0.014

Table B.1.1 Chemical analyses of surface-water samples from Moenkopi Wash (continued)

		LOCATION ID - SAMPLE ID AND LOG DATE							
		778-S1 04/02/86		965-S1 04/02/86		969-S1 04/02/86			
PARAMETER	UNIT OF MEASURE	PARAMETER VALUE+/-UNCERTAINTY		PARAMETER VALUE+/-UNCERTAINTY		PARAMETER VALUE+/-UNCERTAINTY		PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY
ALKALINITY	MG/L CACO3	200.		205.		210.			
ALUMINUM	MG/L	-		-		-			
AMMONIUM	MG/L	0.2		0.2		0.1			
ANTIMONY	MG/L	-		-		-			
ARSENIC	MG/L	-		-		-			
BARIUM	MG/L	-		-		-			
BORON	MG/L	-		-		-			
CADMIUM	MG/L	-		-		-			
CALCIUM	MG/L	64.7		62.4		71.5			
CHLORIDE	MG/L	12.		11.		16.			
CHROMIUM	MG/L	-		-		-			
COBALT	MG/L	-		-		-			
COND, IN-SITU	UMHO/CM	-		-		-			
CONDUCTANCE	UMHO/CM	580.		540.		600.			
COPPER	MG/L	-		-		-			
CYANIDE	MG/L	-		-		-			
FLUORIDE	MG/L	0.5		0.5		0.4			
GROSS ALPHA	PCI/L	0.3	4.5	2.5	4.1	0.	4.9		
GROSS BETA	PCI/L	5.8	2.6	8.5	3.	5.8	2.8		
IRON	MG/L	-		-		-			
LEAD	MG/L	-		-		-			
MAGNESIUM	MG/L	16.6		15.2		17.9			
MANGANESE	MG/L	-		-		-			
MERCURY	MG/L	-		-		-			
MOLYBDENUM	MG/L	0.3		0.17		0.14			
NICKEL	MG/L	-		-		-			
NITRATE	MG/L	< 1.		1.		< 1.			
ORG. CARBON	MG/L	-		-		-			
PB-210	PCI/L	-		-		-			
PH	SU	7.85		7.83		7.97			
PHOSPHATE	MG/L	< 0.1		< 0.1		< 0.1			
PO-210	PCI/L	-		-		-			
POTASSIUM	MG/L	3.66		3.82		5.82			
RA-226	PCI/L	-		-		-			
RA-228	PCI/L	-		-		-			
SELENIUM	MG/L	-		-		-			
SILCON	MG/L	-		-		-			
SILICA	MG/L	-		-		-			
SILVER	MG/L	-		-		-			
SODIUM	MG/L	122.		111.		128.			
STRONTIUM	MG/L	-		-		-			
SULFATE	MG/L	300. **		258. **		342. **			
SULFIDE	MG/L	-		-		-			
TEMP, IN-SITU	C-DEGREE	-		-		-			
TEMPERATURE	C - DEGREE	7.5		8.		7.			
TH-230	PCI/L	-		-		-			
TIN	MG/L	-		-		-			
TOTAL SOLIDS	MG/L	581.		573.		701.			
TOX	MG/L	-		-		-			
U-234	PCI/L	-		-		-			

Table B.1.1 Chemical analyses of surface-water samples from Moenkopi Wash (concluded)

		LOCATION ID - SAMPLE ID AND LOG DATE				
		778-S1 04/02/86	965-S1 04/02/86	969-S1 04/02/86		
PARAMETER	UNIT OF MEASURE	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY		
U-238	PCI/L	-	-	-		
URANIUM	MG/L	0.0043	0.0031	0.0043		
VANADIUM	MG/L	-	-	-		
ZINC	MG/L	-	-	-		

MAPPER INPUT FILE: TUB01*UDPSWQ100030

* = Concentration exceeds EPA primary drinking water standards.
** = Concentration exceeds EPA secondary drinking water standards.
<X.XX = Concentration less than detection limit.
--- = Not analyzed.

Table B.1.2 National drinking water standards[a]

Constituent	EPA primary standard[b]	EPA secondary standard[c]
Arsenic	0.05	
Barium	1.0	
Cadmium	0.01	
Chloride		250.0
Chromium	0.05	
Copper		1.0
Foaming agents		0.5
Fluoride	4.0	
Iron		0.3
Lead	0.05	
Manganese		0.05
Mercury	0.002	
Nitrate	45.0	
pH (S.U.)		6.5-8.5
Selenium	0.01	
Silver	0.05	
Sulfate		250.0
Total dissolved solids		500.0
Zinc		5.0
<u>Radioactivity</u>		
Combined radium-226 and radium-228	5.0	
Gross alpha	3.0	

[a]All units are in milligrams per liter except radioactive constituents which are expressed in picocuries per liter and pH which is expressed in standard units. State water-quality standards for Arizona are the same as the Federal water-quality standards (Arizona Water Quality Standards, 1982).

[b]The National Primary standard defines the level of water quality deemed necessary to protect the public health.

[c]The National Secondary Standard defines the level of water quality necessary to maintain aesthetic qualities.

Ref. EPA, 1981, 1982.

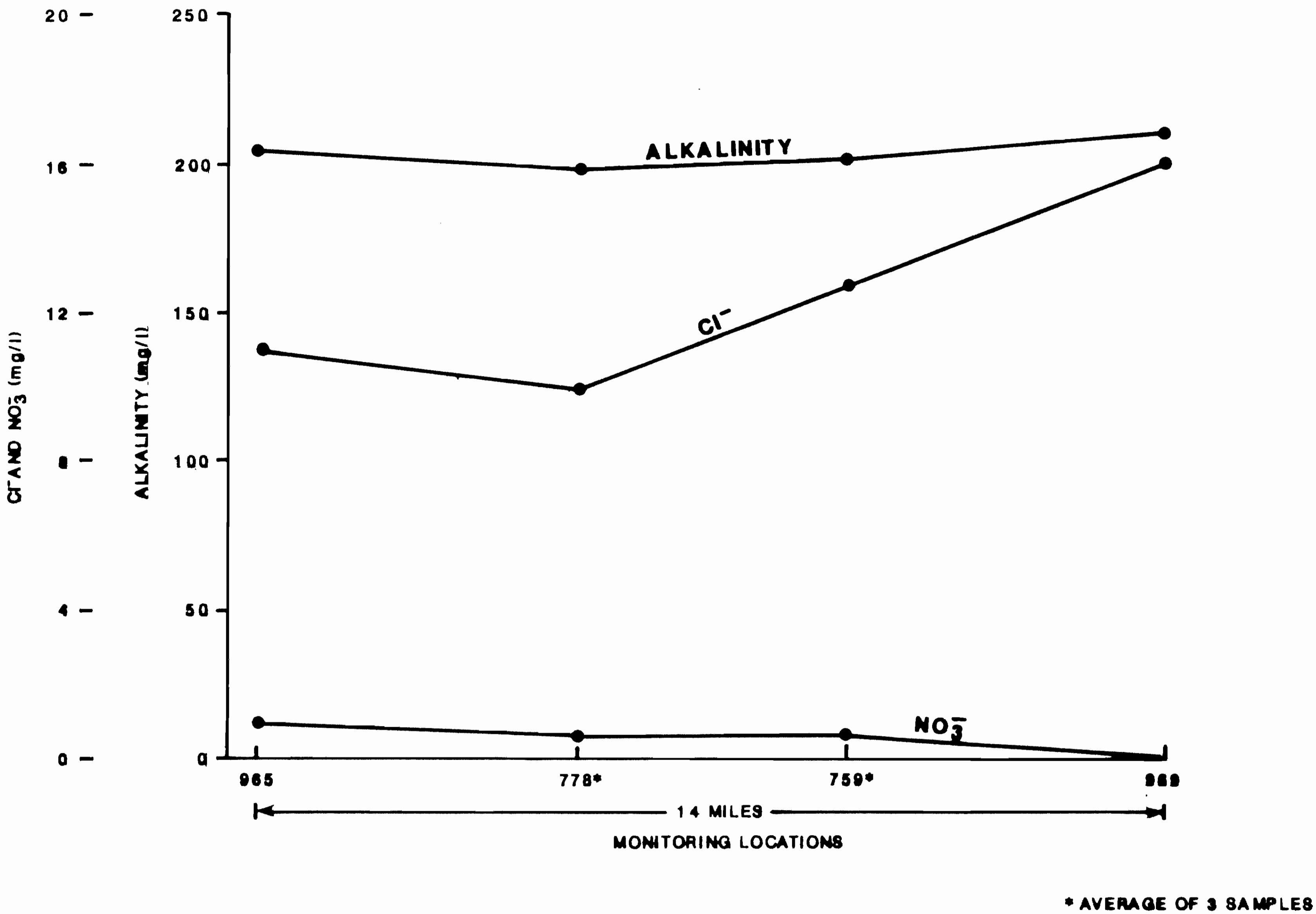


FIGURE B.1.4

CONCENTRATIONS OF SELECTED CONSTITUENTS IN MOENKOPI WASH

B.2 GROUND WATER

B.2.1 INTRODUCTION

U.S. Environmental Protection Agency (EPA) regulations (40 CFR Part 192, 47 CFR Part 32274) require the U.S. Department of Energy (DOE) to address the following topics at each Uranium Mill Tailings Remedial Action (UMTRA) Project site:

- o Geohydrologic conditions.
- o Background water quality and the extent of ground-water contamination.
- o Water use and value.
- o Health effects.
- o The risk of human exposure and options for protecting aquifer users.
- o Feasibility and cost/benefit of aquifer protection designs and aquifer restoration.
- o The effects of remedial actions.

The investigations presented in this appendix section address these topics.

Most of the information presented here is derived from investigations conducted by the DOE in 1985. Nineteen monitor wells were installed around the tailings pile (Table B.2.1 and Figure B.2.1);

Table B.2.1 Monitor well construction data

Well no.	Boring diameter (in)	Casing diameter (in)	Screened interval (depth below land surface, ft)	Formation of completion
901	6.6	2	58-78	Navajo Ss
902	6.5	2	63-73	Kayenta Fmn.?
903	6.5	2	28-48	Navajo Ss
904	6.6	2	32-42	Navajo Ss
906	6.6	2	45-65	Navajo Ss
907	6.0	2	70-90	Navajo Ss
908	6.6	2	52-67	Navajo Ss
909	6.6	2	62-77	Navajo Ss
910	8.5	4	97-197	Navajo Ss
911	8.5	4	311-351	Navajo Ss
912	8.5	4	123-163	Navajo Ss
913	8.5	4	331-371	Navajo Ss
914	8.5	4	139-156	Navajo Ss
915	8.5	4	172-182	Navajo Ss
916	8.5	4	348-358	Navajo Ss
917	8.5	4	130-150	Navajo Ss
919	8.5	4	340-350	Navajo Ss
920	8.5	4	116-156	Navajo Ss
921	8.5	4	315-355	Navajo Ss

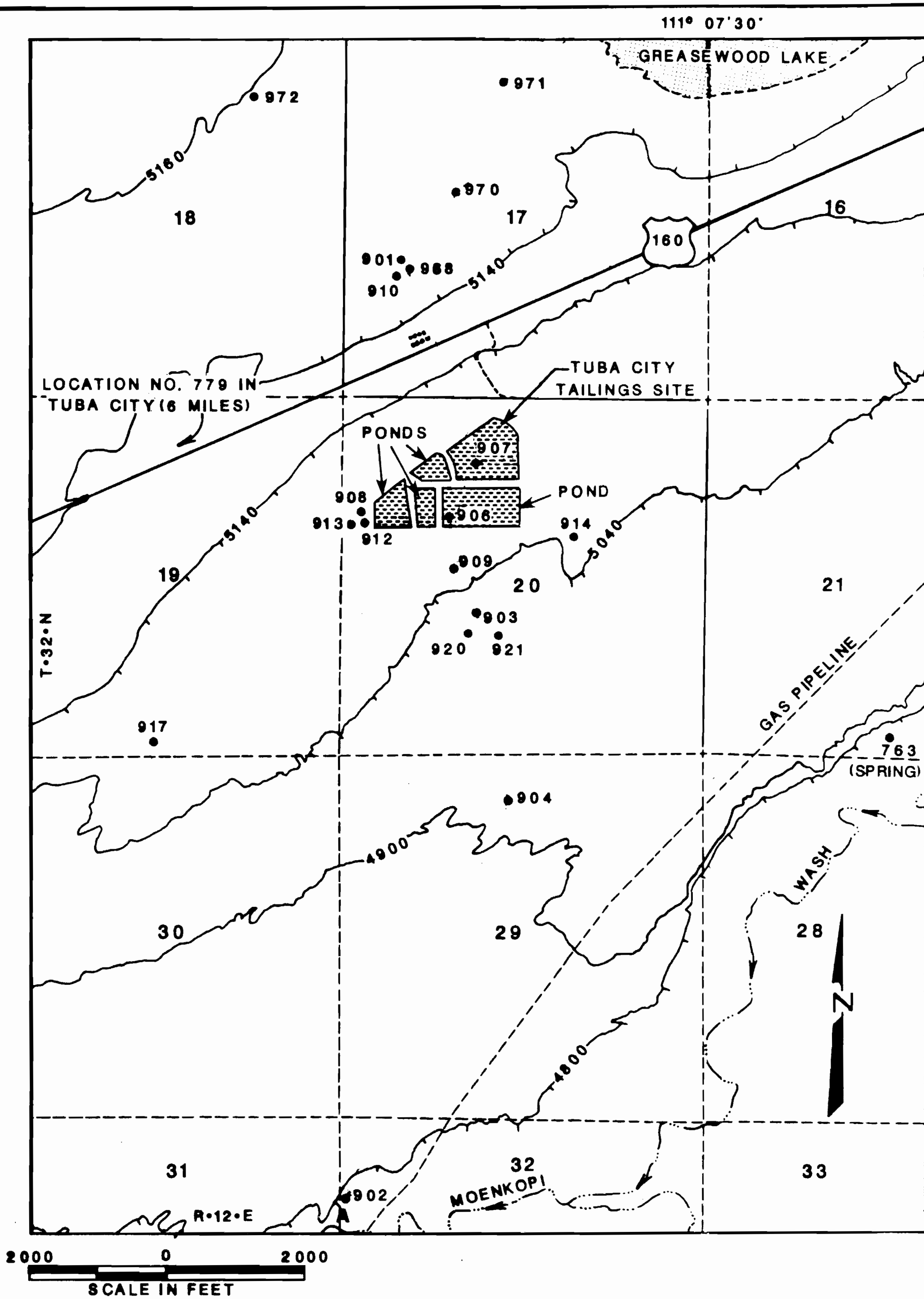


FIGURE B.2.1
GROUND-WATER MONITORING LOCATIONS

however, no wells were placed south of Moenkopi Wash because there were no usable roads. Water-level measurements and water samples were taken from each of these wells, as well as from four other wells in the area and a spring (Figure B.2.1).

B.2.2 GEOHYDROLOGIC SETTING

B.2.2.1 Geology

The Tuba City site lies in the southwestern quadrant of the Colorado Plateau physiographic province. In contrast to the highly deformed Cordilleran Fold Belt to the west and the Rocky Mountains to the east, the Colorado Plateau is characterized by gently dipping strata, broad monoclines, and uplifts. The site is in the Navajo Uplands physiographic subdivision of the Plateau (Harshbarger, 1953).

Near Tuba City, the uppermost bedrock unit is the Navajo Sandstone of the Glen Canyon Group. The Glen Canyon Group is comprised of, in ascending order, the Moenave and Kayenta Formations and the Navajo Sandstone. Borehole logs indicate that the Navajo is a fine- to medium-grained sandstone locally cemented with carbonate materials which displays large-scale crossbeds. The Navajo Sandstone intertongues with the underlying Kayenta Formation in a zone as much as 100 feet thick. In the vicinity of Tuba City, the Kayenta Formation consists of interbedded fine-grained sandstone and mudstone. The bedding is lenticular and crossbedding is common in the sandy units. Most of the mudstone occurs as thin flat-lying beds. The Moenave Formation consists of very fine- to fine-grained sandstone and thin siltstone strata. The Glen Canyon Group is underlain by the Chinle Formation, a sequence of mudstones and siltstones.

Down-hole geophysical logging of the abandoned Rare Metals production wells (locations numbered 970 and 971) approximately one mile north of the tailings site indicated a thickness of the Navajo Sandstone of hundreds of feet (Figure B.2.2). A few miles to the south, on the Moenkopi Plateau, wells have penetrated 800 feet of the sandstone (Akers et al., 1962). A detailed stratigraphic section six miles west of Tuba City indicated 105 feet of Navajo Sandstone, 495 feet of Kayenta Formation, and 385 feet of Moenave Formation (Figure B.2.3). Much of the Navajo Sandstone near the site is mantled by up to 10 feet of dune sand underlain by alluvium and pediment gravels.

B.2.2.2 Geohydrology

There is no continuous hydraulic barrier to ground-water flow between the Navajo Sandstone and the Kayenta Formation in the vicinity of the site. Together they comprise what is known as the N-aquifer of the Navajo and Hopi Reservations.

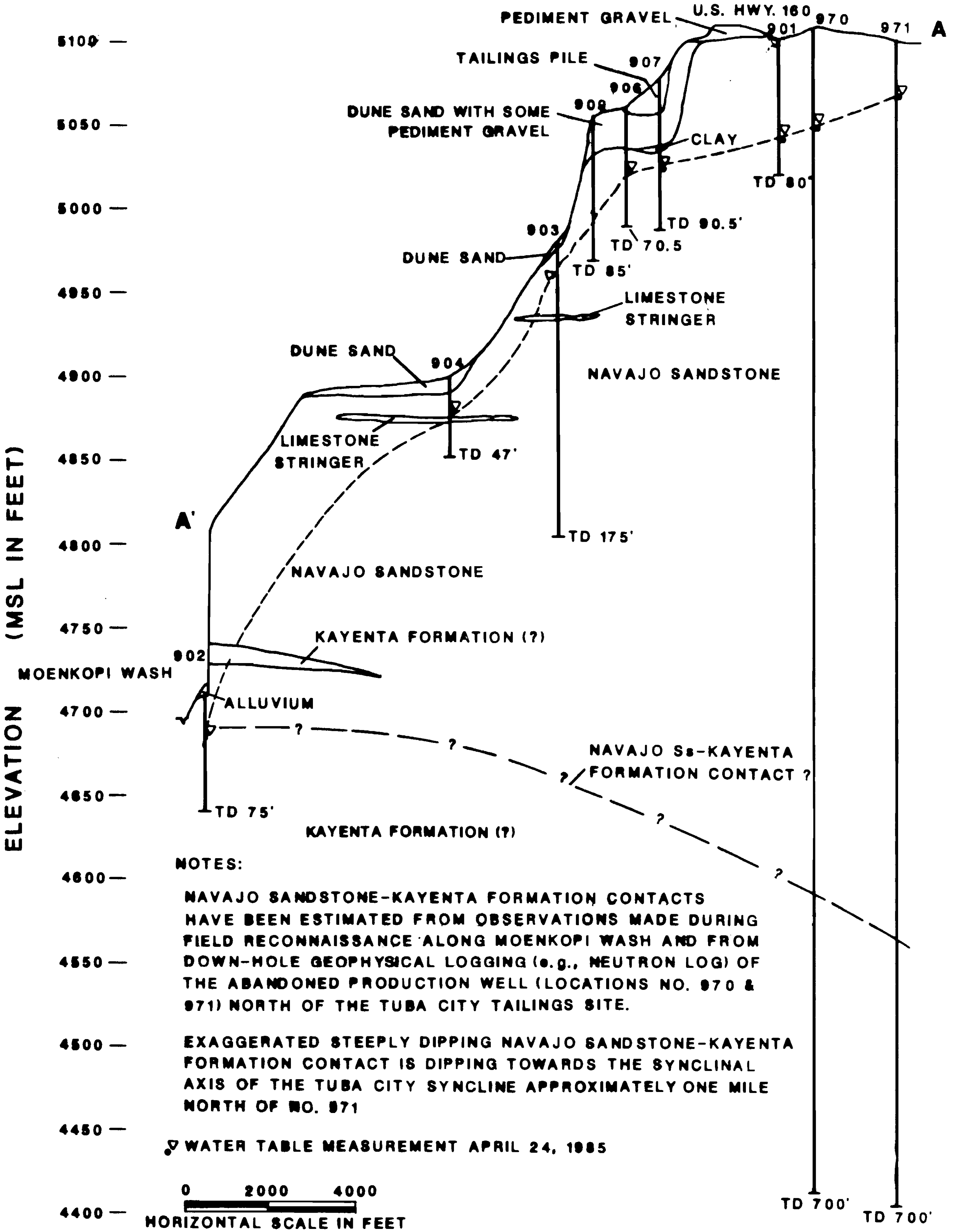


FIGURE B.2.2
TUBA CITY TAILINGS SITE - NORTH-SOUTH GEOLOGIC CROSS-SECTION

FIGURE B.2.3

STRATIGRAPHY NEAR THE TUBA CITY TAILINGS SITE

Age	Unit	Description
QUATERNARY	Qd DUNE SAND	Eolian deposits - Dune sand and unconsolidated well sorted sand.
QUATERNARY	Qal ALLUVIUM	Silt, sand, and gravel along streams, in broad valleys and flood plains; windblown silt and sand on benches and small terraces.
QUATERNARY	Qap PEDIMENT GRAVELS	Poorly sorted angular to well-rounded gravels and pebbles that have been slightly cemented.
JURASSIC AND TRIASSIC	JTRn NAVAJO SANDSTONE	Fine to medium-grained eolian sandstone; local calcareous cementation; numerous thin lenticular beds of cherty limestone; conspicuous large-scale trough-type crossbedding.
TRIASSIC	TRK KAYENTA FORMATION	Lenticular very thin to thin flat-lying beds of mudstone and crossbedded fine-grained lenticular sandstone.
TRIASSIC	TRmo MOENAVE FORMATION	Fine to medium-grained commonly crossbedded fluvial and paludal sandstone, claystone, siltstone, mudstone and local conglomerate lenses.
TRIASSIC	TRc CHINLE FORMATION	Divided into six members of which only three members are present in this area. These are the Owl Creek, Petrified Forest and the sandstone and mudstone portion of the Shinarump member. Owl Creek member is a mudstone and thin beds of gray silicified limestone and sandstone. The Petrified Forest member is comprised of well-indurated siltstone, mudstone, bentonitic clay and lenticular strata of limestone-pebble conglomerate, sandstone, and conglomeratic sandstone.

The Kayenta-Moenave contact is probably the lower bound of the N-aquifer. Although much of the N-aquifer is overlain by the Carmel Formation and a silty member of the Entrada Sandstone which creates confined conditions in many areas (Harshbarger et al., 1957), the N-aquifer is unconfined in the Tuba City area. According to Eychaner (1983), the aquifer's major recharge area is in the vicinity of Shonto approximately 40 miles northeast of Tuba City. Ground-water flow diverges from the recharge area, some flowing northeast toward Laguna Creek, and some flowing south toward Tuba City and Moenkopi Wash (Figure B.2.4). In addition to the area around Shonto, it is likely that other unconfined portions of the aquifer are recharge areas, especially where precipitation may percolate through dune sands, such as in the area around the tailings site.

The water table in the Navajo Sandstone ranges from about 20 to 150 feet below land surface in the vicinity of the site. Water levels taken between January, 1985, and April, 1986, are presented in Table B.2.2. The water table slopes toward Moenkopi Wash and ground water flows from the site toward the wash (Figure B.2.5).

Springs and seeps emerging from the N-aquifer flow from the cliffs along the north side of Moenkopi Wash (see Figure B.2.1). Therefore, ground water from at least the upper portion of the N-aquifer is discharged to the wash.

Ground-water flow rates were calculated with Darcy's Law:

$$q_n = \frac{K \, \Delta h/\Delta L}{n_e} \, ,$$

where:

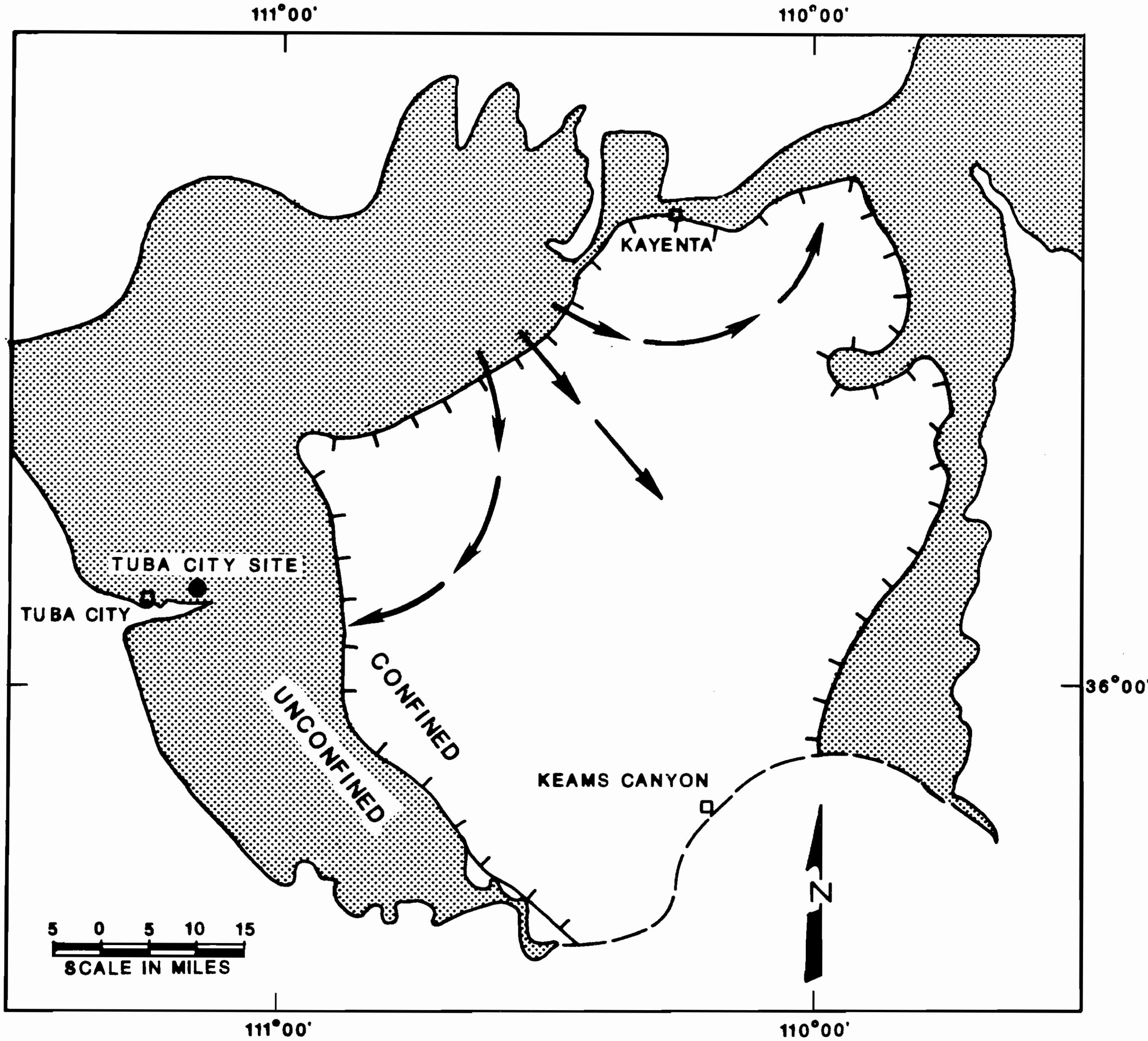
q_n = ground-water flow rate.
K = hydraulic conductivity.
$\Delta h/\Delta L$ = hydraulic gradient.
n_e = effective porosity.

The hydraulic gradient was calculated using values shown on Figure B.2.5.

$$\frac{\Delta h}{\Delta L} = \frac{h_1 - h_2}{\Delta L}$$

where:

h_1 = 5000 feet.
h_2 = 4700 feet.
ΔL = 7000 feet, distance between points where water levels were measured (h_1 and h_2).



REF: EYCHANER, 1983

AREA OF NAVAJO SANDSTONE (N AQUIFER) OUTCROP.

APPROXIMATE BOUNDARY BETWEEN CONFINED AND UNCONFINED AQUIFER.

GENERALIZED DIRECTION OF GROUND-WATER FLOW.

APPROXIMATE SOUTH LIMIT OF AQUIFER.

FIGURE B.2.4
HYDROLOGIC FEATURES OF THE NAVAJO SANDSTONE

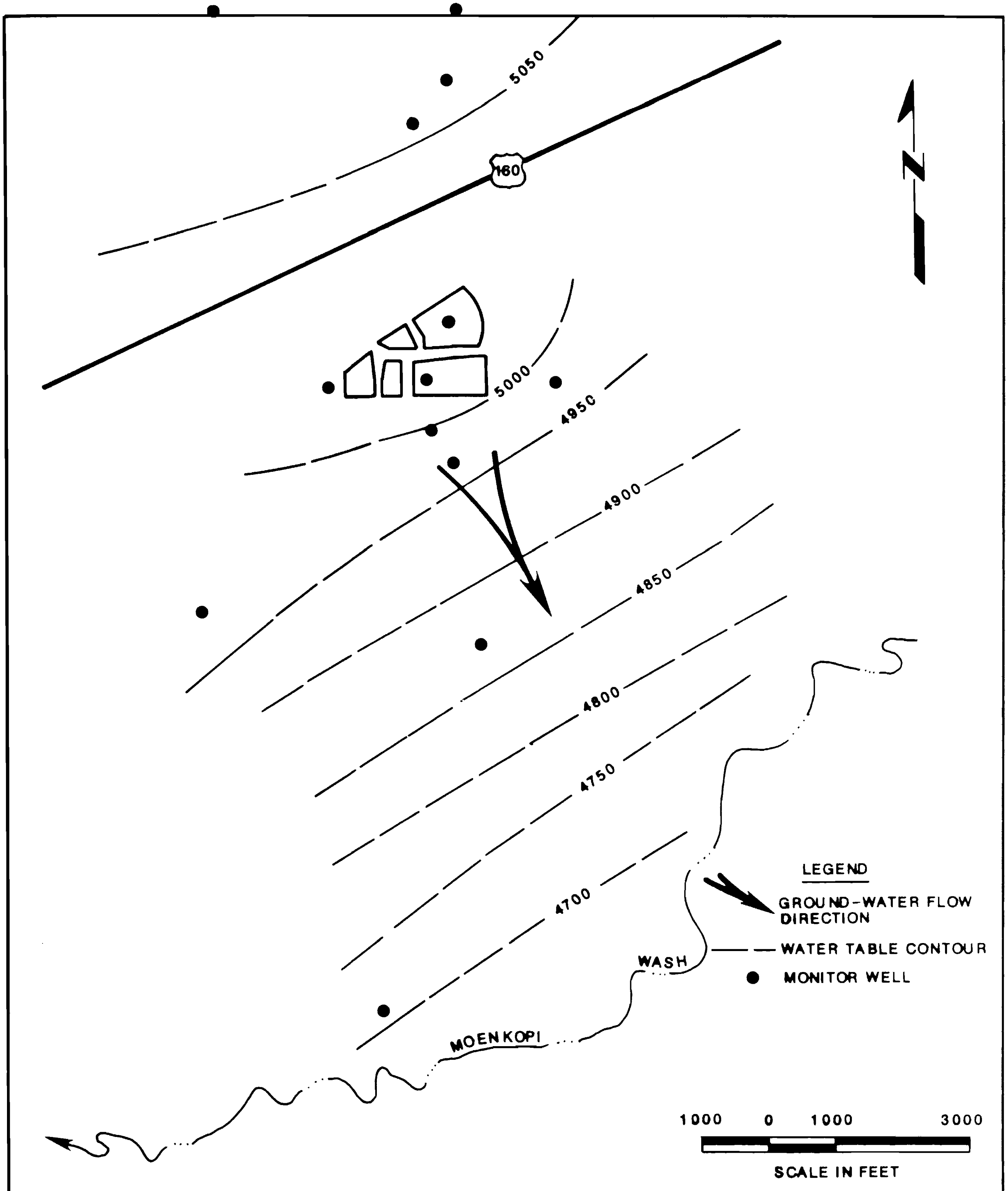


FIGURE B.2.5
WATER TABLE ELEVATIONS, NAVAJO SANDSTONE 1985-1986

Table B.2.2 Water table elevations, January, 1985, through April, 1986 (feet above mean sea level)

Well	JAN 85	MAR 85	APR 85	JULY 85	APR 86	Maximum fluctuation (ft)
901	5049.17	5049.44	5049.14	5049.70	5049.40	0.56
902	4703.49	4704.05	4704.06	4703.79	4704.20	0.57
903	4957.14	4957.41	4957.36	4957.56	4957.29	0.42
904	4879.40	4880.20	4879.15	4879.25	4879.17	1.05
906	5022.21	5021.99	5021.81	5021.68	5021.28	0.53
907	5026.63	--	5026.28	5026.31	5026.12	0.35
908	5012.15	5012.00	5012.90	5012.90	5011.14	1.76
909	5003.12	5003.42	5003.24	5003.40	4998.01	5.41
910					5048.74	
911					5054.25	
912					5009.21	
913					4987.45	
914					4969.90	
915					4976.68	
916					4954.65	
917					4977.24	
919					4902.34	
920					4954.50	
921					4940.88	
970					5047.91	
971					5073.03	
972					5082.32	

Slug tests have been performed on eight monitor wells installed by the DOE. These data were analyzed with the Bouwer-Rice and Hvorslev methods (Bouwer, 1978; Hvorslev, 1951), yielding the hydraulic conductivities presented in Table B.2.3. Data from aquifer tests performed on the Rare Metals wells in 1955 were also analyzed (Table B.2.4). The range of ground-water flow rates calculated using these hydraulic conductivities is presented in Table B.2.5.

B.2.3 Ground-water quality

Ground-water quality in the vicinity of the tailings pile has been characterized by sampling 24 wells and one spring (see Figure B.2.1). The samples were withdrawn with a nitrogen bladder pump or a submersible pump and preserved in accordance with EPA recommendations (EPA, 1983). The temperature, pH, electrical conductivity, and alkalinity of each sample were measured in the field. Field measurements were performed in accordance with approved procedures (TAC, 1985).

Table B.2.3 Slug test analysis results

Well location number	Hydraulic conductivity - K (feet per year)	
	Bouwer-Rice	Hvorslev
901	206.0	486.0
902	48.0	56.8
903	187.0	260.0
904	892.0	845.0
906	83.6	169.0
907	149.0	214.0
908	81.0	127.0
909	60.9	87.7

Table B.2.4 Aquifer test analyses summary of results

Well #	Type of well	Method of analysis	T (ft^2/day)	Hydraulic conductivity K (Ft/TR)[a]	Coefficient of storage S
968	Observation (970 pumped)	Theis	322.5	234	0.00017
968	Observation (970 pumped)	Jacob-Cooper early time	838.9	614	0.00011
968	Observation (970 pumped)	Jacob-Cooper late time	838.9	278	0.00013
972	pumped well	Theis recovery	550.6	402	--
970	pumped well	Theis recovery	151.2	110	--
968	Observation (970 pumped)	Theis recovery	577.6	424	--

[a]All Ks calculated assuming a 500-ft saturated thickness.

Table B.2.5 Range of ground-water flow rates calculated from slug test and aquifer data

	Well location number	Formation	Hydraulic conductivity (feet per year)	Hydraulic gradient	Effective porosity[a]	Flow rate (feet per year)
Minimum	902	Kayenta	48.3	$4x10^{-2}$	0.35	5.5
Geometric mean	--	--	163.0	$4x10^{-2}$	0.30	21.7
Maximum	904	Navajo Sandstone	892.0	$4x10^{-2}$	0.25	140.0

[a]Porosity for the Navajo Sandstone ranges from 25 to 35 percent as reported by Cooley et al. (1969), and is assumed to equal effective porosity.

Results of the water-quality analyses used to define background concentrations in the N-aquifer are presented in Table B.2.6. Table B.2.7 presents water-quality data for monitoring wells that were found to be contaminated.

The samples were analyzed by Bendix Field Engineering Corporation of Grand Junction, Colorado, Accu-Labs of Denver, Colorado, and EDA of Denver, Colorado. All laboratories used EPA-approved analytical methods (EPA, 1983) or methods approved by the DOE. The analytical results submitted by each laboratory were subjected to quality assurance checks.

The spring and 18 of the monitor wells yield water from the Navajo Sandstone. Monitor well number 902 probably yields its water from the Kayenta Formation. The former Rare Metals Production wells (970, 971, 972) are completed in the N-aquifer (Navajo and Kayenta Formations combined). Well number 779 is owned by the cement plant in Tuba City and is probably completed in the N-aquifer. Samples from the spring and 13 of the wells represent background water quality. Samples from the other five wells have been affected by the tailings pile. The arguments supporting these statements are presented in the following sections.

B.2.3.1 Background water quality

Chemical analyses of water samples from wells numbered 779, 901, 902, 903, 904, 910, 914, 917, 920, 921, 970, 971, 972, and the spring (location numbered 763) show that they represent background water quality as defined by the draft Nuclear Regulatory Commission Standard Review Plan for UMTRA Project Sites (NRC, 1985). The plan defines background water quality as ". . . the quality of water that would be expected at a site if contamination had not occurred from the designated facility." Background water quality is summarized in Table B.2.8.

Table B.2.6 Chemical analyses of background ground-water samples

PARAMETER	UNIT OF MEASURE	763-S1 12/17/84 PARAMETER VALUE	+/-UNCERTAINTY	763-01 03/27/85 PARAMETER VALUE	+/-UNCERTAINTY	763-S1 07/22/85 PARAMETER VALUE	+/-UNCERTAINTY	901-01 12/18/84 PARAMETER VALUE	+/-UNCERTAINTY	901-01 03/26/85 PARAMETER VALUE	+/-UNCERTAINTY
ALKALINITY	MG/L CACO3	128.		146.		135.		110.		107.	
ALUMINUM	MG/L	< 0.1		< 0.1		-		< 0.1		< 0.1	
AMMONIUM	MG/L	< 0.1		< 0.1		< 0.1		0.1		0.1	
ANTIMONY	MG/L	< 0.003		< 0.003		-		< 0.003		< 0.003	
ARSENIC	MG/L	< 0.01		< 0.01		< 0.01		< 0.01		< 0.01	
BARIUM	MG/L	< 0.1		< 0.1		0.2		< 0.1		0.1	
BORON	MG/L	0.04		0.1		0.2		0.01		-	
CADMIUM	MG/L	< 0.001		0.004		0.004		< 0.001		< 0.001	
CALCIUM	MG/L	34.9		29.		29.		32.2		30.	
CHLORIDE	MG/L	50.		26.		30.		12.		-	
CHROMIUM	MG/L	< 0.01		0.01		< 0.01		< 0.01		< 0.01	
COBALT	MG/L	< 0.05		< 0.05		-		< 0.05		< 0.05	
COND, IN-SITU	UMHO/CM	-		420.		-		-		195.	
CONDUCTANCE	UMHO/CM	0.739		-		270.		438.		-	
COPPER	MG/L	< 0.02		< 0.02		< 0.02		< 0.02		< 0.02	
CYANIDE	MG/L	-		< 0.01		-		-		< 0.01	
FLUORIDE	MG/L	0.63		0.7		0.7		0.24		-	
GROSS ALPHA	PCI/L	-		< 10. **	2.00	3.	2.00	-		< 2.	0.50
GROSS BETA	PCI/L	-		11.	1.00	3.	3.00	-		2.	0.20
IRON	MG/L	< 0.03		< 0.03		< 0.03		< 0.03		< 0.03	
LEAD	MG/L	< 0.01		< 0.01		< 0.01		< 0.01		< 0.01	
MAGNESIUM	MG/L	10.2		9.		8.7		7.11		5.2	
MANGANESE	MG/L	< 0.01		< 0.01		0.01		0.1 **		0.01	
MERCURY	MG/L	< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002	
MOLYBDENUM	MG/L	< 0.01		< 0.01		-		< 0.01		< 0.01	
NICKEL	MG/L	< 0.04		< 0.04		-		< 0.04		< 0.04	
NITRATE	MG/L	20.		20.		21.		10.		-	
ORG. CARBON	MG/L	1.5		2.		2.		3.2		1.	
PB-210	PCI/L	< 1.5		0.9	0.80	-		< 1.5		0.9	0.80
PH	SU	7.84		7.78		7.44		7.94		7.86	
PHOSPHATE	MG/L	< 0.15		< 0.1		-		< 0.15		-	
PO-210	PCI/L	< 1.		0.1	0.40	-		< 1.		0.1	0.50
POTASSIUM	MG/L	2.3		2.1		2.		1.2		1.2	
RA-226	PCI/L	< 1.		0.6	0.40	0.2	0.20	< 1.		-0.1	0.30
RA-228	PCI/L	< 1.		0.2	0.70	0.1	2.20	< 1.		0.3	0.80
SELENIUM	MG/L	0.006		0.005		0.009		< 0.005		< 0.005	
SILCON	MG/L	5.9		-		-		6.4		-	
SILICA	MG/L	-		12.		-		-		-	
SILVER	MG/L	-		-		< 0.01		< 0.01		< 0.01	
SODIUM	MG/L	79.3		76.		77.		15.		16.	
STRONTIUM	MG/L	0.75		0.7		0.7		0.59		0.4	
SULFATE	MG/L	160.		92.		81.		70.		-	
SULFIDE	MG/L	-		< 0.1		< 0.1		-		< 0.1	
TEMP, IN-SITU	C-DEGREE	-		16.		-		-		15.	
TEMPERATURE	C - DEGREE	14.9		-		19.		15.		-	
TH-230	PCI/L	< 1.		0.1	0.10	-		< 1.		0.	0.20
TIN	MG/L	< 0.005		0.011		-		< 0.005		0.007	

Table B.2.6 Chemical analyses of background ground-water samples (continued)

		LOCATION ID - SAMPLE ID AND LOG DATE				
		763-S1 12/17/84	763-01 03/27/85	763-S1 07/22/85	901-01 12/18/84	901-01 03/26/85
PARAMETER	UNIT OF MEASURE	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY
TOTAL SOLIDS	MG/L	380.	350.	370.	260.	-
TOX	MG/L	-	< 0.1	-	-	< 0.1
U-234	PCI/L	4.	-	-	2.	-
U-238	PCI/L	2.	-	-	1.	-
URANIUM	MG/L	-	0.005	0.006	-	0.01
VANADIUM	MG/L	0.06	0.01	-	0.02	0.01
ZINC	MG/L	0.009	< 0.005	0.017	0.018	0.005

Table B.2.6 Chemical analyses of background ground-water samples (continued)

PARAMETER	UNIT OF MEASURE	901-01 07/24/85 PARAMETER VALUE	+/-UNCERTAINTY	901-01 03/20/86 PARAMETER VALUE	+/-UNCERTAINTY	902-01 12/18/84 PARAMETER VALUE	+/-UNCERTAINTY	902-01 03/26/85 PARAMETER VALUE	+/-UNCERTAINTY	902-01 07/23/85 PARAMETER VALUE	+/-UNCERTAINTY
ALKALINITY	MG/L CACO3	93.		104.		129.		138.		132.	
ALUMINUM	MG/L	-		-		< 0.1		0.6		-	
AMMONIUM	MG/L	< 0.1		< 0.1		0.1		0.1		< 0.1	
ANTIMONY	MG/L	-		-		< 0.003		< 0.003		-	
ARSENIC	MG/L	< 0.01		-		0.02		0.01		0.02	
BARIUM	MG/L	0.1		-		< 0.1		< 0.1		0.1	
BORON	MG/L	0.2		-		0.01		0.1		0.3	
CADMIUM	MG/L	0.001		< 0.001		< 0.001		< 0.001		0.002	
CALCIUM	MG/L	31.		31.4		0.76		0.62		0.7	
CHLORIDE	MG/L	11.		11.		10.		8.		8.	
CHROMIUM	MG/L	< 0.01		0.02		< 0.01		< 0.01		< 0.01	
COBALT	MG/L	< 0.05		-		< 0.05		< 0.05		-	
COND,IN-SITU	UMHO/CM	-		-		-		250.		-	
CONDUCTANCE	UMHO/CM	210.		210.		366.		-		250.	
COPPER	MG/L	< 0.02		-		< 0.02		< 0.02		< 0.02	
CYANIDE	MG/L	-		-		-		< 0.01		-	
FLUORIDE	MG/L	0.2		-		0.21		0.2		0.2	
GROSS ALPHA	PCI/L	1.	2.00	-		-		< 3.	0.60	8. *	3.00
GROSS BETA	PCI/L	-1.	2.00	-		-		2.	0.20	2.	3.00
IRON	MG/L	< 0.03		-		< 0.03		0.17		0.04	
LEAD	MG/L	< 0.01		-		< 0.01		< 0.01		< 0.01	
MAGNESIUM	MG/L	5.9		5.		0.08		0.11		0.15	
MANGANESE	MG/L	< 0.01		-		< 0.01		< 0.01		< 0.01	
MERCURY	MG/L	0.0002		-		< 0.0002		< 0.0002		0.0002	
MOLYBDENUM	MG/L	< 0.01		0.2		< 0.01		< 0.01		-	
NICKEL	MG/L	< 0.04		-		< 0.04		< 0.04		-	
NITRATE	MG/L	34.		3.		2.		< 1.		11.	
ORG. CARBON	MG/L	< 1.		-		2.3		11.		3.	
PB-210	PCI/L	0.2	0.70	-		< 1.5		0.5	0.80	-	
PH	SU	7.3		7.95		9.75 **		9.57 **		9.15 **	
PHOSPHATE	MG/L	-		-		< 0.15		< 0.1		-	
PO-210	PCI/L	-0.1	0.30	-		< 1.		0.	0.50	-	
POTASSIUM	MG/L	1.1		1.2		1.28		1.		1.1	
RA-226	PCI/L	-0.1	0.20	-		< 1.		0.2	0.30	0.	0.20
RA-228	PCI/L	0.	0.80	-		< 1.		-0.3	0.70	-0.1	1.90
SELENIUM	MG/L	< 0.005		< 0.005		< 0.005		0.005		< 0.005	
SILCON	MG/L	-		-		8.1		-		-	
SILICA	MG/L	-		-		-		16.		-	
SILVER	MG/L	< 0.01		-		< 0.01		< 0.01		< 0.01	
SODIUM	MG/L	14.		16.4		72.2		68.		71.	
STRONTIUM	MG/L	0.3		-		0.02		< 0.1		< 0.1	
SULFATE	MG/L	15.		17.		70.		12.		6.	
SULFIDE	MG/L	< 0.1		-		-		< 0.1		< 0.1	
TEMP,IN-SITU	C-DEGREE	-		-		-		17.		-	
TEMPERATURE	C - DEGREE	16.		15.		15.		-		19.	
TH-230	PCI/L	0.	0.10	-		< 1.		-0.1	0.20	-	
TIN	MG/L	< 0.5		-		< 0.005		0.008		-	

Table B.2.6 Chemical analyses of background ground-water samples (continued)

		LOCATION ID - SAMPLE ID AND LOG DATE				
		901-01 07/24/85	901-01 03/20/86	902-01 12/18/84	902-01 03/26/85	902-01 07/23/85
PARAMETER	UNIT OF MEASURE	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY
TOTAL SOLIDS	MG/L	80.	160.	220.	190.	200.
TOX	MG/L	-	-	-	< 0.1	-
U-234	PCI/L	-	-	1.	-	-
U-238	PCI/L	-	-	< 1.	-	-
URANIUM	MG/L	0.006	0.0057	-	0.01	0.006
VANADIUM	MG/L	< 0.01	-	0.03	0.03	-
ZINC	MG/L	0.008	-	0.019	0.008	0.19

Table B.2.6 Chemical analyses of background ground-water samples (continued)

		LOCATION ID - SAMPLE ID AND LOG DATE									
		903-01 01/03/85		903-01 03/27/85		903-01 07/24/85		903-01 04/03/86		904-01 01/03/85	
PARAMETER	UNIT OF MEASURE	PARAMETER VALUE	+/-UNCERTAINTY	PARAMETER VALUE	+/-UNCERTAINTY	PARAMETER VALUE	+/-UNCERTAINTY	PARAMETER VALUE	+/-UNCERTAINTY	PARAMETER VALUE	+/-UNCERTAINTY
ALKALINITY	MG/L CACO3	88.		93.		88.		98.		127.	
ALUMINUM	MG/L	< 0.1		< 0.1		-		-		< 0.1	
AMMONIUM	MG/L	< 0.1		< 0.1		< 0.1		0.3		0.1	
ANTIMONY	MG/L	< 0.003		< 0.003		-		-		< 0.003	
ARSENIC	MG/L	< 0.01		< 0.01		< 0.01		-		< 0.01	
BARIUM	MG/L	< 0.1		< 0.1		0.1		-		< 0.1	
BORON	MG/L	< 0.01		0.1		0.2		-		0.02	
CADMIUM	MG/L	< 0.001		< 0.001		< 0.001		< 0.001		< 0.001	
CALCIUM	MG/L	37.4		38.		37.		38.6		51.2	
CHLORIDE	MG/L	13.		16.		16.		16.		79.	
CHROMIUM	MG/L	< 0.01		< 0.01		< 0.01		0.02		< 0.01	
COBALT	MG/L	< 0.05		< 0.05		< 0.05		-		< 0.05	
COND, IN-SITU	UMHO/CM	-		230.		-		-		-	
CONDUCTANCE	UMHO/CM	328.		-		160.		240.		647.	
COPPER	MG/L	< 0.06		< 0.02		< 0.02		-		< 0.02	
CYANIDE	MG/L	-		< 0.01		-		-		-	
FLUORIDE	MG/L	0.16		0.2		0.2		-		0.47	
GROSS ALPHA	PCI/L	-		< 3.	0.70	2.	2.00	-		-	
GROSS BETA	PCI/L	-		2.	0.20	2.	3.00	-		-	
IRON	MG/L	< 0.03		< 0.03		< 0.03		-		< 0.03	
LEAD	MG/L	< 0.01		< 0.01		< 0.01		-		< 0.01	
MAGNESIUM	MG/L	8.22		7.3		8.2		7.79		5.87	
MANGANESE	MG/L	< 0.01		< 0.01		< 0.01		-		< 0.01	
MERCURY	MG/L	< 0.0002		< 0.0002		< 0.0002		-		< 0.0002	
MOLYBDENUM	MG/L	< 0.01		< 0.01		< 0.01		0.1		< 0.01	
NICKEL	MG/L	< 0.04		< 0.04		< 0.04		-		< 0.04	
NITRATE	MG/L	28.		10.		24.		5.		5.	
ORG. CARBON	MG/L	1.5		1.		< 1.		-		4.8	
PB-210	PCI/L	< 1.5		0.2	0.70	0.8	0.80	-		< 1.5	
PH	SU	7.83		7.2		7.86		7.81		9.7 **	
PHOSPHATE	MG/L	< 0.15		< 0.1		-		-		< 0.15	
PO-210	PCI/L	< 1.		0.6	0.60	0.1	0.50	-		< 1.	
POTASSIUM	MG/L	1.78		1.6		1.5		1.67		2.98	
RA-226	PCI/L	< 1.		1.4	0.40	1.	0.30	-		< 1.	
RA-228	PCI/L	1.5		-0.7	0.70	-0.2	0.80	-		< 1.	
SELENIUM	MG/L	< 0.005		< 0.005		< 0.005		< 0.005		< 0.005	
SILCON	MG/L	5.6		-		-		-		10.9	
SILICA	MG/L	-		12.		-		-		-	
SILVER	MG/L	< 0.01		< 0.01		< 0.01		-		< 0.01	
SODIUM	MG/L	10.4		11.		9.		12.1		82.2	
STRONTIUM	MG/L	0.65		0.6		0.6		-		0.68	
SULFATE	MG/L	44.		20.		18.		38.6		62.	
SULFIDE	MG/L	-		< 0.1		< 0.1		-		-	
TEMP, IN-SITU	C-DEGREE	-		15.		-		-		-	
TEMPERATURE	C - DEGREE	12.		-		19.		16.		11.	
TH-230	PCI/L	< 1.		0.	0.20	0.	0.10	-		< 1.	
TIN	MG/L	< 0.005		0.007		< 0.5		-		< 0.005	

Table B.2.6 Chemical analyses of background ground-water samples (continued)

PARAMETER	UNIT OF MEASURE	903-01 01/03/85 PARAMETER VALUE+/-UNCERTAINTY	903-01 03/27/85 PARAMETER VALUE+/-UNCERTAINTY	903-01 07/24/85 PARAMETER VALUE+/-UNCERTAINTY	903-01 04/03/86 PARAMETER VALUE+/-UNCERTAINTY	904-01 01/03/85 PARAMETER VALUE+/-UNCERTAINTY
TOTAL SOLIDS	MG/L	190.	180.	120.	190.	370.
TOX	MG/L	-	< 0.1	-	-	-
U-234	PCI/L	2.	-	-	-	2.
U-238	PCI/L	< 1.	-	-	-	< 1.
URANIUM	MG/L	-	0.004	0.004	0.0047	-
VANADIUM	MG/L	< 0.01	0.01	< 0.01	-	< 0.01
ZINC	MG/L	0.045	0.016	0.008	-	0.013

Table B.2.6 Chemical analyses of background ground-water samples (continued)

		LOCATION ID - SAMPLE ID AND LOG DATE						
		904-01 03/27/85		904-01 07/24/85		910-01 10/07/85	910-01 04/08/86	911-01 04/08/86
PARAMETER	UNIT OF MEASURE	PARAMETER VALUE	+/-UNCERTAINTY	PARAMETER VALUE	+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY
ALKALINITY	MG/L CACO3	114.		115.		105.	93.	74.
ALUMINUM	MG/L	< 0.1		-		0.1	-	-
AMMONIUM	MG/L	< 0.1		< 0.1		0.1	< 0.1	< 0.1
ANTIMONY	MG/L	< 0.003		-		-	-	-
ARSENIC	MG/L	< 0.01		< 0.01		-	-	-
BARIUM	MG/L	< 0.1		0.2		-	-	-
BORON	MG/L	0.1		0.2		0.4	-	-
CADMIUM	MG/L	0.001		0.002		< 0.001	< 0.001	< 0.001
CALCIUM	MG/L	35.		38.		30.9	31.	16.9
CHLORIDE	MG/L	87.		84.		9.4	11.	9.
CHROMIUM	MG/L	< 0.01		< 0.01		< 0.01	0.02	0.02
COBALT	MG/L	< 0.05		-		< 0.05	-	-
COND, IN-SITU	UMHO/CM	445.		-		-	-	-
CONDUCTANCE	UMHO/CM	-		240.		200.	140.	150.
COPPER	MG/L	< 0.02		< 0.02		< 0.02	-	-
CYANIDE	MG/L	< 0.01		-		< 0.001	-	-
FLUORIDE	MG/L	0.3		0.4		-	-	-
GROSS ALPHA	PCI/L	< 7. *	2.00	4. *	2.00	-	-	-
GROSS BETA	PCI/L	5.	0.50	0.	3.00	-	-	-
IRON	MG/L	< 0.03		< 0.03		< 0.03	-	-
LEAD	MG/L	< 0.01		0.02		-	-	-
MAGNESIUM	MG/L	10.		12.		6.03	5.01	2.55
MANGANESE	MG/L	0.02		< 0.01		< 0.01	-	-
MERCURY	MG/L	< 0.0002		0.0002		-	-	-
MOLYBDENUM	MG/L	< 0.01		-		0.2	0.21	0.18
NICKEL	MG/L	< 0.04		-		< 0.04	-	-
NITRATE	MG/L	5.		12.		12.	3.	3.
ORG. CARBON	MG/L	2.		3.		-	-	-
PB-210	PCI/L	0.4	0.80	-		-	-	-
PH	SU	8.72 **		7.62		8.38	7.62	9.46 **
PHOSPHATE	MG/L	< 0.01		-		-	-	-
PO-210	PCI/L	0.1	0.30	-		-	-	-
POTASSIUM	MG/L	2.2		1.2		2.11	1.2	7.57
RA-226	PCI/L	0.	0.30	0.	0.20	-	-	-
RA-228	PCI/L	0.	0.70	0.1	4.00	-	-	-
SELENIUM	MG/L	< 0.005		0.018 *		< 0.005	< 0.005	< 0.005
SILCON	MG/L	-		-		-	-	-
SILICA	MG/L	23.		-		10.	-	-
SILVER	MG/L	< 0.01		< 0.01		< 0.1	-	-
SODIUM	MG/L	68.		64.		16.2	16.6	30.
STRONTIUM	MG/L	0.9		0.8		0.2	-	-
SULFATE	MG/L	53.		48.		20.1	17.1	84.9
SULFIDE	MG/L	< 0.1		< 0.1		-	-	-
TEMP, IN-SITU	C-DEGREE	15.5		-		-	-	-
TEMPERATURE	C - DEGREE	-		17.		16.	16.	16.
TH-230	PCI/L	0.4	0.40					
TIN	MG/L	< 0.05						

Table B.2.6 Chemical analyses of background ground-water samples (continued)

PARAMETER	UNIT OF MEASURE		904-01 03/27/85 PARAMETER VALUE+/-UNCERTAINTY	904-01 07/24/85 PARAMETER VALUE+/-UNCERTAINTY	910-01 10/07/85 PARAMETER VALUE+/-UNCERTAINTY	910-01 04/08/86 PARAMETER VALUE+/-UNCERTAINTY	911-01 04/08/86 PARAMETER VALUE+/-UNCERTAINTY
TOTAL SOLIDS	MG/L		340.	370.	185.	158.	161.
TOX	MG/L	<	0.1	-	-	-	-
U-234	PCI/L		-	-	-	-	-
U-238	PCI/L		-	-	-	-	-
URANIUM	MG/L		0.005	0.007	0.0034	0.0028	0.0018
VANADIUM	MG/L	<	0.01	-	-	-	-
ZINC	MG/L	<	0.005	0.18	0.118	-	-

Table B.2.6 Chemical analyses of background ground-water samples (continued)

PARAMETER	UNIT OF MEASURE	913-01 04/10/86 PARAMETER VALUE+/-UNCERTAINTY	914-01 08/31/85 PARAMETER VALUE+/-UNCERTAINTY	914-01 04/09/86 PARAMETER VALUE+/-UNCERTAINTY	917-01 10/08/85 PARAMETER VALUE+/-UNCERTAINTY	917-01 04/10/86 PARAMETER VALUE+/-UNCERTAINTY
ALKALINITY	MG/L CACO3	65.	93.	93.	103.	88.
ALUMINUM	MG/L	-	0.5	-	0.2	-
AMMONIUM	MG/L	0.8	< 0.1	< 0.1	< 0.1	0.4
ANTIMONY	MG/L	-	-	-	-	-
ARSENIC	MG/L	-	-	-	-	-
BARIUM	MG/L	-	-	-	-	-
BORON	MG/L	-	0.4	-	0.4	-
CADMIUM	MG/L	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
CALCIUM	MG/L	8.52	16.2	31.9	24.9	31.2
CHLORIDE	MG/L	6.	12.	14.	9.2	10.
CHROMIUM	MG/L	0.05	< 0.01	0.02	0.01	0.04
COBALT	MG/L	-	< 0.05	-	< 0.05	-
COND,IN-SITU	UMHO/CM	-	-	-	-	-
CONDUCTANCE	UMHO/CM	140.	285.	215.	210.	190.
COPPER	MG/L	-	0.02	-	< 0.02	-
CYANIDE	MG/L	-	< 0.1	-	< 0.001	-
FLUORIDE	MG/L	-	-	-	-	-
GROSS ALPHA	PCI/L	-	-	-	-	-
GROSS BETA	PCI/L	-	-	-	-	-
IRON	MG/L	-	0.15	-	< 0.03	-
LEAD	MG/L	-	-	-	-	-
MAGNESIUM	MG/L	1.54	3.78	6.83	4.53	6.12
MANGANESE	MG/L	-	0.07 **	-	< 0.01	-
MERCURY	MG/L	-	-	-	-	-
MOLYBDENUM	MG/L	0.16	0.15	0.18	0.09	0.24
NICKEL	MG/L	-	< 0.04	-	< 0.04	-
NITRATE	MG/L	3.	10.	3.	17.	5.
ORG. CARBON	MG/L	-	-	-	-	-
PB-210	PCI/L	-	-	-	-	-
PH	SU	9.69 **	7.96	8.22	8.04	8.08
PHOSPHATE	MG/L	-	-	-	-	-
PO-210	PCI/L	-	-	-	-	-
POTASSIUM	MG/L	10.7	1.94	2.18	2.28	1.86
RA-226	PCI/L	-	-	-	-	-
RA-228	PCI/L	-	-	-	-	-
SELENIUM	MG/L	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
SILCON	MG/L	-	-	-	-	-
SILICA	MG/L	-	16.	-	11.	-
SILVER	MG/L	-	< 0.01	-	< 0.01	-
SODIUM	MG/L	20.1	48.1	14.4	26.6	9.31
STRONTIUM	MG/L	-	< 0.1	-	0.2	-
SULFATE	MG/L	10.2	37.4	19.	17.3	15.1
SULFIDE	MG/L	-	-	-	-	-
TEMP,IN SITU	C-DEGREE	-	-	-	-	-
TEMPERATURE	C - DEGREE	17.	23.	17.	16.	17.
TH-230	PCI/L	-	-	-	-	-
TIN	MG/L	-	-	-	-	-

Table B.2.6 Chemical analyses of background ground-water samples (continued)

		LOCATION ID - SAMPLE ID AND LOG DATE				
		913-01 04/10/86	914-01 08/31/85	914-01 04/09/86	917-01 10/08/85	917-01 04/10/86
PARAMETER	UNIT OF MEASURE	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY
TOTAL SOLIDS	MG/L	142.	231.	474.	176.	182.
TOX	MG/L	-	-	-	-	-
U-234	PCI/L	-	-	-	-	-
U-238	PCI/L	-	-	-	-	-
URANIUM	MG/L	0.0011	0.0186 +	0.0023	0.0015	0.0024
VANADIUM	MG/L	-	-	-	-	-
ZINC	MG/L	-	0.02	-	0.042	-

Table B.2.6 Chemical analyses of background ground-water samples (continued)

PARAMETER	UNIT OF MEASURE	920-01 09/08/85 PARAMETER VALUE+/-UNCERTAINTY	920-01 04/09/86 PARAMETER VALUE+/-UNCERTAINTY	921-01 10/10/85 PARAMETER VALUE+/-UNCERTAINTY	921-01 04/10/86 PARAMETER VALUE+/-UNCERTAINTY	9/0-01 07/22/85 PARAMETER VALUE+/-UNCERTAINTY	
ALKALINITY	MG/L CACO3	94.	93.	75.	73.	86.	
ALUMINUM	MG/L	0.2	-	0.3	-	-	
AMMONIUM	MG/L	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	
ANTIMONY	MG/L	-	-	-	-	-	
ARSENIC	MG/L	-	-	-	-	< 0.01	
BARIUM	MG/L	-	-	-	-	0.2	
BORON	MG/L	0.4	-	0.5	-	0.2	
CADMIUM	MG/L	< 0.001	< 0.001	< 0.001	< 0.001	0.004	
CALCIUM	MG/L	28.4	30.7	7.19	20.3	23.	
CHLORIDE	MG/L	9.	10.	6.	7.	7.	
CHROMIUM	MG/L	0.02	< 0.01	0.02	< 0.01	< 0.01	
COBALT	MG/L	< 0.05	-	< 0.05	-	< 0.05	
COND,IN-SITU	UMHO/CM	-	-	-	-	-	
CONDUCTANCE	UMHO/CM	215.	185.	180.	140.	180.	
COPPER	MG/L	< 0.02	-	< 0.02	-	< 0.02	
CYANIDE	MG/L	< 0.01	-	< 0.001	-	-	
FLUORIDE	MG/L	-	-	-	-	0.2	
GROSS ALPHA	PCI/L	-	-	-	-	1.	1.00
GROSS BETA	PCI/L	-	-	-	-	0.	2.00
IRON	MG/L	0.05	-	< 0.03	-	< 0.03	
LEAD	MG/L	-	-	-	-	< 0.01	
MAGNESIUM	MG/L	6.49	6.74	3.01	3.12	6.	
MANGANESE	MG/L	0.04	-	< 0.01	-	< 0.01	
MERCURY	MG/L	-	-	-	-	0.0003	
MOLYBDENUM	MG/L	0.12	0.18	0.13	0.22	< 0.01	
NICKEL	MG/L	0.06	-	< 0.04	-	< 0.04	
NITRATE	MG/L	10.	3.	10.	2.	17.	
ORG. CARBON	MG/L	-	-	-	-	< 1.	
PB-210	PCI/L	-	-	-	-	0.6	0.60
PH	SU	8.01	8.08	9.48 **	8.66 **	8.	
PHOSPHATE	MG/L	-	-	-	-	-	
PO-210	PCI/L	-	-	-	-	0.	0.30
POTASSIUM	MG/L	1.9	2.36	8.28	6.87	1.2	
RA-226	PCI/L	-	-	-	-	-0.1	0.20
RA-228	PCI/L	-	-	-	-	-0.2	0.70
SELENIUM	MG/L	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	
SILCON	MG/L	-	-	-	-	-	
SILICA	MG/L	22.	-	8.	-	-	
SILVER	MG/L	< 0.01	-	< 0.01	-	< 0.01	
SODIUM	MG/L	9.46	7.3	24.4	12.7	14.	
STRONTIUM	MG/L	< 0.1	-	0.4	-	0.7	
SULFATE	MG/L	13.9	13.1	9.	8.1	8.	
SULFIDE	MG/L	-	-	-	-	< 0.1	
TEMP,IN-SITU	C DEGREE	-	-	-	-	-	
TEMPERATURE	C - DEGREE	17.	17.	16.5	17.	16.	
TH-230	PCI/L	-	-	-	-	0.	0.10
TIN	MG/L					< 0.5	

Table B.2.6 Chemical analyses of background ground-water samples (continued)

		LOCATION ID - SAMPLE ID AND LOG DATE				
		920-01 09/08/85	920-01 04/09/86	921-01 10/10/85	921-01 04/10/86	970-01 07/22/85
PARAMETER	UNIT OF MEASURE	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY
TOTAL SOLIDS	MG/L	147.	163.	121.	126.	210.
TOX	MG/L	-	-	-	-	-
U-234	PCI/L	-	-	-	-	-
U-238	PCI/L	-	-	-	-	-
URANIUM	MG/L	0.001	0.0031	0.0051	0.0046	0.004
VANADIUM	MG/L	-	-	-	-	< 0.01
ZINC	MG/L	0.037	-	0.115	-	0.012

Table B.2.6 Chemical analyses of background ground-water samples (continued)

		LOCATION ID - SAMPLE ID AND LOG DATE						
		971-04 07/23/85		972-04 07/23/85				
PARAMETER	UNIT OF MEASURE	PARAMETER VALUE	+/-UNCERTAINTY	PARAMETER VALUE	+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY
ALKALINITY	MG/L CACO3	292.		100.				
ALUMINUM	MG/L	-		-				
AMMONIUM	MG/L	< 0.1		-				
ANTIMONY	MG/L	-		-				
ARSENIC	MG/L	< 0.01		< 0.01				
BARIUM	MG/L	0.1		0.1				
BORON	MG/L	1.3		0.2				
CADMIUM	MG/L	< 0.001		0.003				
CALCIUM	MG/L	2.2		30.				
CHLORIDE	MG/L	49.		11.				
CHROMIUM	MG/L	< 0.01		< 0.01				
COBALT	MG/L	< 0.05		< 0.05				
COND, IN-SITU	UMHO/CM	-		-				
CONDUCTANCE	UMHO/CM	800.		205.				
COPPER	MG/L	< 0.02		< 0.02				
CYANIDE	MG/L	-		-				
FLUORIDE	MG/L	4.6		0.2				
GROSS ALPHA	PCI/L	2.	4.00	3.	2.00			
GROSS BETA	PCI/L	-2.	5.00	1.	3.00			
IRON	MG/L	< 0.03		< 0.03				
LEAD	MG/L	< 0.01		< 0.01				
MAGNESIUM	MG/L	0.84		5.7				
MANGANESE	MG/L	< 0.01		0.02				
MERCURY	MG/L	< 0.0002		< 0.0002				
MOLYBDENUM	MG/L	< 0.01		< 0.01				
NICKEL	MG/L	0.04		< 0.04				
NITRATE	MG/L	35.		< 1.				
ORG. CARBON	MG/L	1.		3.				
PB-210	PCI/L	0.2	0.60	-0.2	0.60			
PH	SU	8.79 **		7.49				
PHOSPHATE	MG/L	-		-				
PO-210	PCI/L	-0.1	0.30	0.	0.30			
POTASSIUM	MG/L	0.8		1.1				
RA-226	PCI/L	-0.1	0.20	0.3	0.20			
RA-228	PCI/L	-0.5	0.80	-0.1	0.80			
SELENIUM	MG/L	< 0.005		< 0.005				
SILCON	MG/L	-		-				
SILICA	MG/L	-		-				
SILVER	MG/L	< 0.01		< 0.01				
SODIUM	MG/L	230.		12.				
STRONTIUM	MG/L	0.2		0.4				
SULFATE	MG/L	150.		19.				
SULFIDE	MG/L	< 0.1		< 0.1				
TEMP, IN-SITU	C-DEGREE	-		-				
TEMPERATURE	C - DEGREE	15.		16.				
TH-230	PCI/L	0.	0.10	-0.1	0.10			
TIN	MG/L	< 0.5		< 0.5				

Table B.2.6 Chemical analyses of background ground-water samples (concluded)

		LOCATION ID - SAMPLE ID AND LOG DATE				
		971-01 07/23/85	972-01 07/23/85			
PARAMETER	UNIT OF MEASURE	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY			
TOTAL SOLIDS	MG/L	600.	140.			
TOX	MG/L	-	-			
U-234	PCI/L	-	-			
U-238	PCI/L	-	-			
URANIUM	MG/L	0.004	0.004			
VANADIUM	MG/L	< 0.01	< 0.01			
ZINC	MG/L	< 0.005	0.005			

MAPPER INPUT FILE: TUB01*UDPGWQ100287

* = Concentration exceeds EPA primary drinking water standards.
** = Concentration exceeds EPA secondary drinking water standards.
<X.XX = Concentration less than detection limit.
--- = Not analyzed
\+ = Uranium concentration greater than interim EPA advisory level of 0.015 mg/L.

Table B.2.7 Chemical analyses of contaminated ground-water samples

PARAMETER	UNIT OF MEASURE	906-01 01/05/85 PARAMETER VALUE	+/-UNCERTAINTY	906-01 03/31/85 PARAMETER VALUE	+/-UNCERTAINTY	906-01 07/25/85 PARAMETER VALUE	+/-UNCERTAINTY	907-01 01/05/85 PARAMETER VALUE	+/-UNCERTAINTY	907-01 03/30/85 PARAMETER VALUE	+/-UNCERTAINTY
ALKALINITY	MG/L CACO3	691.		857.		901.		625.		1151.	
ALUMINUM	MG/L	< 0.1		< 0.1		-		< 0.1		< 0.1	
AMMONIUM	MG/L	1.3		0.5		0.1		138.		250.	
ANTIMONY	MG/L	< 0.003		< 0.003		-		< 0.003		< 0.003	
ARSENIC	MG/L	< 0.01		< 0.01		< 0.01		< 0.01		< 0.01	
BARIUM	MG/L	< 0.1		< 0.1		0.1		< 0.1		< 0.1	
BORON	MG/L	0.06		0.3		0.3		0.14		0.4	
CADMIUM	MG/L	< 0.001		< 0.03		0.012 *		0.002		0.031 *	
CALCIUM	MG/L	580.		760.		810.		350.		540.	
CHLORIDE	MG/L	74.		100.		140.		60.		110.	
CHROMIUM	MG/L	< 0.01		0.03		0.02		< 0.01		0.03	
COBALT	MG/L	< 0.05		< 0.05		< 0.05		0.15		0.22	
COND, IN-SITU	UMHO/CM	-		3950.		-		-		6000.	
CONDUCTANCE	UMHO/CM	4390.		-		4600.		4380.		-	
COPPER	MG/L	< 0.02		0.03		0.02		< 0.02		0.03	
CYANIDE	MG/L	-		< 0.01		-		-		< 0.01	
FLUORIDE	MG/L	0.15		0.1		0.1		0.23		0.2	
GROSS ALPHA	PCI/L	-		< 20. *	4.00	860. *	350.00	-		< 120. *	24.00
GROSS BETA	PCI/L	-		64. *	4.00	120. *	460.00	-		87. *	8.00
IRON	MG/L	< 0.03		0.06		0.04		1.14 **		0.57 **	
LEAD	MG/L	< 0.01		< 0.01		< 0.01		< 0.01		< 0.01	
MAGNESIUM	MG/L	210.		260.		310.		246.		460.	
MANGANESE	MG/L	0.15 **		0.15 **		0.13 **		2.02 **		2.4 **	
MERCURY	MG/L	< 0.0002		< 0.0002		0.0002		< 0.0002		< 0.0002	
MOLYBDENUM	MG/L	< 0.01		0.07		0.21		< 0.01		0.02	
NICKEL	MG/L	< 0.04		0.16		0.17		0.08		0.26	
NITRATE	MG/L	580. *		920. *		1000. *		630. *		1400. *	
NITRITE	MG/L	-		-		-		-		-	
ORG. CARBON	MG/L	6.		7.		2.		3.5		20.	
PB-210	PCI/L	< 1.5		0.7	0.90	0.3	0.80	< 1.5		1.	0.80
PH	SU	6.63		6.47 **		6.19 **		6.69		6.39 **	
PHOSPHATE	MG/L	< 0.15		< 0.1		-		< 0.15		< 0.1	
PO-210	PCI/L	< 1.		0.1	0.20	-0.1	0.30	< 1.		-0.2	0.40
POTASSIUM	MG/L	5.29		5.9		5.4		26.2		30.	
RA-226	PCI/L	< 1.		0.2	0.40	0.2	0.20	< 1.		0.3	0.40
RA-228	PCI/L	< 1.		-0.3	1.10	-0.1	0.90	< 1.		0.3	0.70
SELENIUM	MG/L	0.015 *		0.027 *		0.039 *		0.012 *		0.024 *	
SILCON	MG/L	8.6		-		-		12.4		-	
SILICA	MG/L	-		19.		-		-		24.	
SILVER	MG/L	< 0.01		0.02		0.01		< 0.01		0.02	
SODIUM	MG/L	135.		200.		210.		236.		450.	
STRONTIUM	MG/L	4.43		7.9		8.4		2.6		5.5	
SULFATE	MG/L	1200. **		1800. **		1500. **		1300. **		2500. **	
SULFIDE	MG/L	-		< 0.1		< 0.1		-		< 0.1	
TEMP, IN-SITU	C-DEGREE	-		15.		-		-		14.	
TEMPERATURE	C - DEGREE	13.		-		18.		13.		-	
TH-230	PCI/L	< 1.		0.	0.10	-0.1	0.10	< 1.		0.	0.10

Table B.2.7 Chemical analyses of contaminated ground-water samples (continued)

PARAMETER	UNIT OF MEASURE	906-01 01/05/85 PARAMETER VALUE+/-UNCERTAINTY	906-01 03/31/85 PARAMETER VALUE+/-UNCERTAINTY	906-01 07/25/85 PARAMETER VALUE+/-UNCERTAINTY	907-01 01/05/85 PARAMETER VALUE+/-UNCERTAINTY	907-01 03/30/85 PARAMETER VALUE+/-UNCERTAINTY
TIN	MG/L	< 0.005	< 0.05	< 0.5	< 0.005	< 0.05
TOTAL SOLIDS	MG/L	3820. **	5000. **	5100. **	3660. **	6200. **
TOX	MG/L	-	< 0.1	-	-	< 0.1
U-234	PCI/L	122. +	-	-	41. +	-
U-238	PCI/L	95. +	-	-	22. +	-
URANIUM	MG/L	-	1. +	2.4 +	-	0.21 +
VANADIUM	MG/L	0.01	< 0.01	0.01	0.04	< 0.01
ZINC	MG/L	0.211	0.11	0.068	0.078	0.1

Table B.2.7 Chemical analyses of contaminated ground-water samples (continued)

PARAMETER	UNIT OF MEASURE	907-01 07/26/85 PARAMETER VALUE+/-UNCERTAINTY		908-01 04/29/85 PARAMETER VALUE+/-UNCERTAINTY		908-01 03/29/85 PARAMETER VALUE+/-UNCERTAINTY		908-01 07/25/85 PARAMETER VALUE+/-UNCERTAINTY		908-01 04/03/86 PARAMETER VALUE+/-UNCERTAINTY	
ALKALINITY	MG/L CACO3	1292.		1105.		1243.		1059.		1025.	
ALUMINUM	MG/L	-		< 0.1		< 0.1		-		-	
AMMONIUM	MG/L	290.		89.		110.		98.		96.	
ANTIMONY	MG/L	-		< 0.003		< 0.003		-		-	
ARSENIC	MG/L	< 0.01		< 0.01		< 0.01		< 0.01		-	
BARIUM	MG/L	< 0.1		< 0.1		< 0.1		< 0.1		-	
BORON	MG/L	0.2		0.15		0.3		0.2		-	
CADMIUM	MG/L	0.013	*	< 0.001		0.036	*	0.014	*	< 0.001	
CALCIUM	MG/L	610.		537.		540.		530.		545.	
CHLORIDE	MG/L	170.		120.		120.		130.		53.	
CHROMIUM	MG/L	0.03		< 0.01		0.04		0.04		0.06	*
COBALT	MG/L	0.15		< 0.05		0.08		< 0.05		-	
COND, IN-SITU	UMHO/CM	-		-		6000.		-		-	
CONDUCTANCE	UMHO/CM	6500.		8590.		-		6500.		5500.	
COPPER	MG/L	0.02		< 0.02		0.02		0.02		-	
CYANIDE	MG/L	-		-		< 0.01		-		-	
FLUORIDE	MG/L	0.2		0.16		< 0.1		0.1		-	
GROSS ALPHA	PCI/L	210.	*100.00	-		< 120.	* 25.00	170.	*100.00	-	
GROSS BETA	PCI/L	-2.	* 94.00	-		76.	* 7.00	-18.	* 94.00	-	
IRON	MG/L	0.55	**	< 0.03		0.05		0.04		-	
LEAD	MG/L	< 0.01		< 0.01		< 0.01		< 0.01		-	
MAGNESIUM	MG/L	540.		817.		710.		790.		723.	
MANGANESE	MG/L	0.92	**	0.29	**	0.33	**	0.3	**	-	
MERCURY	MG/L	0.0002		< 0.0002		< 0.0002		0.0002		-	
MOLYBDENUM	MG/L	< 0.01		< 0.01		< 0.01		< 0.01		0.14	
NICKEL	MG/L	0.19		< 0.04		0.19		0.18		-	
NITRATE	MG/L	1800.	*	1300.	*	1300.	*	1300.	*	290.	*
NITRITE	MG/L	-		-		-		-		< 0.1	
ORG. CARBON	MG/L	3.		-		4.		3.		-	
PB-210	PCI/L	0.7	0.80	< 1.5		0.9	0.90	0.6	0.90	-	
PH	SU	6.28	**	6.94		6.37	**	6.33	**	6.41	**
PHOSPHATE	MG/L	-		< 0.15		< 0.1		-		-	
PO-210	PCI/L	-0.1	0.30	< 1.		0.	0.20	-0.1	0.40	-	
POTASSIUM	MG/L	30.		21.1		21.		19.		26.1	
RA-226	PCI/L	0.1	0.20	< 1.		2.	0.50	0.1	0.20	-	
RA-228	PCI/L	0.2	0.80	< 1.		0.1	0.80	0.8	0.80	-	
SELENIUM	MG/L	0.021	*	0.04	*	0.058	*	0.066	*	< 0.005	
SILICON	MG/L	-		12.4		-		-		-	
SILICA	MG/L	-		-		26.		-		-	
SILVER	MG/L	0.01		< 0.01		0.02		0.01		-	
SODIUM	MG/L	480.		585.		580.		500.		440.	
STRONTIUM	MG/L	6.4		5.6		5.5		5.6		-	
SULFATE	MG/L	2600.	**	3900.	**	3900.	**	3600.	**	4010.	**
SULFIDE	MG/L	< 0.1		-		< 0.1		< 0.1		-	
TEMP, IN-SITU	C-DEGREE	-		-		12.5		-		-	
TEMPERATURE	C DEGREE	16.		10.9		-		17.		16.	
TH-230	PCI/L	0.1	0.2	< 1.		0.	0.10	0.	0.10		

Table B.2.7 Chemical analyses of contaminated ground-water samples (continued)

		LOCATION ID - SAMPLE ID AND LOG DATE				
		907-01 07/26/85	908-01 01/29/85	908-01 03/29/85	908-01 07/25/85	908-01 04/03/86
PARAMETER	UNIT OF MEASURE	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY
TIN	MG/L	< 0.5	< 0.005	< 0.05	< 0.5	-
TOTAL SOLIDS	MG/L	7000. **	8550. **	8200. **	8000. **	8350. **
TOX	MG/L	-	-	< 0.1	-	-
U-234	PCI/L	-	70. +	-	-	-
U-238	PCI/L	-	37. +	-	-	-
URANIUM	MG/L	0.26 +	-	0.19 +	0.21 +	0.127 +
VANADIUM	MG/L	< 0.01	0.02	< 0.01	< 0.01	-
ZINC	MG/L	0.081	0.111	0.066	0.039	-

Table B.2.7 Chemical analyses of contaminated ground-water samples (continued)

PARAMETER	UNIT OF MEASURE	909-01 04/04/85 PARAMETER VALUE	+/-UNCERTAINTY	909-01 03/29/85 PARAMETER VALUE	+/-UNCERTAINTY	909-01 07/24/85 PARAMETER VALUE	+/-UNCERTAINTY	912-01 08/29/85 PARAMETER VALUE	+/-UNCERTAINTY	912-01 04/11/86 PARAMETER VALUE	+/-UNCERTAINTY
ALKALINITY	MG/L CACO3	331.		347.		315.		250.		238.	
ALUMINUM	MG/L	< 0.1		0.2		-		0.4		-	
AMMONIUM	MG/L	0.2		0.2		0.4		< 0.1		0.3	
ANTIMONY	MG/L	< 0.003		< 0.003		-		-		-	
ARSENIC	MG/L	< 0.01		< 0.01		< 0.01		-		-	
BARIUM	MG/L	< 0.1		< 0.1		0.1		-		-	
BORON	MG/L	0.09		0.4		0.2		0.4		-	
CADMIUM	MG/L	< 0.001		0.033 *		0.01		< 0.001		0.003	
CALCIUM	MG/L	840.		800.		790.		224.		217.	
CHLORIDE	MG/L	216.		200.		240.		27.		30.	
CHROMIUM	MG/L	< 0.01		0.03		0.02		< 0.01		0.03	
COBALT	MG/L	< 0.05		0.06		0.05		< 0.05		-	
COND, IN-SITU	UMHO/CM	-		3500.		-		-		-	
CONDUCTANCE	UMHO/CM	4890.		-		3800.		1200.		700.	
COPPER	MG/L	< 0.02		0.03		< 0.02		0.04		-	
CYANIDE	MG/L	-		< 0.01		-		< 0.01		-	
FLUORIDE	MG/L	< 0.01		< 0.1		0.1		-		-	
GROSS ALPHA	PCI/L	-		< 70. *	22.00	43. *	28.00	-		-	
GROSS BETA	PCI/L	-		26.	3.00	18.	27.00	-		-	
IRON	MG/L	1.96 **		0.06		0.04		0.05		-	
LEAD	MG/L	< 0.01		< 0.01		< 0.01		-		-	
MAGNESIUM	MG/L	169.		160.		160.		45.1		48.2	
MANGANESE	MG/L	0.09 **		0.07 **		0.05		0.11 **		-	
MERCURY	MG/L	< 0.0002		< 0.0002		0.0002		-		-	
MOLYBDENUM	MG/L	< 0.01		< 0.01		< 0.01		0.08 *		0.23	
NICKEL	MG/L	< 0.04		0.18		0.16		0.09		-	
NITRATE	MG/L	1100. *		1100. *		970. *		170. *		64. *	
NITRITE	MG/L	-		-		-		< 0.01		< 0.1	
ORG. CARBON	MG/L	1.4		1.		2.		-		-	
PB-210	PCI/L	< 1.5		0.9	0.80	0.1	0.80	-		-	
PH	SU	6.67		6.66		6.34 **		7.01		6.76	
PHOSPHATE	MG/L	< 0.15		< 0.1		-		-		-	
PO-210	PCI/L	< 1.		0.	0.30	-0.1	0.30	-		-	
POTASSIUM	MG/L	6.04		5.5		4.7		3.64		4.16	
RA-226	PCI/L	< 1.		0.1	0.40	0.5	0.20	-		-	
RA-228	PCI/L	< 1.		0.9	0.80	0.3	0.80	-		-	
SELENIUM	MG/L	0.006		0.005		0.013 *		< 0.005		< 0.005	
SILCON	MG/L	9.7		-		-		-		-	
SILICA	MG/L	-		18.		-		12.		-	
SILVER	MG/L	< 0.01		0.01		0.01		< 0.01		-	
SODIUM	MG/L	164.		160.		170.		48.		39.3	
STRONTIUM	MG/L	6.96		7.9		8.6		< 0.1		-	
SULFATE	MG/L	1400. **		1600. **		1400. **		407. **		439. **	
SULFIDE	MG/L			< 0.1		< 0.1		-		-	
TEMP, IN-SITU	C DEGREE	-		14.5		-		-		-	
TEMPERATURE	C DEGREE	13.		-		17.		18.		17.	
TH-230	PCI/L	< 1.		[illegible]	0.40	[illegible]	0.10				

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Table B.2.7 Chemical analyses of contaminated ground-water samples (concluded)

		LOCATION ID - SAMPLE ID AND LOG DATE				
		909-01 01/04/85	909-01 03/29/85	909-01 07/24/85	912-01 08/29/85	912-01 04/11/86
PARAMETER	UNIT OF MEASURE	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY
TIN	MG/L	0.007	< 0.05	< 0.5	-	-
TOTAL SOLIDS	MG/L	4470. **	4600. **	4000. **	1360. **	1340. **
TOX	MG/L	-	0.9	-	-	-
U-234	PCI/L	48. +	-	-	-	-
U-238	PCI/L	22. +	-	-	-	-
URANIUM	MG/L	-	0.088 +	0.072 +	0.018 +	0.0212 +
VANADIUM	MG/L	0.02	< 0.01	< 0.01	-	-
ZINC	MG/L	0.05	0.051	0.035	0.014	-

MAPPER INPUT FILE: TUB01*UDPGWQ100290

* = Concentration exceeds EPA primary drinking water standards.
** = Concentration exceeds EPA secondary drinking water standards.
<X.XX = Concentration less than detection limit.
--- = Not analyzed.
\+ = Uranium concentration greater than interim EPA advisory level of 0.015 mg/L.

Table B.2.8 Summary of background ground-water quality[a]

Constituent	Observed concentration range[b]	Number of analyses	Mean concentration[b]	Two standard deviations[b]	Statistical concentration range[c]
Sodium	7.3-230	32	40.4	83.2	0-123
Potassium	0.8-10.7	30	2.53	2.4	0.1-4.9
Magnesium	0.08-12.0	32	5.59	6.0	0-11.6
Calcium	0.62-51.2	32	25.9	25.4	0.5-51.2
Ammonium	ND-0.8	31	ND	0.32	0.39
Chloride	6.0-87.0	31	21.2	45.8	0-67.0
Sulfate	6.0-160	31	40.3	78.4	0-119
Nitrate	ND-34	31	11.1	19.1	0-28[d]
Alkalinity (as $CaCO_3$)	72-292	32	109	79.2	29.8-188
Aluminum	ND-0.60	16	0.4	0.38	0-0.52
Manganese	ND-0.10	22	0.01	0.05	0-0.06
Iron	ND-0.17	22	ND	0.09	0-0.11
Nickel	ND-0.06	20	ND	0.02	0-0.04
Arsenic	ND-0.02	22	ND	0.01	0-0.01
Barium	ND-0.2	18	ND	0.15	0-0.20[d]
Cadmium	ND-0.004	32	0.001	0.003	0-0.003
Chromium	ND-0.05	32	0.01	0.03	0-0.03[d]
Molybdenum	ND-0.24	29	0.08	0.18	0-0.24[d]
Lead	ND-0.02	18	ND	0.009	0-0.01
Selenium	ND-0.018	32	0.001	0.007	0-0.008
Uranium	0.001-0.018	30	0.004	0.005	0-0.009
pH (S.U.)	7.2-9.75	25			
Gross alpha	ND-10.0	13	3.4	6.2	0-9.7
Gross beta	ND-11.0	13	2.3	5.7	0-8.0
TDS	80-600	31	222	216	6-438

[a]All constituent concentrations are expressed in milligrams per liter except pH which is expressed in standard units (S.U.); ND - not detected.
[b]Calculated from all background samples.
[c]Mean $\pm$ two standard deviations.
[d]Highest observed concentration used in range instead of mean plus two standard deviations.

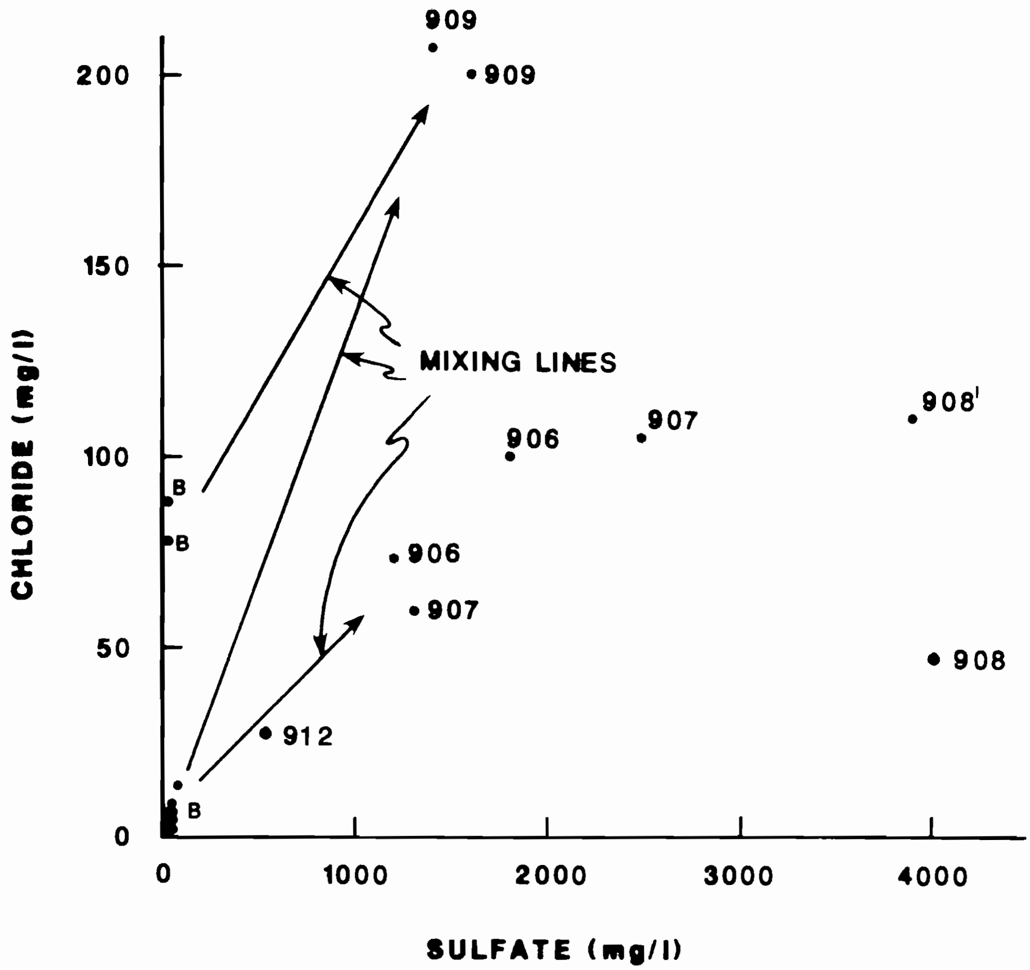
Wells numbered 779, 901, 910, 970, 971, and 972 are unaffected by contaminants emanating from the pile because they are far crossgradient or upgradient of the site. Well number 779 is in Tuba City and wells 901, 910, 970, 971, and 972 are more than 2500 feet north of the site. Although monitor wells numbered 902, 903, 904, 914, 917, 920, 921, and the spring are downgradient of the site, they are unaffected by the pile and also represent background water quality.

The differences between background and contaminated samples can be seen by comparing Table B.2.8 with Table B.2.9, which summarizes the quality of the contaminated samples. Concentrations of the major contaminants (i.e., sodium, potassium, magnesium, calcium, nitrate, alkalinity, sulfate, selenium, cadmium, and uranium) are significantly higher in the contaminated samples than in the background samples. The differences between background and contaminated samples are also seen in bivariate plots, Figures B.2.6 through B.2.8. The background samples are narrowly distributed and do not infringe on the area of the plots occupied by the contaminated samples. If any of these samples were affected by the tailings, they would either plot in the area occupied by contaminated samples or plot along mixing lines between the two sample types. An equal mixture of background and contaminated waters would plot halfway between the areas occupied by the two sample types. Based on the data distribution on the bivariate plots, none of these background samples have been affected by the pile.

Table B.2.9 Summary of contaminated ground-water quality[a]

Constituent	Number of analyses	Minimum	Maximum	Average
Sodium	15	48	585	299
Potassium	15	3.64	30.0	14.3
Magnesium	15	45.1	817	377
Calcium	15	217	840	578
Ammonium	15	ND	290.0	71.6
Chloride	15	27	240	119
Sulfate	15	407	4010	2100
Nitrate	15	64	1800	928
Alkalinity (as $CaCO_3$)	15	238	1290	762
Aluminum	9	ND	0.40	0.1
Manganese	13	0.05	2.4	0.54
Iron	13	ND	1.96	0.35
Nickel	13	ND	0.26	0.13
Arsenic	12	ND	ND	--
Barium	12	ND	0.1	ND
Cadmium	15	ND	0.036	0.011
Chromium	15	ND	0.06	0.02
Molybdenum	15	ND	0.23	0.05
Lead	12	ND	ND	--
Selenium	15	ND	0.066	0.022
Uranium	15	0.018	2.4	0.42
pH (S.U.)	15	6.19	7.01	--
Gross alpha	8	10	860	181
Gross beta	8	ND	120	46.4
TDS	15	1340	8550	5310

[a]All constituents are expressed in milligrams per liter except pH which is expressed in standard units (S.U.); ND - not detected; -- = not analyzed.

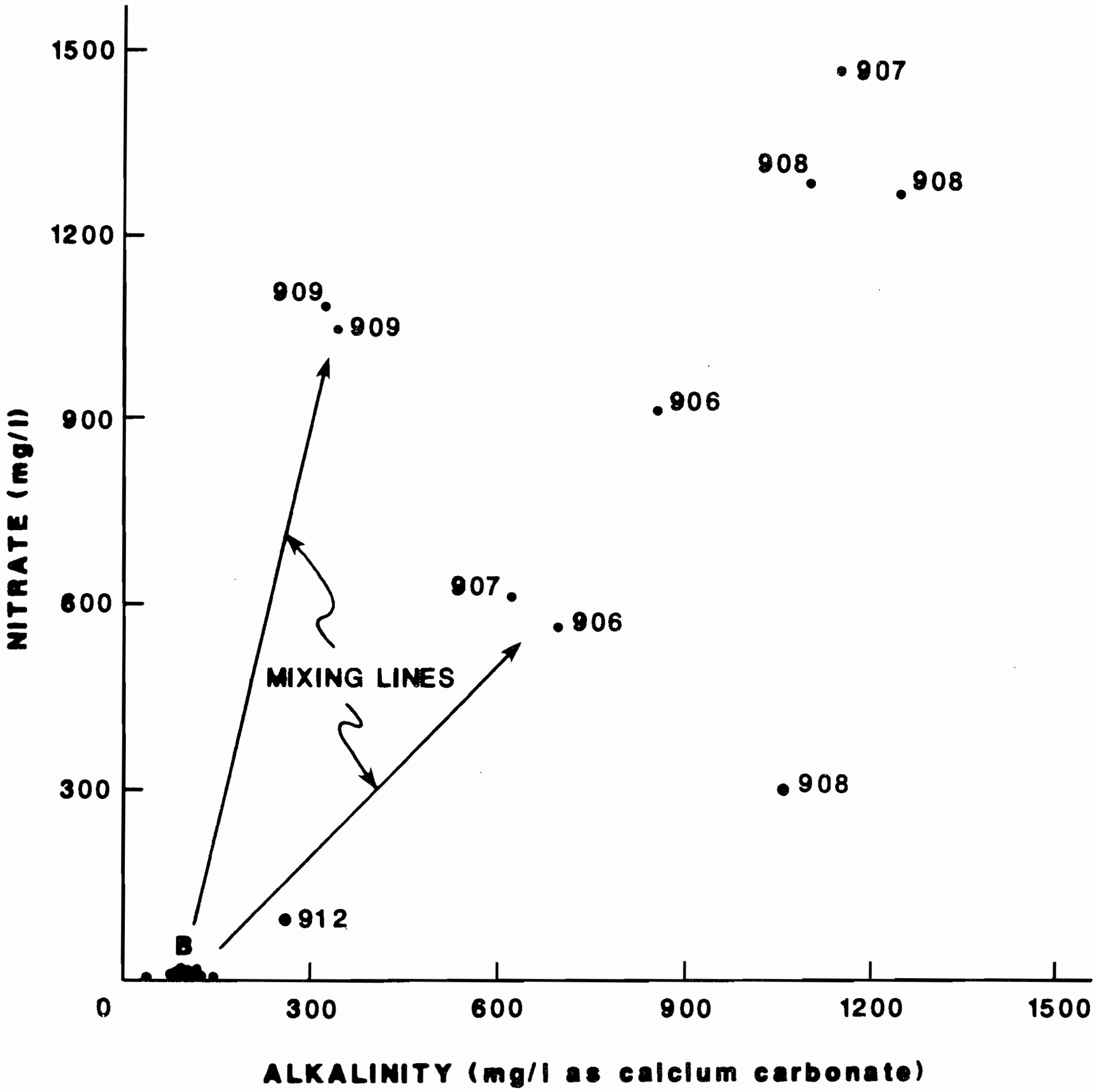


NOTES: 1. TWO SAMPLES, DIFFERENT DATES, IDENTICAL VALUES.

2. B INDICATES BACKGROUND SAMPLES.

3. INFORMATION FROM WATER SAMPLES TAKEN JANUARY AND MARCH 1985.

FIGURE B.2.6
BIVARIATE PLOT - CHLORIDE vs. SULFATE



NOTES: 1. B INDICATES BACKGROUND SAMPLES.

2. INFORMATION FROM WATER SAMPLES TAKEN JANUARY AND MARCH, 1985.

FIGURE B.2.7
BIVARIATE PLOT - NITRATE vs. ALKALINITY

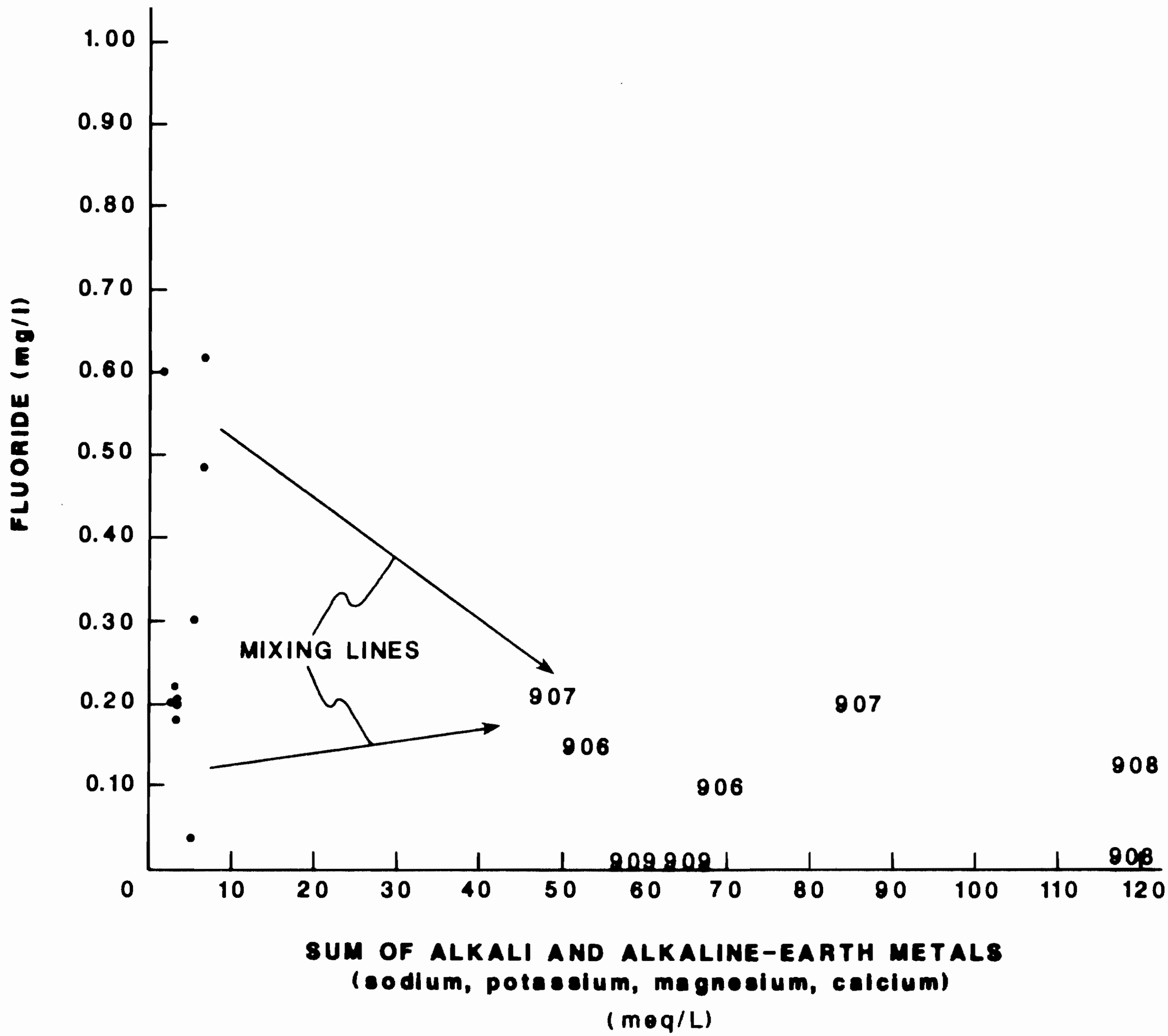


FIGURE B.2.8
BIVARIATE PLOT - FLUORIDE vs. SUM OF ALKALI & ALKALINE-EARTH METALS

The background samples show that the uncontaminated ground water in the N-aquifer is potable. Most of the samples are $Ca-HCO_3$ or $Na-HCO_3$ type waters and all of them are fresh, with an average total dissolved solids content of 240 milligrams per liter. Most are slightly alkaline, with pHs ranging from seven to eight, but four are very alkaline with pH's as high as 9.75 (locations numbered 902, 904, 921, and 971). The cause of these higher pHs is not known.

In addition to the high pHs, the Secondary Drinking Water Standards for other constituents are exceeded in a few instances. A sample from well 901 exceeded the secondary standard for manganese by a factor of two. A sample from well 971 exceeded the secondary standard for fluoride and total dissolved solids by a factor of 1.2. The EPA Primary Drinking Water Standard for selenium was exceeded in well 904 by a factor of 1.8. Secondary standards are based on aesthetic considerations while primary standards are based on health considerations (Table B.1.2) (EPA, 1982). The State of Arizona's drinking water standards are the same as the EPA standards.

B.2.3.2 The tailings pile and ground-water contamination

The tailings pile is composed of interbedded slimes and sands. The slimes are 90 to 100 percent saturated and the sands are 40 to 60 percent saturated with tailings pore solution. The eastern portion of the pile was deposited while a sulfuric acid process was used to extract the uranium. Ammonium hydroxide and nitric acid were used as resin strippers in the acid process. The western portion of the pile was deposited while a carbonate process was used. These tailings also contain stringers of acidified tailings which are due to the acid leaching of sulfide flotation concentrations (Lewis, 1985; Merritt, 1971). The ponds associated with the tailings pile (Figures B.2.1 and B.2.9) are not raffinate ponds. They were built to capture any slurry that might escape from the pile while the mill was operating (Lewis, 1985). The ponds presently contain some windblown tailings but little, if any, slurried tailings.

Water extracts of tailings samples (Table B.2.10; GECR, 1983) and samples of tailings pore solution taken through suction lysimeters (Tables B.2.11, B.2.12, and B.2.13) show that the tailings contain high concentrations of metals and reagents used in the milling process. These metals and reagents have been leached to the water table and a contaminant plume containing elevated concentrations of cadmium, chromium, molybdenum, selenium, uranium, nitrate, iron, manganese, boron, copper, nickel, zinc, sodium, potassium, magnesium, calcium, strontium, ammonium, chloride, sulfate, and bicarbonate extends at least 1300 feet downgradient from the pile. This lower limit is based on

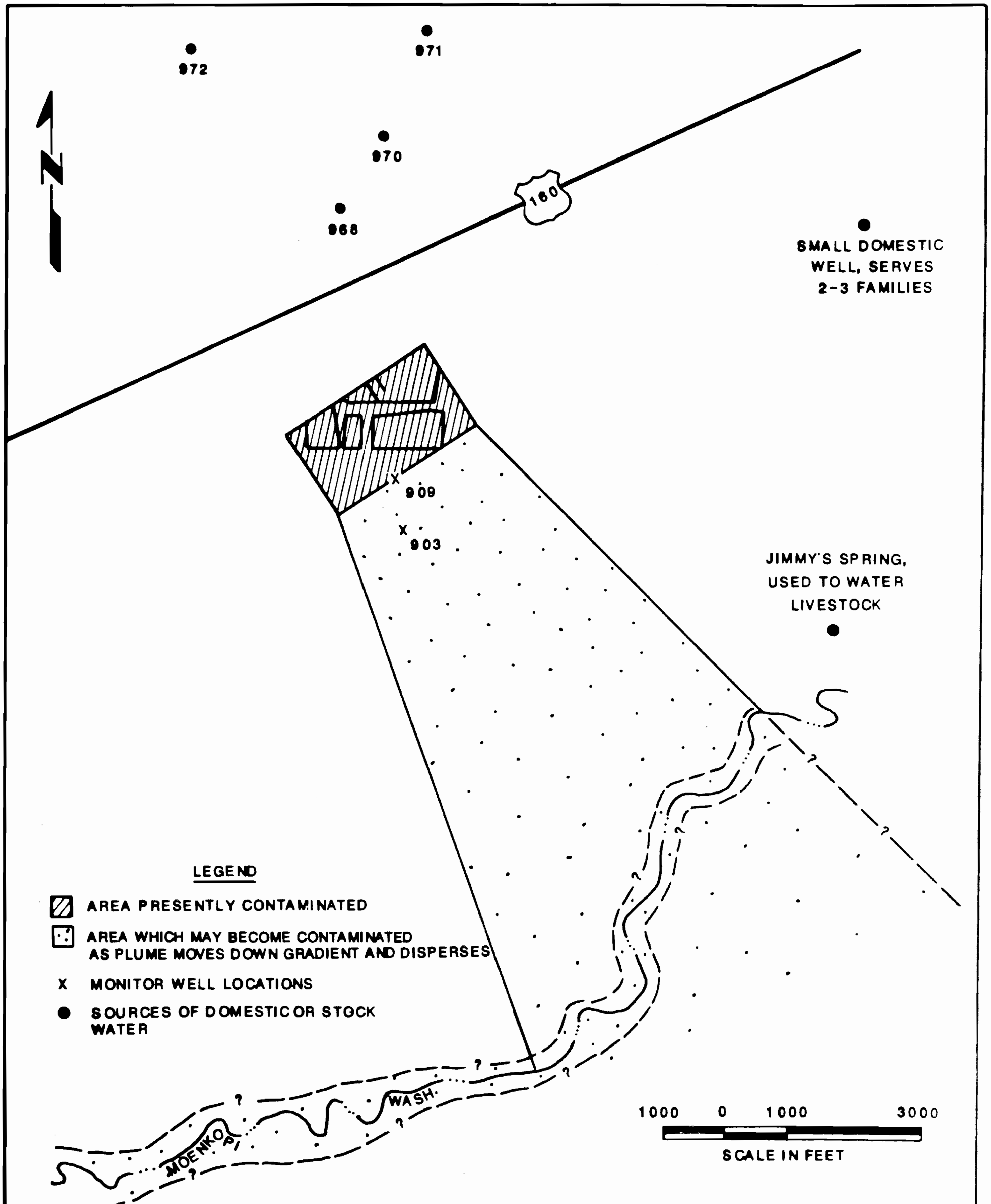


FIGURE B.2.9
AREA PRESENTLY CONTAMINATED AND AREA WHICH MAY BECOME CONTAMINATED

Table B.2.10 Constituents found in water extracts of the Tuba City tailings[a]

Constituents	Acid tailings Minimum	Acid tailings Maximum	Acid tailings Average	Alkaline tailings Minimum	Alkaline tailings Maximum	Alkaline tailings Average
Sodium	ND	1810	346	482	9050	4160
Potassium	ND	266	69.1	21.9	381	120
Magnesium	33.3	2620	806	ND	85	12.1
Calcium	2410	18200	12900	40.5	2190	424
Chloride	86.5	334	199	154	739	412
Sulfate	5560	69400	42800	ND	7620	3320
Aluminum	18.0	1210	382	1.5	577	146
Manganese	ND	573	168	ND	ND	--
Iron	4.58	2740	315	ND	116	38.2
Nickel	3.75	491	109	ND	14.2	6.5
Arsenic	ND	34.6	5.25	8.33	238	134
Barium	0.833	25.5	5.79	115	585	322
Cadmium	ND	11.7	2.28	ND	ND	--
Chromium	ND	2.08	0.11	ND	1.21	0.17
Molybdenum	ND	12.3	1.14	1.32	233.0	78.6
Lead	ND	62.1	15.6	ND	13.3	4.92
Selenium	ND	ND	--	ND	0.5	0.17
Uranium	0.22	66.0	16.2	1.0	1370.0	313.0
pH (S.U.)	2.9	4.2	--	8.4	10.6	--

[a]Concentrations for acid tailings were based on the analysis of 19 samples (GECR 76.05-76.19, 77.01-77.29); concentrations for alkaline tailings were based on the analysis of seven samples (GECR 71.01-71.07, 74.01-74.04); all constituents are expressed in micrograms per gram except pH which is expressed in standard units (S.U.); ND = not detected; -- = not analyzed.

Ref. GECR, 1983.

Table B.2.11 Suction lysimeter depths

Eastern nest Lysimeter ID	Eastern nest Depth (ft)	Western nest Lysimeter ID	Western nest Depth (ft)
682	5	666	5
680	10	664	10
679	15	661	20
677	20		
676	25		
673	35		

Table B.2.12 Chemical analyses of suction lysimeter samples

		LOCATION ID - SAMPLE ID AND LOG DATE				
		661-01 04/11/86	664-01 04/11/86	666-01 04/11/86	673-01 04/11/86	676-01 04/11/86
PARAMETER	UNIT OF MEASURE	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY
ALKALINITY	MG/L CACO3	-	0.	-	-	-
ALUMINUM	MG/L	-	42.9	-	-	-
AMMONIUM	MG/L	220.	< 0.1	< 0.1	-	-
ARSENIC	MG/L	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
CALCIUM	MG/L	519.	457.	534.	565.	478.
CHLORIDE	MG/L	-	150.	120.	-	-
CONDUCTANCE	UMHO/CM	3400.	3900.	2800.	-	-
FLUORIDE	MG/L	-	-	-	-	-
GROSS ALPHA	PCI/L	-	-	-	-	-
GROSS BETA	PCI/L	-	-	-	-	-
IRON	MG/L	-	1600.	-	-	-
MAGNESIUM	MG/L	1040.	182.	36.7	1280.	1620.
MANGANESE	MG/L	-	9.82	-	-	-
MOLYBDENUM	MG/L	0.19	0.1	1.46	-	-
NITRATE	MG/L	-	-	-	-	-
NITRITE	MG/L	-	-	-	-	-
PH	SU	6.	3.96	6.5	7.17	6.1
PHOSPHATE	MG/L	-	-	-	-	-
POTASSIUM	MG/L	110.	20.6	16.5	95.8	66.
SELENIUM	MG/L	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
SODIUM	MG/L	1180.	2980.	1560.	374.	267.
SULFATE	MG/L	-	15100.	1200.	-	-
TEMPERATURE	C - DEGREE	15.	15.	14.	-	-
TOTAL SOLIDS	MG/L	-	-	-	-	-
URANIUM	MG/L	0.925	43.3	30.7	2.53	0.711
ZINC	MG/L	-	-	-	-	-

Table B.2.12 Chemical analyses of suction lysimeter samples (concluded)

LOCATION ID - SAMPLE ID AND LOG DATE

PARAMETER	UNIT OF MEASURE	677-01 04/11/86 PARAMETER VALUE+/-UNCERTAINTY	679-01 04/11/86 PARAMETER VALUE+/-UNCERTAINTY	680-01 04/11/86 PARAMETER VALUE+/-UNCERTAINTY	682-01 04/11/86 PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY
ALKALINITY	MG/L CACO3	0.	0.	0.	0.	
ALUMINUM	MG/L	347.	-	354.	1390.	
AMMONIUM	MG/L	-	-	< 0.1	110.	
ARSENIC	MG/L	< 0.01	< 0.01	< 0.01	-	
CALCIUM	MG/L	475.	474.	466.	335.	
CHLORIDE	MG/L	140.	-	110.	65.	
CONDUCTANCE	UMHO/CM	4600.	-	4000.	5000.	
FLUORIDE	MG/L	-	-	-	5.	
GROSS ALPHA	PCI/L	-	-	-	95300. 2300	
GROSS BETA	PCI/L	-	-	-	36900. 600	
IRON	MG/L	1110.	-	354.	2100.	
MAGNESIUM	MG/L	2150.	955.	2250.	3180.	
MANGANESE	MG/L	89.6	-	90.3	1500.	
MOLYBDENUM	MG/L	-	-	-	5.8	
NITRATE	MG/L	-	-	-	95.	
NITRITE	MG/L	-	-	-	< 0.1	
PH	SU	3.63	3.07	2.9	2.43	
PHOSPHATE	MG/L	-	-	-	100.	
POTASSIUM	MG/L	81.3	31.2	24.	18.6	
SELENIUM	MG/L	< 0.005	< 0.005	< 0.005	-	
SODIUM	MG/L	298.	165.	164.	198.	
SULFATE	MG/L	15800.	-	15600.	32800.	
TEMPERATURE	C - DEGREE	17.	-	17.	17.	
TOTAL SOLIDS	MG/L	-	-	-	51000.	
URANIUM	MG/L	4.85	2.17	7.41	54.5	
ZINC	MG/L	-	-	-	0.005	

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Table B.2.13 Statistical summary of suction lysimeter samples[a]

Constituent	Number of analyses	Minimum	Maximum	Average
Sodium	9	164	2980	798
Potassium	9	16.5	110	51.6
Magnesium	9	36.7	3180	1410
Calcium	9	335	565	478
Ammonium	5	ND	220	66.0
Chloride	5	65	150	117
Sulfate	5	4200	32,800	16,700
Conductance	6	2800	5000	3950
pH	9	2.4	7.2	3.2
Arsenic	8	ND	ND	ND
Molybdenum	4	0.10	5.80	2.64
Selenium	8	ND	ND	ND
Uranium	9	0.71	54.5	16.3

[a]Concentrations given as mg/l except pH which is expressed as standard units and conductance which is expressed as µmho's/cm; ND = not detected.

analyses of samples from well number 909. Analyses of samples from wells 903, 920, and 921 show that the plume has not yet reached them, a distance of about 2000 feet downgradient of the pile (see Figure B.2.9). The vertical extent of contamination is approximately 120 feet (Figures B.2.10 and B.2.11). The volume of contaminated ground water is approximately 1.44×10^8 ft^3 (assuming a porosity of 0.3, Figure B.2.9).

Wells numbered 906, 907, 908, 909, and 912 have been contaminated (Tables B.2.7 and B.2.9; Figures B.2.6 through B.2.9). Cadmium, selenium, gross alpha activity, and nitrate exceed the EPA Interim Primary Drinking Water Standards. Concentrations of total dissolved solids, iron, manganese, and sulfate exceed the EPA Secondary Drinking Water Standards (see Table B.1.2).

Besides the tailings pile and associated ponds, two other possible sources of contaminants are known to exist: (1) a sewage lagoon immediately north of the pile; and (2) a garbage dump approximately 0.33 mile north of the pile.

The tailings pile is the most likely source of the contaminants found in the ground water. This is because all of the identified contaminants are known to exist within the pile; are known to have been used in the milling process; or are commonly associated with uranium mill tailings. In addition, the contaminants are found only below and downgradient of the pile.

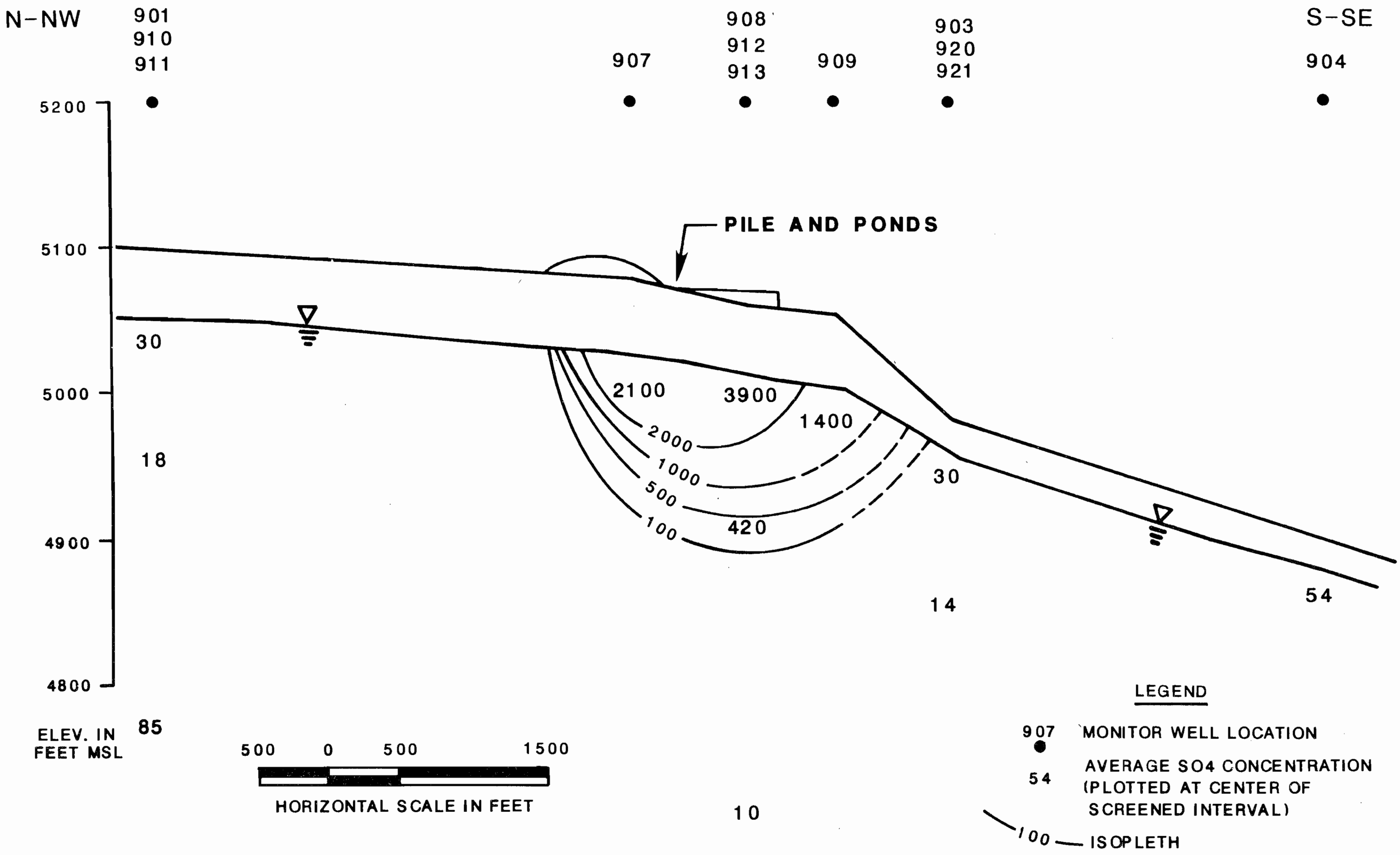


FIGURE B.2.10

VERTICAL EXTENT OF SULFATE PLUME (SO_4 CONCENTRATIONS AVERAGED FOR EACH WELL, mg/l)

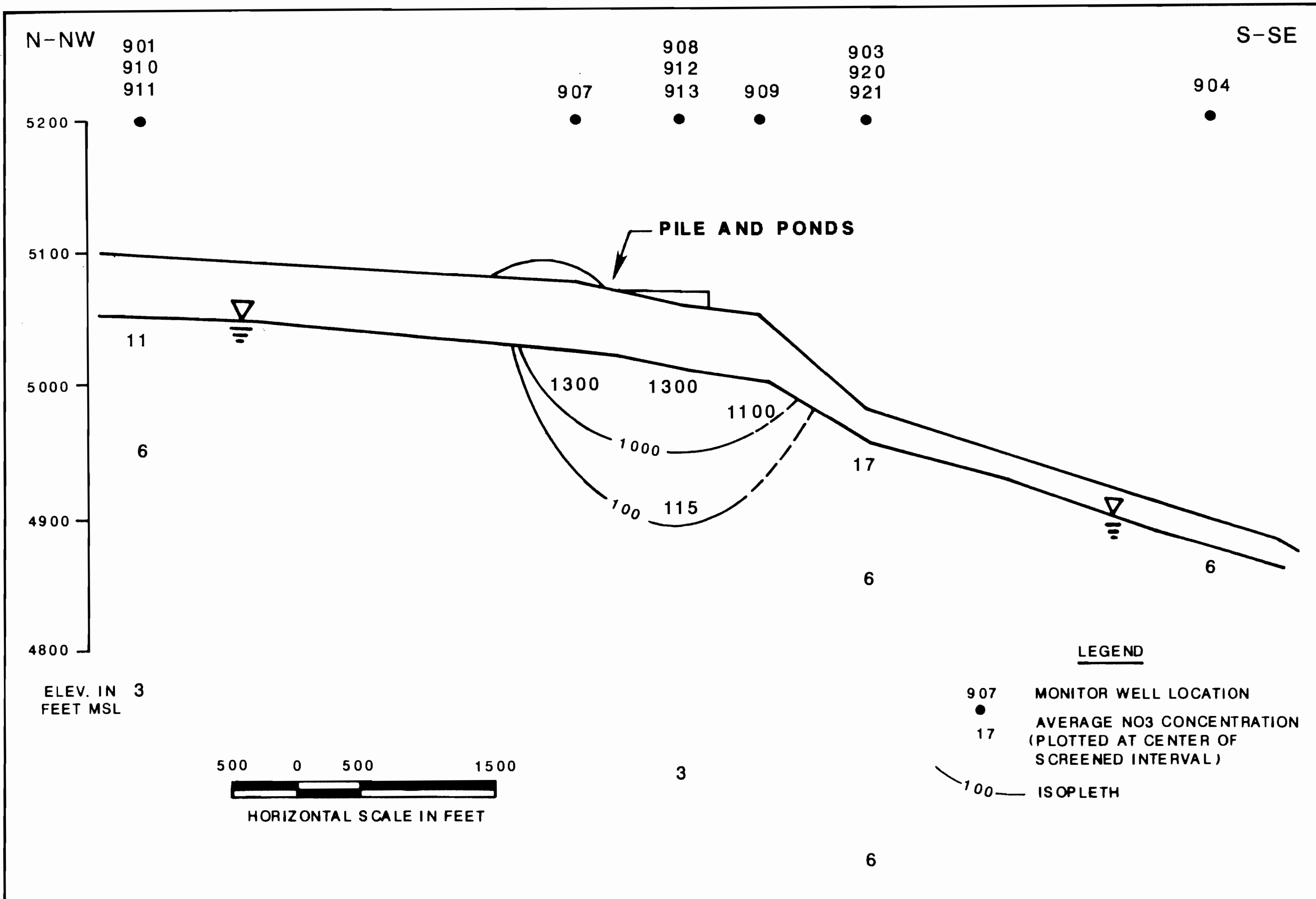


FIGURE B.2.11

VERTICAL EXTENT OF NITRATE PLUME (NO3 CONCENTRATIONS AVERAGED FOR EACH WELL, mg/l)

It is possible that some of the observed nitrate and ammonium originated in the sewage lagoon north of the site. However, this is unlikely because elevated nitrate and ammonium concentrations occur only, and always, in samples which also contain high concentrations of contaminants associated with the pile.

The ponds associated with the pile are not likely to be a significant source of contaminants because they contain only minor amounts of contaminated materials. There is no reason to attribute the observed contamination to the garbage dump. Because the pile contains high concentrations of the observed contaminants, the contamination is only known to exist beneath and downgradient of the pile, and other sources of contamination cannot be identified, it is reasonable to conclude that all, or nearly all, of the contamination is due to the pile.

Although all the contaminants probably originated in the pile, the character of water from one of the contaminated wells is markedly different from the others. This can be seen in Figures B.2.7 and B.2.8 where samples from well number 909 plot well away from the other contaminated samples. The reason for these differences is not known. It may be that the water near this well contains contaminants derived from one milling process, while the others contain contaminants derived from another.

B.2.3.3 Contaminant migration and the attenuative capacity of the aquifer

The existing contaminant plume will continue to move to the southeast. As it does, physical and chemical attenuation mechanisms will act to reduce contaminant concentrations and spread the plume through a larger volume of water. Physical attenuation is caused by molecular diffusion and mechanical dispersion. Molecular diffusion causes contaminants to move into uncontaminated water in response to concentration gradients. Diffusion is a slow process and would probably not be significant in this case.

Mechanical dispersion is due to the tortuosity of ground-water flow paths and the variation of aquifer pore sizes. These two components cause ground-water flow directions and rates to vary. As a result, some contaminants will be transported perpendicularly to the general direction of ground-water flow and others will travel more quickly or slowly than the main body of the plume. Therefore, the plume will expand in all directions and become more dilute as it moves downgradient.

The following is an analysis of the effects of dispersion of future contaminant concentrations. This analysis overestimates eventual plume boundaries because the following assumptions were used.

- The strength of the source does not diminish with time.
- The highest calculated ground-water speed (about 140 ft/year) was used to calculate hydrodynamic dispersion.
- A longitudinal dispersivity of 300 feet and a transverse (horizontal) dispersivity of 60 feet were used to calculate dispersions. According to Freeze and Cherry (1979), these values are high. Given the fact that the Navajo Sandstone is relatively homogeneous, one would expect actual dispersivities to be smaller.
- A vertical dispersivity of 0.003 foot.

The resulting plume represents the largest area over which future ground-water withdrawals might have to be restricted.

The following equation was used to estimate concentration ratios at Moenkopi Wash, approximately 9000 feet downgradient of the present plume (Domenico and Robbins, 1985).

$$C(x,y,z,t) = (C_0/8)\ \mathrm{erfc}\ [(x-vt)/2(D_x t)^{1/2}]$$
$$\{\mathrm{erf}[(y+Y/2)/2(D_y x/v)^{1/2}]-\mathrm{erf}[(y-Y/2)/2(D_y x/v)^{1/2}]\}$$
$$\{\mathrm{erf}[(z+Z/2)/2(D_z x/v)^{1/2}]-\mathrm{erf}[(z-Z/2)/2(D_z x/v)^{1/2}]\}$$

where:

$C(x,y,z,t)$ = concentration at point and time of interest.
C_0 = initial concentration = 1.
x,y,z = space coordinates. Plume axis along x = 0.
v = ground-water speed = 140 ft/year.
t = time = 123 years. The plume reaches steady state at this time.
D_x, D_y, D_z = x, y and z coefficients of dispersion = 42,000 ft^2/year, 8400 ft^2/year, and one ft^2/year, respectively.
Y = initial width of plume = 2500 feet.
Z = initial thickness of plume = 110 feet.

At Moenkopi Wash, concentration ratios shown on Table B.2.14 were calculated.

The width of the plume was determined by calculating the amount of dilution required to bring nitrate within drinking water standards. Because nitrate must be diluted by a factor of about 40, the concentration ratio at the edge of the plume must be less than 0.025. The maximum estimated extent of the plume is shown in Figure B.2.9.

The term chemical attenuation covers many processes, including: (1) neutralization of acidic and alkaline solutions; (2) mineral precipitation; (3) filtering of suspended

Table B.2.14 Concentration ratios as a function of distance from plume axis

Distance along plume axis (x, ft)	Horizontal distance from plume axis (y, ft)	Concentration ratio (c/C_0)
9000	0	0.77
9000	500	0.72
9000	1000	0.58
9000	1500	0.40
9000	2000	0.24
9000	2500	0.12
9000	3000	0.045
9000	3500	0.015
9000	4000	0.005

or colloidal solids; (4) biological decomposition of organic compounds; (5) biological denitrification of nitrate; (6) ion exchange of major cations; (7) adsorption of trace metals; (8) ion sieving by dense clay layers (ultrafiltration); and (9) decay of radioactive elements. This discussion will focus on the primary chemical processes in the N-aquifer and unsaturated systems that might affect contaminant mobility near the site. These processes are: (1) denitrification of nitrate; (2) neutralization of the pH; and (3) mineral precipitation and solute adsorption for iron, manganese, selenium, sulfate, total uranium, and total dissolved solids.

Biological denitrification is the process by which bacteria convert nitrate to nitrogen gas and water, possibly through an indirect mechanism by which nitrate is first converted to nitrite, followed by a reaction of nitrite and ammonium to produce nitrogen gas and water (Stumm and Morgan, 1970). Chemical denitrification results in the same products but may be restricted to the somewhat narrow redox range of pe + pH = 13 to 15 (Lindsay, 1979).

One of the factors that makes uranium mill tailings a source of ground-water contaminants is that the tailings pore solution is very acidic (Table B.2.13), and many contaminant solid phases are more soluble in the tailings solutions compared to ground water, which typically has a pH in the range of 6.5 to 8.5. Chemical interactions between the tailings solution and the sediment beneath the pile will tend to neutralize the pH of the tailings solution and lower the dissolved concentration of contaminants because of the formation of solid phases containing the contaminants.

Chemical interactions between the tailings solution, the soil minerals (principally the carbonates), and the alkaline, uncontaminated ground water have raised the pH values of the contaminated solution. The fact that the pH of the solution remains somewhat low (6.2 to 7.0) compared to the uncontaminated ground water suggests that carbonate minerals in the sediment contacted by the tailings have been completely consumed or are nonreactive. It is expected that as the solution contacts fresh sediment additional carbonate minerals will be available to dissolve and raise the solution pH above the drinking water lower limit of 6.5. Lithologic logs of the Navajo Sandstone show the presence of lime concretions and cement that will provide for this neutralization.

As the pH of the solution rises, the solubility of iron and manganese minerals will decrease, causing these elements to precipitate as oxides and oxyhydroxides. The solution concentration of these two metals in equilibrium with their normal soil and aquifer minerals is less than the drinking water standards for the two metals. Therefore, if equilibrium is attained for these metals and their solids, it is expected that they will no longer be present in solution at levels exceeding EPA standards.

Dissolved selenium is present in the contaminated wells at concentrations up to 0.066 milligrams per liter (mg/l). The only well in which the selenium concentration is not above the primary standard of 0.01 mg/l is well number 912. Dissolved uranium in the contaminated wells falls in the range of 0.018 to 2.4 mg/l, well above the maximum value found in the background wells of 0.018 mg/l. At the pH value of the solution expected after neutralization (seven to eight), selenium will probably be present in solution as the mobile selenite (SeO_3^{2-}) or selenate (SeO_4^{2-}) ion and the predominant uranium species will be a uranium carbonate ($UO_2(CO_3)_2^{2-}$ or $UO_2(CO_3)_3^{4-}$). These anions may be partially adsorbed onto clays and metal oxyhydroxides, but they may be fairly mobile under the oxidizing conditions expected in the aquifers. Because the selenium concentration in the contaminated ground water is within a factor of seven of the standard it is possible that chemical and physical attenuation processes will lower the selenium concentration to the standard's level. The maximum uranium concentration in the contaminated wells is two orders of magnitude higher than that in background water samples; however, the highest uranium concentration is in well number 906 directly beneath the pile. In wells numbered 908 and 909 off the pile the uranium concentration is five to 10 times less than that in well number 906. It is possible that chemical attenuation will significantly lower total uranium concentration as the ground water moves away from the pile.

Sulfate concentrations in the five contaminated wells range from 407 to 4010 milligrams per liter. Its concentration may be limited by the precipitation of gypsum

($CaSO_4 \cdot 2H_2O$) if calcium is provided by the dissolution of calcite. However, gypsum is fairly soluble. Sulfate concentration in equilibrium with gypsum, and a reasonable upper limit for dissolved calcium of 500 milligrams per liter, would be on the order of 2000 milligrams per liter, eight times the EPA secondary standard for drinking water.

The TDS content of the contaminated wells is in the range of 1360 to 8550 milligrams per liter, while the mean TDS content of the background wells is 220 milligrams per liter. The fact that the two major anions (sulfate and nitrate) in the contaminated ground water will probably not be removed in significant amounts from solution by chemical attenuation means that the total dissolved solids (TDS) of the solution will also not be affected by chemical processes. Unless physical attenuation mechanisms significantly alter the overall concentration of the contaminant plume, it will have a TDS content much greater than background and several times the EPA secondary standard of 500 milligrams per liter.

Based on the observed mobility of contaminants from the tailings pile to the ground water and the probable future influence of chemical processes on solution concentration, it appears that chemical attenuation alone will not lower the concentration of some of the contaminants (nitrate, selenium, sulfate, and total dissolved solids) to drinking water standards. Natural physical attenuation mechanisms will lower contaminant concentrations; however, in cases where natural chemical and physical attenuation mechanisms are not sufficient to lower contaminant levels below drinking water standards, active treatment methods may be required to make the water potable.

B.2.4 CONTAMINATION MECHANISMS AND THE EFFECTS OF REMEDIAL ACTION

Almost certainly, most of the existing contaminant plume was produced while the mill was operating. During this time the tailings pile was saturated and a strong potential for flow existed between the pile and the underlying ground water. As a result, highly contaminated tailings pore solution flowed from the pile into the ground water.

After the mill closed, the discharge of tailings solutions ceased and although the pile continued draining, the percolation rate became progressively smaller. This resulted in ever decreasing amounts of contaminants entering the ground water. However, the percolation of precipitation through the pile is continuing to contribute contaminants to the ground water.

The pile is not covered so there is no barrier to prevent precipitation from percolating through the permeable sands which comprise most of the pile. In addition, water collects in depressions on the pile's surface. Some portion of this water also percolates through the pile. The pile still contains high concentrations of dissolved or easily dissolved contaminants (see Tables B.2.10 through B.2.13). As the precipitation percolates through the pile, these contaminants are carried with it, producing continuing ground-water contamination.

The amount of ground-water contamination presently being produced is much less than that produced during active milling. The percolating precipitation is moving through the pile as unsaturated flow, which moves more slowly than the saturated flow that occurred while the mill was operating.

The rate at which precipitation is percolating through the pile was estimated with Darcy's law for unsaturated flow.

$$q = K(\Psi)\nabla h$$

where

q = percolation rate.
$K(\Psi)$ = unsaturated hydraulic conductivity of pile materials.
∇h = hydraulic gradient through pile.

The unsaturated hydraulic conductivity was taken from a plot of conductivity versus percent saturation for a sand-slime tailings sample (Figure B.2.12). Sand-slimes are the most common tailings material and are approximately 59 percent saturated with tailings pore solution (DOE, 1985).

The hydraulic gradient through the tailings was measured using two nests of tensiometers, one installed near the western end of the pile and one near the eastern end. The average hydraulic gradient through the pile is approximately 0.6 (Figures B.2.13 and B.2.14; Table B.2.15).

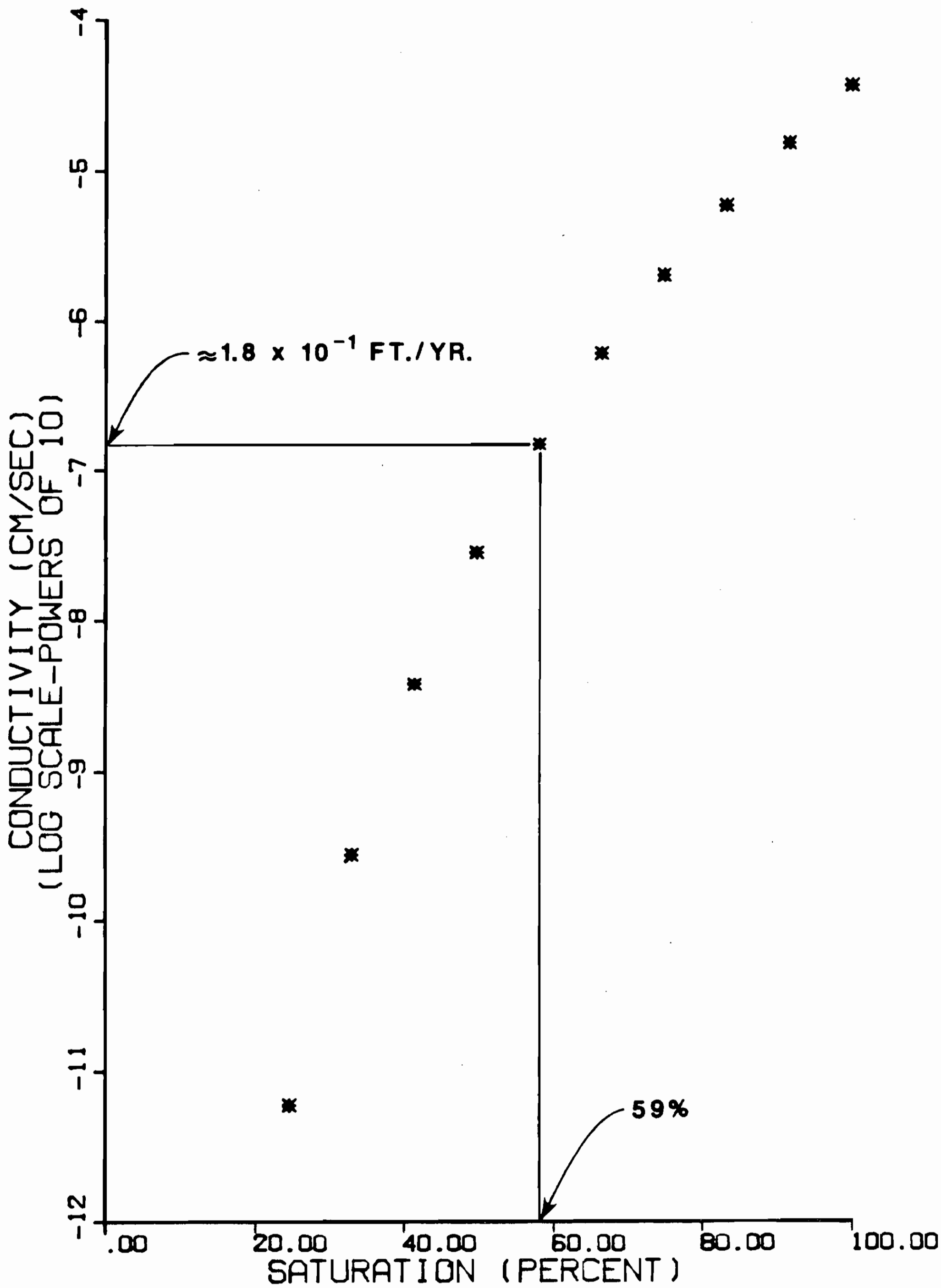
The present rate of percolation through the pile is:

$$q = 1.8 \times 10^{-1} \text{ ft/yr } (0.6) = 0.1 \text{ ft/yr.}$$

The ground water will continue to be contaminated at this rate until the amount of percolation is reduced by remedial action.

The proposed remedial action will reduce ground-water contamination by reducing the amount of precipitation which percolates through the pile. The stabilized pile will be covered by a layer of low-permeability soil, which will present a barrier to infiltration. In addition, the surface of the pile will be sloped, so precipitation will run off the pile, instead of collecting in depressions.

The amount of precipitation which will percolate through the low permeability cover after remedial action was also estimated using Darcy's law for unsaturated flow. A hydraulic conductivity of 1×10^{-6} ft/yr was taken from Figure B.2.15. This figure represents the hydraulic properties of the most permeable sample of cover material that was tested. The cover is to be placed at less than 70 percent of saturation and over the long term is not expected to exceed this



LOCATION ID: 812 SAMPLE ID: 004

FIGURE B.2.12
UNSATURATED HYDRAULIC CONDUCTIVITY TUB01 - 4.5 - 6.0 FT.
MOST PERMEABLE SAMPLE OF TAILINGS MATERIAL TESTED
(*=CALCULATED VALUE)

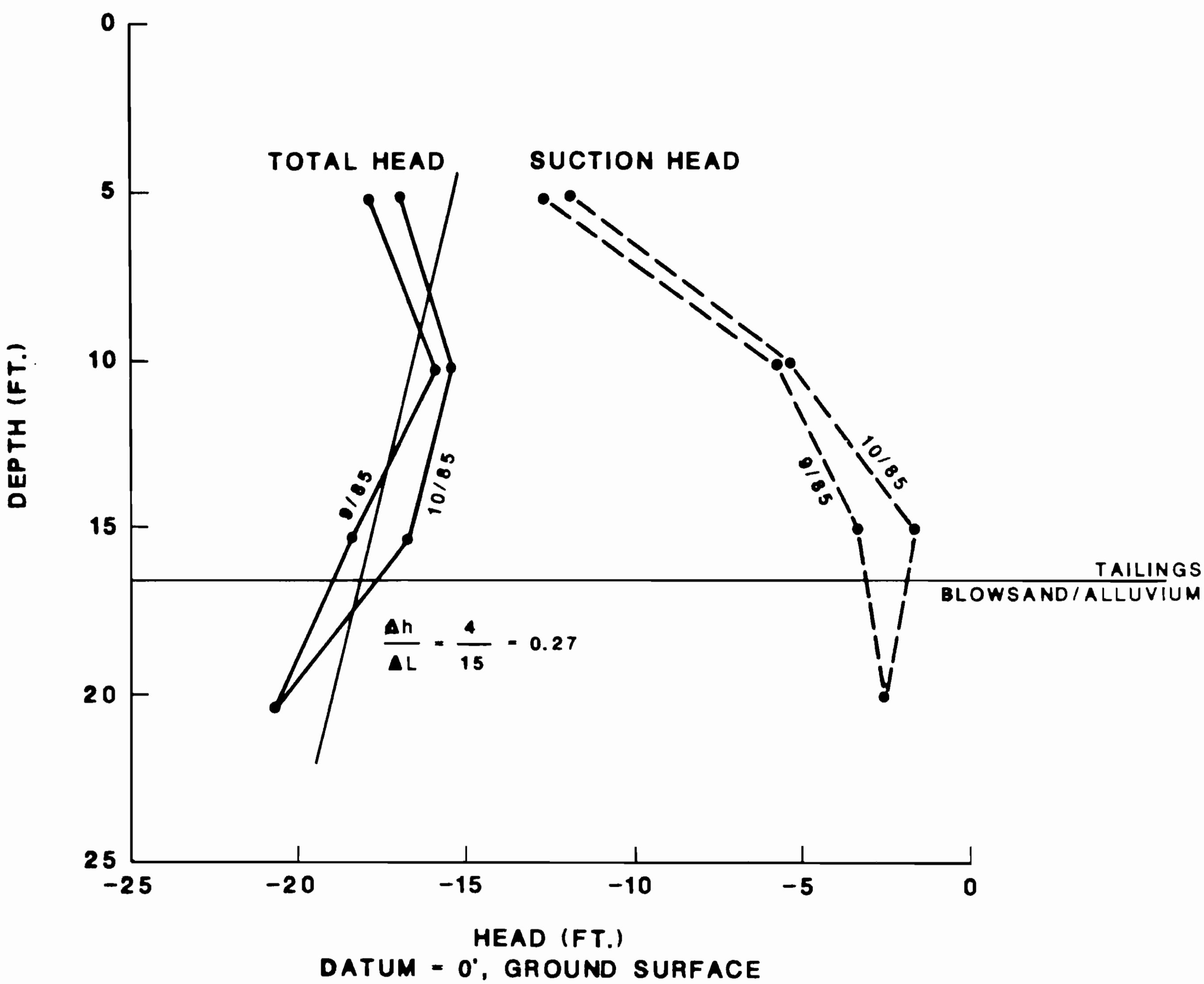


FIGURE B.2.13

HEAD THROUGH TUBA CITY PILE EASTERN NEST

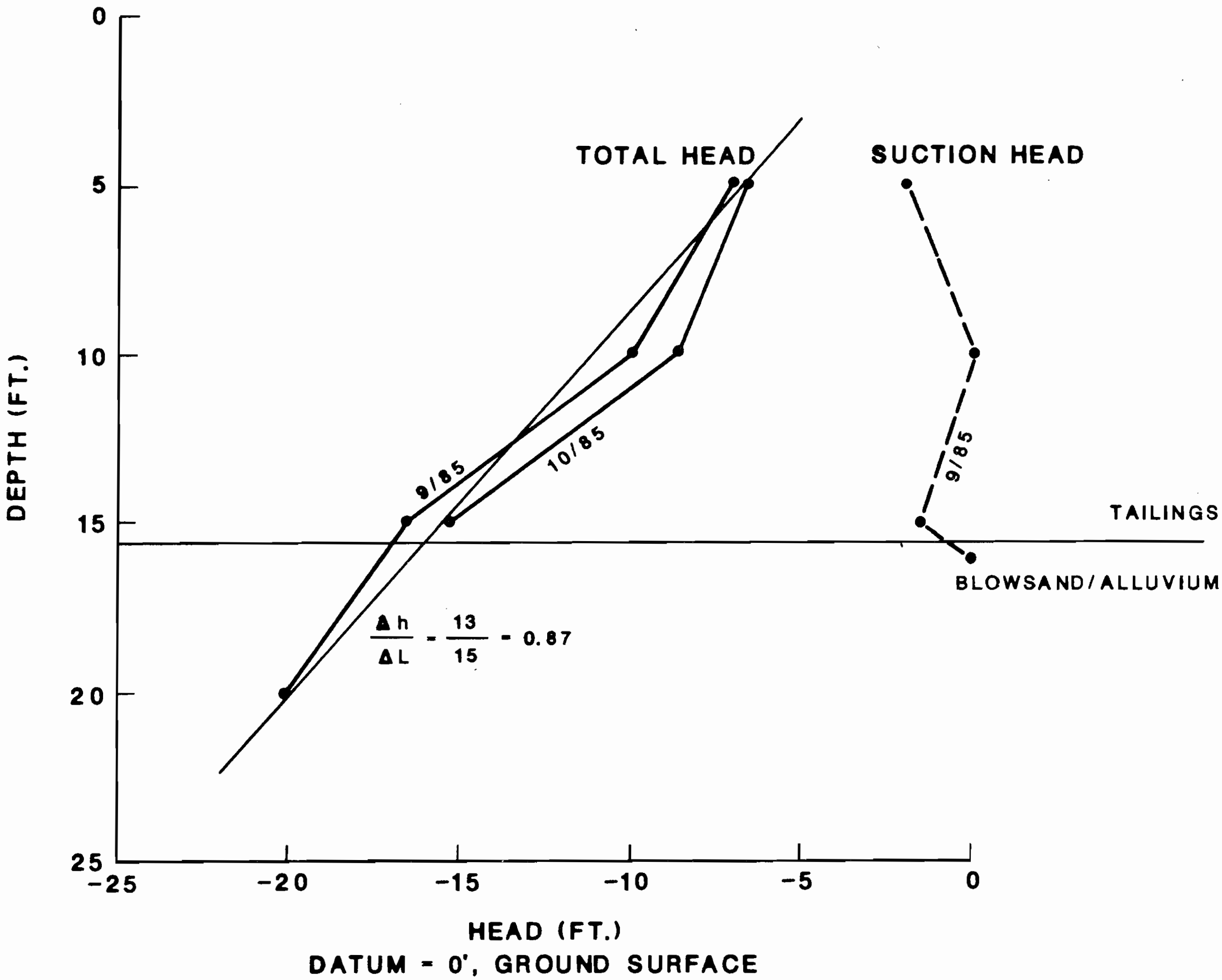
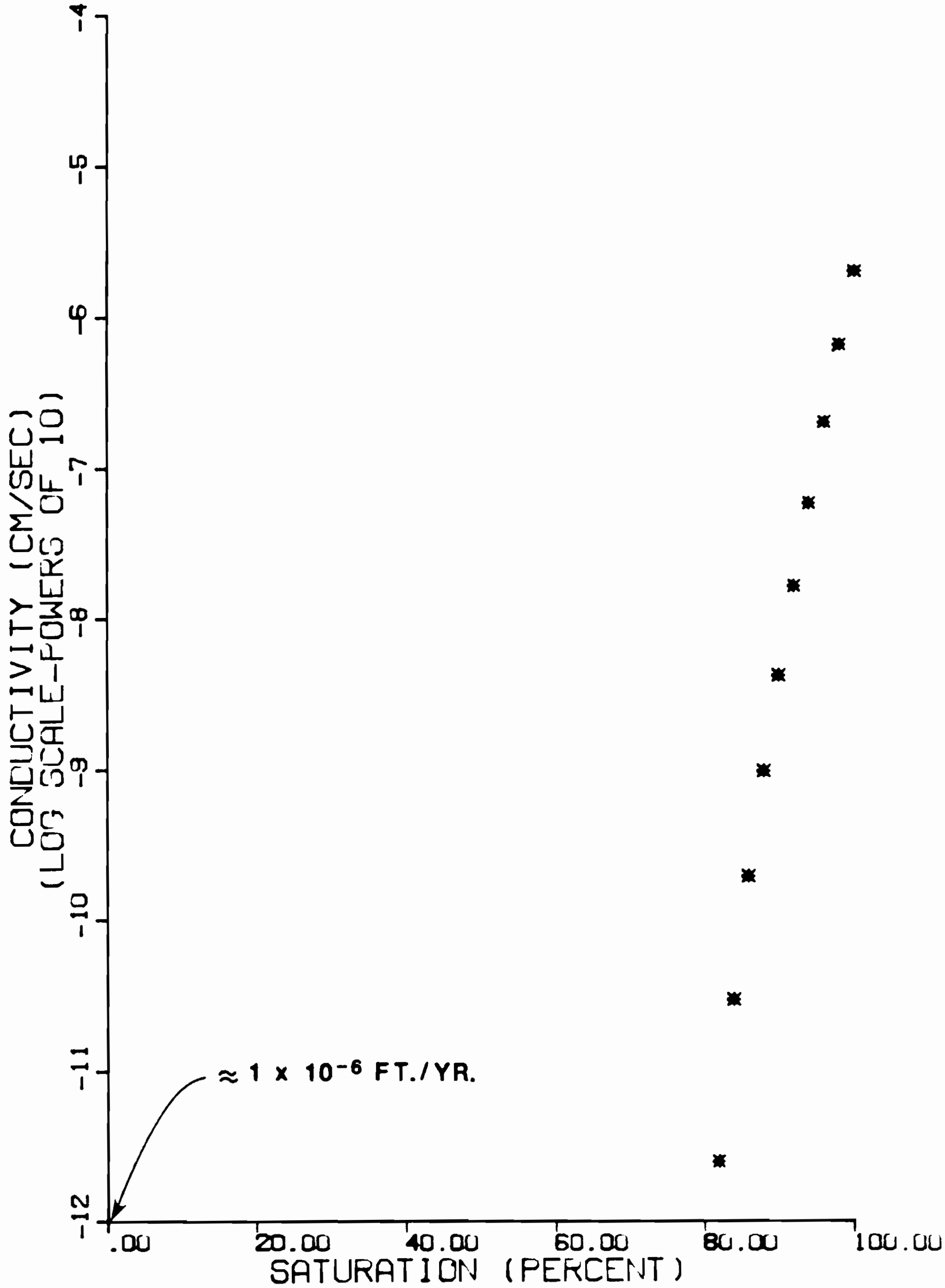


FIGURE B.2.14

HEAD THROUGH TUBA CITY PILE
WESTERN NEST



LOCATION ID: 876 SAMPLE ID: 001

FIGURE B.2.15
UNSATURATED HYDRAULIC CONDUCTIVITY TUB01 - 0.0 - 8.0 FT.
MOST PERMEABLE SAMPLE OF COVER MATERIAL TESTED
(*=CALCULATED VALUE)

Table B.2.15 Tensiometer measurements

Tensiometer	Depth (ft)	Reading (cb) 9/85	Reading (cb) 10/85	Total head (ft) 9/85	Total head (ft) 10/85	Suction head (ft) 9/85	Suction head (ft) 10/85
			Eastern nest				
668	5	52	50	17.4	16.7	12.4	11.7
678	10	47	45	15.7	15.1	5.7	5.1
674	15	54	50	18.1	16.7	3.1	1.7
672	20	62	62	20.7	20.7	2.7	2.7
			Western nest				
652	5	21	20	7.0	6.7	2.0	1.7
662	10	30	26	10.0	8.7	0.0	--
658	15	50	46	16.7	15.4	1.7	0.4
656	20	60	--	20.1	--	0.1	--

value. The hydraulic gradient through the cover was assumed to equal unity. This means that the suction gradient through the cover will either be uniform or randomly distributed and the flow will be driven primarily by gravity. Then, the amount of percolation after remedial action is estimated to be:

$$q = 1 \times 10^{-6} \text{ ft/yr } (1) = 1 \times 10^{-6} \text{ ft/yr.}$$

Clearly, the average amount of contamination produced after remedial action will be insignificant. However, it is possible that unusually heavy rains may saturate the radon barrier and result in ground-water contaminant concentrations which would exceed EPA standards. It is expected that this would only occur once or twice per decade and affect only small volumes of water beneath the pile.

B.2.5 WATER USE AND THE PRESENT AND FUTURE VALUE OF WATER IN THE AREA

Water in the Tuba City area is used primarily for domestic purposes and livestock watering.

B.2.5.1 Ground water

There are no withdrawals of ground water between the tailings pile and Moenkopi Wash, between 6500 and 9000 feet downgradient. This includes the area that is presently contaminated and the area that may become contaminated as the contaminant plume moves toward the wash (Figure B.2.9).

Figure B.2.9 shows the location of all known wells or springs which have been or are now used as sources of ground water within a two-mile radius of the site. The Rare Metals Corporation, which operated the mill, operated four production wells until the mill closed in 1966. One of these production wells (location number 968) was used as a source of water by several families living just north of U.S. Highway 160 until a few years ago when power to the well was shut off.

Within a two-mile radius of the site, two points of ground-water withdrawal are presently being used. A small yield domestic well, approximately 1.5 miles east-northeast of the site is used by two or three families. Jimmy's Spring, about 1.25 miles east-southeast of the site, is used to water livestock. Because of their locations, neither of these sources of ground water will be affected by contaminants emanating from the pile.

The Navajo Tribal Utility Authority (NTUA) operates a municipal well field just north of Tuba City, about five miles west of the site. The field consists of six wells (Table B.2.16). The Moencopi Village also operates two wells. All eight wells are thought to derive their water from the N-aquifer.

Table B.2.16 Tuba City municipal well production (gallons)[a]

Well Number	Depth (feet)[b]	February-December, 1983[c]	1984[c]	January-May, 1985[c]
1	526	29,831,200	46,259,000	18,410,000
2	453	7,911,000	44,048,000	17,135,000
3	440	45,945,000	38,948,000	52,000,000
4	576	44,495,000	42,262,000	11,332,000
5	542	95,347,000	82,242,000	43,252,000
6	UNK	N/O	655,000	N/O

[a]UNK - unknown; N/O - not operative.
[b]Ref. Begay, 1985.
[c]Ref. Scarborough, 1985.

Under worst-case conditions, the cone of depression caused by pumping the municipal wells could intersect the contaminant plume and draw contaminants toward the wells. The extent of the cone of depression was calculated using the following assumptions.

- A single well is pumped at a rate of 3.84 cubic feet per second for 30 years. This pumping rate was calculated by assuming a 2.8 percent increase in pumping rate per year (DOC, 1984). The present rate is 1.52 cubic feet per second for the NTUA wells (Zaman, 1986), and 0.16 cubic feet per second for the Moencopi Village wells (Shingoitewa, 1986).

- The transmissivity is 1.4×10^{-2} ft^2/s. This was calculated using the highest measured hydraulic conductivity (see Table B.2.3) and assuming the effective thickness of the N-aquifer to be 500 feet.

- $S = 1.4 \times 10^{-4}$ (see Table B.2.4).

- r = five miles, approximate distance from wells to contaminant plume.

$u = \frac{r^2 S}{4Tt}$, the amount of drawdown was calculated using the Thesis Method (Davis and DeWiest, 1966).

where

r = distance from pumped well to point of interest.
S = storage coefficient.
T = transmissivity.
t = time.

then

$$u = \frac{(26,400\ ft)^2\ 1.4 \times 10^{-4}}{4(1.4 \times 10^{-2}\ ft^2/s)\ 9.6 \times 10^8\ s} = 1.84 \times 10^{-3}$$

W(u) = 5.75, (Davis and DeWiest, 1966)

$$s = \frac{Q}{4\pi T} W(u)$$

where

s = drawdown at distance r from pumped well.
Q = pumping rate.

$$s = \frac{3.84\ ft^3/s}{4\pi\ 1.4 \times 10^{-2} ft^2/s}\ 5.75 = 125.5\ ft$$

However, this will have little effect on the movement of contaminants because the cone of depression is very shallow near the plume, as shown below.

One thousand feet west of the plume, the drawdown will be:

$$u = \frac{(25{,}400\ ft)^2\ 1.4 \times 10^{-4}}{4(1.4 \times 10^{-2} ft^2/s)\ 9.46 \times 10^8 s} = 1.7 \times 10^{-3}$$

$$w(u) = 5.85$$

$$s = \frac{3.84\ ft^3/s}{4\pi\ 1.4 \times 10^{-2} ft^2/s}\ 5.85 = 127.7\ ft$$

Then, the hydraulic gradient from the plume toward the municipal wells is:

$$\frac{127.7 - 125.5}{1000} = 2.2 \times 10^{-3}$$

And, the speed at which contaminants will travel toward the municipal wells is:

$$q = \frac{K}{n_e} \frac{\Delta h}{\Delta L}$$

where

k = hydraulic conductivity = 892 ft/yr (highest calculated value, Table B.2.3).

$\Delta h/\Delta L = 2.2 \times 10^{-3}$

n_e = 0.25, lower range of porosity according to Cooley et al., 1969.

$$q = \frac{892\ ft/yr\ 2.2 \times 10^{-3}}{0.25} = 7.8\ ft/yr$$

Clearly, even given the worst-case assumptions used in the above analysis, the contaminants would require a very long time to reach the municipal wells. However, the contaminants probably would not travel toward the municipal wells at all. Instead, they would probably continue traveling toward the south, along a gradient which is the vector sum of the relatively weak westward gradient produced by pumpage and the far stronger southward gradient that currently exists.

B.2.5.2 Surface water

Moenkopi Wash is an intermittent stream. Descriptions of its flow regime and water quality are presented in Sections B.1.1 through B.1.3. Moenkopi Wash is used to water livestock in the Tuba City area and for irrigation of a limited amount of farmland near Moencopi Village.

B.2.5.3 Present and future value

The present value of a unit of water at the wellhead is assumed to equal the price charged by the NTUA (Table B.2.17). The value of the water in the ground is considerably less than this.

Table B.2.17 NTUA rate schedule for Tuba City

Use	Rate
Residential	$4.50 for 1st 3000 gallons $2.20 for every additional 1000 gallons
Commercial	$2.45 per 1000 gallons

Ref. Scarborough, 1985.

The future value of a unit of water will change in response to two factors: (1) changes in the type of use, and (2) changes in its relative abundance. At present there is no reason to expect the primary types of use in the Tuba City area to change, nor is it expected that the relative abundance of water will change significantly. The N-aquifer extends for hundreds of square miles around Tuba City. This is a vast reserve of potable water. Additional demands on this resource can be estimated by projecting population growth over the next 30 years. (Population growth projections for periods greater than 30 years are considered invalid.) Between 1980 and 1983, the population in the Tuba City area grew at a rate of 2.8 percent per year (DOC, 1984; Navajo Nation, 1984). This represents a population increase of about 230 percent over 30 years. The increased demand could be handled by installing additional wells in the N-aquifer, outside the zone of present or potential contamination (see Section B.2.3.2, Figure B.2.9). Withdrawals of contaminated water could be prevented through legal restrictions on use, or other methods, as discussed in Section B.2.7. In view of the above, the value of water in the Tuba City area is not expected to change significantly in the foreseeable future.

B.2.6 HEALTH EFFECTS

B.2.6.1 Radiological effects

General public health effects from ingestion of contaminated drinking water were calculated based upon a radiological assessment prepared by Millard and Baggett (1984) which concluded that the risk from inhalation of radon daughters dominated the health effects analysis compared to the estimated risk from the water ingestion pathway for people living in the vicinity of an operating uranium mill. The radiological risk was assessed for hypothetical individuals living in the vicinity of the Tuba City tailings pile who use ground water contaminated by the tailings pile as their source of drinking water. It must be emphasized that there is no use of contaminated ground water at this time.

The maximum concentrations of radionuclides in samples drawn from monitor wells in the unconfined sandstone aquifer directly beneath or downgradient of the pile were used to calculate health effects.

These concentrations were found under existing conditions and were used to maximize estimated health effects from the ingestion of drinking water. It should be noted that conservative assumptions were used in the calculations, and no people would be exposed to the radionuclide concentrations used because the wells from which the radionuclide concentrations were monitored are not used as a source of drinking water. The individual risk calculated for ingestion of contaminated drinking water was 6.6 percent of the individual risk calculated for inhalation of radon daughters by a person within 0.5 mile from the pile under no action conditions. Details of the health effects calculations are contained in Appendix D, Radiation.

B.2.6.2 Non-radiological effects

Only those non-radioactive contaminants exceeding the EPA Primary Drinking Water Standards are discussed in this section. In the area affected by the contaminant plume (Figure B.2.9), nitrate exceeds the standards by a factor of about 40, cadmium by 3.6, and selenium by 6.6.

Nitrate can cause methemoglobinemia, also known as blue baby disease, in infants under three months old. Fatal poisonings have occurred in infants after ingesting water containing more than 45 milligrams per liter of nitrate. The physiological effects of nitrate are not well understood. Therefore, the EPA recommends that water containing more than 4.5 milligrams per liter of nitrate not be used for infant feeding (EPA, 1976).

Ingestion of cadmium can cause symptoms similar to food poisoning, kidney disease, and itai-itai disease (EPA, 1976).

Selenium is an essential nutrient in trace amounts but ingestion of selenium in amounts as low as 0.07 milligrams per day has been shown to give rise to signs of selenium toxicity (this amount is equivalent to 0.035 milligrams per liter when two liters of water per day are ingested). The symptoms of selenium toxicity include fatigue, altered skin color, edema, and kidney degeneration (EPA, 1976).

B.2.7 THE RISK OF HUMAN EXPOSURE AND PROTECTION OF FUTURE AQUIFER USERS

There is no risk of human exposure to contaminated ground water at this time. There is also no present risk of exposure to wildlife or crops. No ground water is being withdrawn from the area downgradient of the pile and the contaminant plume has not emerged along any discharge area. The nearest possible discharge area is along Moenkopi Wash, approximately 6500 feet away in the downgradient direction. The maximum calculated ground-water flow rate (Table B.2.4) indicates that a minimum of about 45 years would be required for the plume to reach the wash. Actual contaminate migration rates are expected to be lower (Section B.2.3.3) and would result in a longer travel time to Moenkopi Wash. Furthermore, based on the absence of springs along the wash downgradient (south and southeast) of the pile, actual surface discharge of contaminated water along Moenkopi Wash is highly unlikely. It is not known whether the contaminant plume will be discharged to the alluvium along the wash or will pass beneath the wash and continue flowing southeastward.

There is a possibility that contaminated ground water will be withdrawn from new wells south of the pile in the future. This could be prevented in two ways. The contaminated water could be removed through aquifer restoration or withdrawals from the area downgradient of the pile could be prohibited by law until the contaminants dissipate within the aquifer by natural processes.

B.2.7.1 Ground-water restoration

Removing man-induced contaminants from ground water is commonly termed aquifer or ground-water restoration. Generally, aquifer restoration is a more inclusive term that involves both removing contaminants from the solid rock or sediment comprising the aquifer structure as well as the ground water that flows through the system. In the case of the Tuba City site, the primary goal is to restore the ground water. This should effectively restore the aquifer because very little solid phase contamination is expected in the aquifer itself. However, it should be kept in mind that, if there are significant amounts of mobile contaminants present in the solid phase, ground-water restoration by the methods discussed below may not be completely effective.

The complexity of a restoration effort depends on a number of physical and chemical factors. These include: the horizontal and vertical extent of the contaminated zone, the types of contaminants, the concentration level of the contaminants, the complexity of the hydrogeologic system, the amount of time allowed for restoration, and the amount of information known about the system. At the Tuba City site, a large amount of water must be treated to lower the concentration of some contaminants by factors of up to 40. Because of the generally low permeability of the aquifer, it is not possible to rapidly flush the contaminated water from the aquifer by ground-water sweeping at high pumping rates. Calculations show that to flush the aquifer and keep drawdowns in the wells to a reasonable maximum value of 100 feet over the period of pumping, requires that the withdrawal cycle last 10 to 20 years.

Presently, five wells show contamination over a 92-acre area. The contamination extends from the water table (approximately 40 feet below land surface) to a depth of about 160 feet. Because the lower boundary of contamination has not been precisely determined, there is some question as to the actual thickness of the contaminated zone. Prior to the commencement of restoration, additional field characterization would be necessary to more accurately determine the contaminated zone and perhaps provide additional hydrologic data to design the recovery and reinjection system.

Although it is reasonable to assume that contaminants appearing in the ground water at levels of hundreds of mg/l can be effectively reduced by common restoration methods, there is some doubt that contaminants such as uranium and cadmium, which are at levels less than 1 mg/l, can be removed down to the very low level (tens of micrograms per liter) required by the drinking water criteria. Past restoration efforts have shown that it is possible to easily remove the first 95 percent of a contaminant but the last five percent can be quite difficult to remove using reasonable methods. The 95 percent level of contaminant removal would be acceptable for many of the contaminants at the Tuba City site but would not be acceptable for uranium to meet the proposed health effects advisory level EPA is using for uranium in drinking water (0.015 mg/l).

Restoration methods

Restoration of ground water may be accomplished in-situ (in place) or by removing the contaminated water and either disposing of it or treating it for use or reinjection. In-situ methods have the advantage of keeping the contamination at depth and not unnecessarily exposing the surface environment to the contaminants. Restoration by in-situ methods includes both the natural processess active in the aquifer environment that reduce contaminant levels and the addition of chemical or biological agents to the contaminated zone to enhance the removal of contaminants from the ground water. At the Tuba City site, nitrate could be removed by nitrogen-fixing bacteria and uranium could be removed by adding a reducing agent to the ground water. However in-situ removal of sulfate and cadmium would be difficult to achieve. Futhermore, all in-situ treatment methods suffer from the difficulty of uniformly injecting the treating agent so that it affects all contaminated water. For these reasons in-situ methods alone are not recommended for this site.

The second general method of restoring the ground water is to remove the contaminated portion from the aquifer and either dispose of it or treat it. After treatment, the clean water can be either used or reinjected. Because of the depth of contamination in this system the only reasonable method of extracting the water is to pump it from recovery wells completed in the zone of contamination. (Intercepting the plume with trenches is not a feasible alternative at this site.) The water that is pumped to the surface can be simply disposed of in solar evaporation ponds, used to irrigate the land, or it can be injected into deep wells completed in zones of unusable water. Instead of disposing of this potential resource, the water could be treated on the surface to remove contaminants. The cleaned water could then be reinjected into the aquifer and the contaminated brine from the treatment process could be disposed of in evaporation ponds or deep wells. In addition to pumping and disposal or treatment followed by reinjection, a third possible restoration alternative would be to pump and mix the contaminated water with fresh ground water to lower the overall level of contamination to the acceptable drinking water standard. These restoration alternatives are discussed in detail in the following section. The cost estimates given with several of the restoration alternatives include expenses due to construction, fifteen-year operation, dismantling, and reclamation. All costs are in 1986 dollars and may vary by as much as 25 percent for each technique.

B.2.7.2 Restoration alternatives for the Tuba City site

Pumping and disposal alternatives

In order to remove the estimated 1.1 billion gallons of contaminated water from the Tuba City site, approximately five times this amount of water must be removed from the aquifer. This overpumping is necessary to sweep the contaminated water out of the system. The factor of five is based on experience gained from similar ground-water sweeping aquifer restoration attempts at in-situ leach uranium mines and may not be totally adequate to clean the aquifer at the Tuba City site. One possible pumping schedule consists of removing 5.5 billion gallons of water in fifteen years. The withdrawal rate to meet this schedule would be on the order of one MGD (million gallons per day). Approximately 40 wells, each pumping at 18 gallons per minute, must be installed in the contaminated zone to achieve this withdrawal rate.

The water pumped to the surface could be disposed of by solar evaporation in ponds, by using it for irrigation purposes, or by injecting it into deep wells, thereby removing it from future possible human use. A solar evaporation pond of adequate size to handle this volume of water would need to have a surface area of approximately 480 acres. This assumes that the brine evaporation rate at the site is 30 inches per year (Riding and Rosswog, 1979). The advantage of the solar evaporation disposal method is that it successfully removes the contaminated water from the aquifer, however it creates a potential surface contamination problem from what was subsurface contamination. Approximately 30,000 metric tons of solid waste will be produced in the evaporation pond over its fifteen-year life. Other considerations in choosing this option are the necessity for a large level site, risk of recontamination by leakage from the pond, and the probable high cost to build, operate, and close a solar evaporation pond of this size. The estimated cost of this restoration technique at Tuba City is $17.4 million.

The water in the contaminated zone of the aquifer is not drinking water quality, but irrigation of non-edible plants may be one permissible use of the water. For this restoration alternative, the water pumped to the surface is used to irrigate a tree farm. The size of the irrigated land (200 acres) has been calculated to be large enough that the recovered water will not recharge the aquifer at the application rate of one million gallons per day. The water will be lost primarily by evapotranspiration in the soil zone. The dissolved constituents become part of the vegetation and soil. Nitrate is a major contaminant as far as drinking water is concerned but it would be considered a nutrient if applied for agricultural purposes. Sulfate, iron, and manganese are common major constituents of soil zones so any increase in concentration due to their application on the ground surface would be minor compared to background. The concentrations of cadmium and uranium in the contaminated water are less than 1 mg/l. Uranium is the highest with an average value of 0.45 mg/l. The five-fold dilution of the contaminated water during sweeping will lower the average uranium concentration to 0.09 mg/l. If 5.5 billion gallons of water with this uranium concentration infiltrated 200 acres of land and reached a depth of three feet, it would increase the solid uranium concentration by only 1.8 milligrams per kilogram of soil or 1.3 pCi per gram of soil. This amount of uranium approximates the background level of uranium in the soil in the vicinity of the Tuba City site (Haywood et al., 1980), and is less than the permissible radium-226 standard of 5 pCi per gram-soil above background. Under the oxidizing conditions of the soil zone, the uranium would be immobilized as either a uranium mineral or an adsorbed species on the metal oxides present in the soil zone. The estimated cost for pumping the contaminated water and using it to operate a tree farm is $5.1 million.

Deep well disposal of water pumped from the contaminated zone keeps the waste in the subsurface and moves it to a depth at which the natural ground-water quality is not good or the aquifer is so deep that it is not practical to use the water for the foreseeable future. In order to dispose of one million gallons of water each day at least five wells would be needed. A characterization effort would be required to determine where to place the wells and ensure that the target zone can accept water at a rate of one MGD. Although many deep disposal wells have been constructed in the midwestern states, there are no known wells in Arizona and it may be difficult to permit such wells at the Tuba City site. The cost for this restoration alternative is estimated at $13.2 million.

Removal, surface treatment, reinjection, and waste disposal

In order to conserve some of the ground water being removed from the aquifer the water could be treated to remove contaminants and then the clean water could be reinjected. The concentrated brine from the treatment process would have to be disposed. Several water treatment methods are available (e.g., electrodialysis, ion exchange, and freezing) but the one considered most likely to achieve the desired result and be moderately priced is reverse osmosis. In this method high pressures are used to force ground water through a semipermeable membrane leaving behind a concentrated brine solution, with clean water being the product. With proper pretreatment of the water and a sufficient number of stages on the reverse osmosis unit, the water quality could potentially be improved to drinking water standards. There is some question as to the efficiency of the unit for trace contaminants such as uranium and cadmium that are at the Tuba City site, and this concern would have to be resolved before choosing this method.

Approximately 15 percent of the water treated in this manner would exit the system as brine. The brine could be disposed of in a solar evaporation pond that would be approximately 15 percent as large as the system needed to handle all the water pumped from the ground. The cost for treating the contaminated water and disposing of the brine in a solar evaporation pond is estimated at $33.1 million. An alternative disposal method for the brine would be to dispose of it in deep injection wells. It may be more difficult to inject this brine than the original contaminated water, therefore the injection method might have to be modified. The estimated cost for treatment and deep well injection of the brine is $31.8 million.

Deep well mixing and reinjection

This method of ground-water restoration involves the installation of deep wells that are screened through the zone of contamination into the clean water below. The purpose of this scheme is to mix clean water with the contaminated water as it comes from the well. The goal is to produce water of drinking water quality that can be reinjected into the aquifer surrounding the contaminated zone. Reinjection will enhance movement of the contaminated water into the recovery wells and will preserve the ground-water resource.

The main disadvantage of this method is the amount of fresh water that must be mixed with the contaminated water to achieve drinking water quality. Given concentration values for contaminated and background waters, about 40 volumes of background water must be mixed with contaminated water to bring the nitrate concentration down to an acceptable drinking water level and over sixty volumes are required for uranium. The design of this system involves sixteen recovery wells that are 500 feet deep throughout the zone of contamination. Fifty-three 500-foot-deep supplemental wells will be necessary to provide all the water required for dilution. Although large amounts of water must be transported, the result will be very little water lost from the aquifer and all the water will be of drinking water quality. Cost estimates were not made for this restoration alternative.

Operating facilities and other considerations

During the estimated fifteen-year life of this restoration project it will be necessary to monitor the progress of restoration by periodically analyzing the solutions drawn from the recovery wells and injected into the recharge and/or disposal wells. This could best be done at a small analytical facility on the site. Monitor wells should also be established on the periphery of the contaminated zone downgradient of the existing plume. These would also be sampled on a regular basis to ensure that part of the contaminant plume is not escaping from the recovery zone. This type of event could occur if localized heterogeneities in the geology provide channels for ground-water flow or if the pumping/reinjection scheme distorts the flow lines in such a manner that a portion of the contaminated water is forced out of the recovery zone.

As mentioned previously, past experience has shown that most contaminants can be removed over a reasonable period of time by the commonly employed restoration methods. However, achieving background levels for dissolved constituents at the microgram per liter level is very difficult to achieve. For instance, to bring the sulfate level in the contaminated water down to the drinking water standard, dissolved sulfate must be reduced by 89 percent; however, uranium must be reduced by 97 percent. Reducing uranium by this much may not be feasible. Therefore, it would be necessary to reach an agreement with the regulatory agencies and concerned parties on an acceptable level of restoration for each constituent.

For an aquifer restoration alternative to be cost effective, the value of the contaminated water must exceed the cost of restoration. The value of the contaminated water may be estimated as follows.

Value = volume contaminated x cost/unit volume.

Volume = 5(1.1 x 10^9 gal) = 16,900 acre feet.

Cost/unit volume = \$10/acre foot.

Value = 16,900 acre feet x \$10/acre foot = \$169,000.

This is less than the cost of the least expensive restoration alternative (\$5,100,000). Therefore, aquifer restoration is not cost effective in this case.

Legal prohibition of ground-water withdrawals from the contaminated or potentially contaminated area would be far less expensive than aquifer restoration. Not performing aquifer restoration would have little effect on available water supplies in the area because large amounts of potable water underlie the hundreds of square miles surrounding the contaminated area. If legal prohibitions, rather than aquifer restoration, are imposed to protect the health of future water users located over the plume, the extra cost incurred would be chiefly a result of transporting water from outside the contaminated area to the point of use. Figure B.2.9 shows the area where legal prohibitions would be imposed.

As an alternative to outright legal prohibition of ground-water use in the potentially contaminated area, those wishing to use the contaminated water in the future could be required to treat it. The most efficient treatment method would probably be individual well-head reverse osmosis units. This would be more expensive than outright prohibition and would require disposal of the concentrated contaminants but would still be far less expensive than aquifer restoration.

DOE will mitigate contaminated ground water by applying institutional controls on water development around the site. When EPA issues revisions to the water protection standards (40 CFR 192.20(a)(2)-(3)) that were remanded by the U.S. Tenth Circuit Court of Appeals, DOE will re-evaluate the ground-water issues at the Tuba City site to assure that the revised standards are met. Performing remedial actions to stabilize the tailings prior to EPA issuing new standards will not affect the measures that are ultimately required to meet the revised water protection EPA standards.

B.2.8 SOURCE OF CONSTRUCTION WATER

Approximately 8,500,000 gallons of water will be required over a period of 18 months (0.024 ft^3/s). This quantity may be withdrawn from well 972, a former Rare Metals production well. As shown below, even under worst case conditions the withdrawal will not adversely affect water quality.

Well 972 is about 6000 feet north-northwest of the tailings. The amount of drawdown caused at the pile by pumpage was estimated by the following equation (values used in the calculations are those which result in the largest cone of depression):

$$u = \frac{r^2 S}{4Tt}$$ (Davis and DeWiest, 1966).

where

r = distance from well 972 to pile = 6000 ft.
S = storage coefficient = 1.4×10^{-4} (see Table B.2.4).
T = transmissivity = 1.4×10^{-2} ft^2/s (calculated assuming effective aquifer thickness = 500 feet and hydraulic conductivity = 892 ft/yr).
t = time = 18 months = $4.73 \times 10^7 s$.

$$u = \frac{(6000)^2 \; 1.4 \times 10^{-4}}{4(1.4 \times 10^{-2}) \; 4.73 \times 10^7} = 1.9 \times 10^{-3}$$

Then, $W(u) = 5.71$ (Davis and DeWiest, 1966).

The drawdown at the plume due to pumpage of well 972 is:

$$s = \frac{Q}{4\pi T} W(u),$$ (Davis and DeWiest, 1966)

where

s = drawdown (ft).
Q = pump rate = 0.024 ft^3/s.

$$s = \frac{0.024}{4\pi \; 1.4 \times 10^{-2}} = 5.71 = 0.78 \text{ ft}$$

Hence, under worst case conditions the cone of depression caused by pumping well 972 will intercept the plume and contaminants will be drawn toward the north. The rate at which the contaminants would be drawn northward was estimated as follows.

Amount of drawdown 1000 feet north of the plume (5000 feet from well 972):

$$u = \frac{(5000)^2 \; 1.4 \times 10^{-4}}{4(1.4 \times 10^{-2}) \; 4.73 \times 10^7} = 1.3 \times 10^{-3}$$

$W(u) = 6.12$

$$s = \frac{0.024}{4\pi\ 1.4 \times 10^{-2}} = 6.12 = 0.85 \text{ ft}$$

Then, the northward hydraulic gradient over the first 1000 feet is:

$$\frac{\Delta h}{\Delta L} = \frac{0.85 - 0.78}{1000} = 7 \times 10^{-4}$$

The distance that contaminants will travel over the 18-month period of pumpage is:

$$q_{n_e} = \frac{K\ \Delta h/\Delta L}{n_e}\ t$$

where

K = hydraulic conductivity = 892 ft/yr.
$\Delta h/\Delta L$ = hydraulic gradient = 7×10^{-4}.
t = time = 1.5 yrs.
n_e = effective porosity = 0.25 (lower range of porosity as reported by Cooley et al., 1969).

$$q_{n_e} = \frac{892 \text{ ft/yr}\ 7 \times 10^{-4}}{0.25}\ 1.5 \text{ yr} = 3.7 \text{ ft}$$

Hence, the contaminants will be drawn less than four feet northward during the period of pumpage. Clearly, pumpage of well 972 will not adversely affect water quality.

B.2.9 SUMMARY OF MAJOR CONCLUSIONS

- o The major water-bearing unit in the vicinity of and underlying the site is the N-aquifer, comprised of the Navajo Sandstone and the Kayenta Formation.
- o The N-aquifer is unconfined in the vicinity of the site with water levels ranging from 20 to 150 feet below land surface.
- o The position of the water table is stable. The maximum fluctuation observed between January, 1985, and April, 1986, is 1.76 feet.
- o Ground water flows from the site southeastward toward Moenkopi Wash. However, no springs or seeps are observed directly downgradient of the site along the wash and therefore, surface discharge to the wash is unlikely.
- o Ground-water flow rates range from about five feet per year to about 140 feet per year in the N-aquifer near the site.
- o Background waters near the site are fresh and potable. Concentrations of total dissolved solids average 240 milligrams per liter.

- The tailings pile has contributed the following contaminants to the underlying ground water: cadmium, chromium, molybdenum, selenium, uranium, nitrate, iron, manganese, boron, copper, nickel, zinc, sodium, potassium, magnesium, calcium, strontium, ammonium, and sulfate.

- Concentrations of cadmium, selenium, gross alpha activity, and nitrates exceed EPA Primary Drinking Water Standards within the contaminant plume in the area immediately south of the tailings pile. Concentrations of total dissolved solids, iron, manganese, and sulfate exceed EPA Secondary Drinking Water Standards within the plume.

- The contaminant plume extends to more than 1300 feet and less than 2000 feet downgradient of the pile. The plume extends to a depth of about 120 feet below the water table. There are approximately 1.1 billion gallons of ground water contaminated.

- The tailings pile is the only source of contaminants known to affect water quality beneath or downgradient from the site.

- The value of water in the Tuba City area is not expected to change significantly in the foreseeable future.

- There is presently no risk of human exposure to contaminated ground water.

- Regulatory controls and/or well-head treatment systems are the most cost-effective means of protecting potential future water users from the contaminated ground water. The value of the contaminated ground water is far less than the cost of aquifer restoration.

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APPENDIX C

FLORA AND FAUNA

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C.1 FLORA AND FAUNA

This appendix contains listings of plant and animal species that may occur at or in the vicinity of the Tuba City tailings site, the Greasewood Lake borrow site, the Shadow Mountain borrow site, and the Pediment Gravel borrow site. The diversity of wildlife habitat at the tailings site and borrow sites is low, with small mammals and reptiles being the principal wildlife expected to occur. Plant species diversity is low at the tailings site and the Shadow Mountain borrow site because both sites have been previously disturbed. Kochia is the principal plant species found at the Greasewood Lake borrow site. Native plant species common to the Tuba City area include Indian ricegrass, galleta, Mormon tea, rabbitbrush, yucca, and blue grama (Roth, 1985).

Table C.1.1 Wildlife that may occur at the Tuba City site, Greasewood Lake borrow site, Shadow Mountain borrow site, and Pediment Gravel borrow site

Scientific name	Common name
MAMMALS	
Ammospermophilus leucurus	white-tailed antelope squirrel
Antrozous pallidus	pallid bat
Canis latrans	coyote
Cynomys gunnison	Gunnison's prairie dog
Dipodomys ordii	Ord's kangaroo rat
Euderma maculatum	spotted bat
Eutamias minimus	least chipmunk
Lepus californicus	black-tailed jackrabbit
Felis rufus	bobcat
Mephitis mephitis	striped skunk
Myotis californicus	California myotis
Myotis yumanensis	Yuma myotis
Neotoma albigula	White-throated woodrat
Notiosorex crawfordi	desert shrew
Onychomys leucogaster	northern grasshopper mouse
Peromyscus crinitus	canyon mouse
Peromyscus maniculatus	deer mouse
Perognathus apache	Apache pocket mouse
Perognathus flavus	silky pocket mouse
Perognathus intermedius	rock pocket mouse
Pipistrellus hesperus	western pipistrel
Plecotus townsendii	Townsend's big-eared bat
Reithrodontomys megalotis	western harvest mouse
Spermophilus spilosoma	spotted ground squirrel
Spermophilus variegatus	rock squirrel
Spilogale gracilis	western spotted skunk
Sylvilagus audubonii	desert cottontail
Taxidea taxus	badger
Thomomys talpoides	northern pocket gopher
Urocyon cinereoargenteus	gray fox
Felis concolor	mountain lion
BIRDS	
Amphispiza bilineata	black-throated sparrow
Archilochus alexandri	black-chinned hummingbird
Carpodacus mexicanus	house finch
Cathartes aura	turkey vulture
Chandestes grammacus	lark sparrow
Corvus corax	common raven

Table C.1.1 Wildlife that may occur at the Tuba City site, Greasewood Lake borrow site, Shadow Mountain borrow site, and Pediment Gravel borrow site (Concluded)

Scientific name	Common name
BIRDS (Concluded)	
Eremophila alpestris	horned lark
Falco mexicanus	prairie falcon
Mimus polyglottus	mockingbird
Petrochelidon pyrrhoneta	cliff swallow
Phalanoptilus nuttallii	poor-will
Salpinctes obsoletus	rock wren
Speotyto cunicularia	burrowing owl
Taxostoma bendirei	Bendire's thrasher
Tyrannus verticalis	western kingbird
Tyrannus vociferans	Cassin's kingbird
Zenaida macrousa	mourning dove
REPTILES	
Cnemidophorus tigris	western whiptail
Crotalus viridis	western rattlesnake
Gambelia wislizeni	leopard lizard
Holbrookia maculata	lesser earless lizard
Hypsiglena torquata	night snake
Masticophis taeniatus	striped whipsnake
Phrynosoma douglassi	short-horned lizard
Pituophis melancleucus	gopher snake
Salvadora hexalepis	patchnosed snake
Sceloporus undulatus	eastern fence lizard
Uta stansburiana	side-blotched lizard
AMPHIBIANS	
Bufo cognatus	great plains toad
Bufo punctatus	red-spotted toad
Scaphiopus hammondi	western spadefoot toad

Ref. Smith and Associates, 1982; Stebbins, 1966; Behler and King, 1979; Whitaker, 1980; Peterson, 1961; Udvardy, 1977.

Table C.1.2 Plants that may occur at the Tuba City site, Greasewood Lake borrow site, Shadow Mountain borrow site, and Pediment Gravel borrow site

Scientific name	Common name
Astragalus fucatus	milk vetch
Atriplex canescens	fourwing saltbush
Atriplex confertifolia	shadscale
Atriplex polycarpa	all scale
Bouteloua eriopoda	black grama
Bouteloua gracilis	blue grama
Brickellia scabra	brickellia
Chrysothamnus sp.	rabbitbrush
Dithyrea wislizenii	spectacle pod
Ephedra viridis	mountain joint-fir
Ephedra torreyana	Torrey joint-fir
Erigeron sp.	fleabane
Eriogonum inflatum	desert trumpet
Eriogonum wrightii	wright buckwheat
Euphorbia sp.	sand mat
Gilia multiflora	gilia
Gutierrezia microcephala	three-leaved snakeweed
Hilaria jamesii	galleta
Kochia sps.	Kochia
Leucelene ericoides	white aster
Opuntia erinacea	Mohave prickly pear
Opuntia polycantha	Plains prickly pear
Oryzopsis hymenoides	Indian ricegrass
Pectis augustifolia	lemon-scented pectis
Poliomintha incana	rosemary mint
Salsola iberica	Russian thistle
Sarcobatus vermiculatus	greasewood
Sphaeralcea coccinea	scarlet globe mallow
Yucca angustissima	Great Plains yucca

Ref. Smith and Associates, 1982; Benson and Darrow, 1954.

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APPENDIX D

RADIATION

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D.1 RADIATION

This appendix addresses the increased radiation doses and health impacts to the general population and remedial action workers for each alternative under consideration for remedial action at the Tuba City tailings pile. The slightly increased doses received by these individuals can, in a statistical sense, increase the potential for individual and general public health effects (excess fatal cancers) above those naturally expected. Assumptions made during the calculations of excess health effects for the general public and remedial action workers are realistic but probably conservative, in order to derive an estimate of excess effects that might occur because of exposure to low levels of radiation from the tailings.

D.1.1 BASIC FACTS ABOUT RADIATION AND ITS MEASUREMENT

Atoms that spontaneously transform, or decay, into new atoms are termed radioactive. The decaying atom is called the parent, and the atom produced by the transformation is called the daughter. The rate at which atoms decay is the radioactivity, measured by the unit curie (Ci). A more convenient unit for measuring the radioactivity of tailings piles is the picocurie (pCi), which is one-millionth of one-millionth (1×10^{-12}) of a curie. The half-life of a radioactive substance is the time required for it to lose 50 percent of its radioactivity by decay. Each radionuclide has a unique half-life.

When atoms undergo radioactive decay, they emit radiation. The most common types of radiation are alpha particles, beta particles, and gamma rays. Alpha and beta radiation are tiny particles with excess energy, and gamma radiation is pure energy without mass. Radiation transmits energy to matter as it travels through matter. Alpha radiation penetrates only a few millimeters into matter and beta radiation penetrates a few centimeters, unlike gamma radiation which can travel deeper into matter in the same way as X-rays. Alpha radiation cannot penetrate through a layer of skin, whereas gamma radiation can easily penetrate tissue and hence deliver a dose to any internal organ.

The amount of radiation to which an individual is exposed may be expressed in terms of the amount of energy imparted to cells and tissue by the radiation and the degree of biological damage associated with the energy as it is absorbed. This absorbed energy is termed the absorbed dose and is given in units of rads, where one rad equals 100 ergs of energy absorbed per gram of material irradiated. When the irradiated material is living tissue, the damage per rad varies depending on the type of radiation. By mathematically applying a "quality factor" to each specific type of radiation, the degree of biological damage can be expressed independently of the type of radiation causing it. The biologically relevant absorbed energy is termed the dose equivalent and the unit is the rem. One rad is equal to one rem for less damaging radiations where the quality factor is equal to one (e.g., gamma rays). For comparison, one rad of internal alpha-deposited energy is equal to 20 rem because alpha particles are more damaging to tissue and the quality factor for alpha radiation is 20. The millirem equals one-thousandth (1×10^{-3}) of a rem and is in more common usage when expressing doses from environmental levels of radiation.

When a succession of radioactive parent atoms decay to radioactive daughter atoms, a radioactive decay series is formed. Uranium-238 (U-238) is such a radioactive parent atom and the U-238 decay series is shown in Figure D.1.1 (Lederer et al., 1967; BRH, 1970). The U-238 decay series includes thorium-230 (Th-230), radium-226 (Ra-226), radon-222 (radon or Rn-222), short-lived radon daughters, and other long-lived radioactive atoms. The uranium-238 decay series ends with lead-206 (Pb-206), an atom that is stable and not radioactive. When the daughter products in a radioactive decay chain have shorter half-lives than the parent, the daughter radioactivities will increase, termed ingrowth, until they equal the radioactivity of the parent.

Radon is the radionuclide of primary importance to the UMTRA Project because it represents the largest radiation exposure pathway to the general public. The half-life of radon (3.8 days) is short relative to the half-life of Ra-226 (1602 years). As Ra-226 decays, the newly produced radon will begin to decay, and the radon radioactivity will become equal to the Ra-226 radioactivity within approximately 30 days. Similarly, the short-lived radon daughter radioactivities will ingrow within approximately four hours to equal the radioactivity of radon and Ra-226. When the radioactivities of the parent and its daughters are equal, the daughters are said to be in 100-percent equilibrium or simply in equilibrium. If the daughters are diluted or carried away in the air as they are formed, they will not reach 100-percent equilibrium.

The only member of the U-238 decay series that is not a solid is radon. Radon is an inert gas and does not react chemically with other elements; it therefore can diffuse out of matter and into the atmosphere. The atmospheric radon concentration is measured in units of picocuries per liter (pCi/l) of air. In the uranium milling process, Ra-226, the parent of radon, is left in the tailings, which then become a source from which radon diffuses into the atmosphere. Once in the atmosphere, radon is transported downwind and, according to its 3.8-day half-life, decays into the short-lived radon daughters which can attach to particulates in the air. Since radon is an inert gas, it is inhaled and exhaled, contributing very little radiation exposure to the lung. The radon daughters are solids, however, and once inhaled can deposit in or attach to the lung and then decay, transmitting alpha energy in the lung. Because of the short half-life, these daughters may decay before being removed from the lung.

Trace amounts of U-238 and its daughters are found everywhere on the earth; therefore, radon and its short-lived daughters contribute significantly to the natural background radiation exposure of the general public. Human exposure to radiation originates from both natural and man-made sources. The major natural radiations originate from cosmic and terrestrial external sources, and from naturally

Nuclide	Historical name	Half-life	Major radiation energies (MeV) and intensities†		
			α	β	γ
$^{238}_{92}U$	Uranium I	4.51×10^{9} y	4.15 (25%) 4.20 (75%)	---	---
$^{234}_{90}Th$	Uranium X_1	24.1d	---	0.103 (21%) 0.193 (79%)	0.063c‡ (3.5%) 0.093c (4%)
$^{234}_{91}Pa^{m}$ (99.87% → $^{234}_{92}U$; 0.13% → $^{234}_{91}Pa$)	Uranium X_2	1.17m	---	2.29 (98%)	0.765 (0.30%) 1.001 (0.60%)
$^{234}_{91}Pa$	Uranium Z	6.75h	---	0.53 (66%) 1.13 (13%)	0.100 (50%) 0.70 (24%) 0.90 (70%)
$^{234}_{92}U$	Uranium II	2.47×10^{3} y	4.72 (28%) 4.77 (72%)	---	0.053 (0.2%)
$^{230}_{90}Th$	Ionium	8.0×10^{4} y	4.62 (24%) 4.68 (76%)	---	0.068 (0.6%) 0.142 (0.07%)
$^{226}_{88}Ra$	Radium	1602y	4.60 (6%) 4.78 (95%)	---	0.186 (4%)
$^{222}_{86}Rn$	Emanation Radon (Rn)	3.823d	5.49 (100%)	---	0.510 (0.07%)
$^{218}_{84}Po$ (99.98% → $^{214}_{82}Pb$; 0.02% → $^{218}_{85}At$)	Radium A	3.05m	6.00 (~100%)	0.33 (~0.019%)	---
$^{214}_{82}Pb$	Radium B	26.8m	---	0.65 (50%) 0.71 (40%) 0.98 (6%)	0.295 (19%) 0.352 (36%)
$^{218}_{85}At$	Astatine	~2s	6.65 (6%) 6.70 (94%)	? (~0.1%)	---
$^{214}_{83}Bi$ (99.98% → $^{214}_{84}Po$; 0.02% → $^{210}_{81}Tl$)	Radium C	19.7m	5.45 (0.012%) 5.51 (0.008%)	1.0 (23%) 1.51 (40%) 3.26 (19%)	0.609 (47%) 1.120 (17%) 1.764 (17%)
$^{214}_{84}Po$	Radium C'	164μs	7.69 (100%)	---	0.799 (0.014%)
$^{210}_{81}Tl$	Radium C"	1.3m	---	1.3 (25%) 1.9 (56%) 2.3 (19%)	0.296 (80%) 0.795 (100%) 1.31 (21%)
$^{210}_{82}Pb$	Radium D	21y	3.72 (.000002%)	0.016 (85%) 0.061 (15%)	0.047 (4%)
$^{210}_{83}Bi$ (~100% → $^{210}_{84}Po$; .00013% → $^{206}_{81}Tl$)	Radium E	5.01d	4.65 (.00007%) 4.69 (.00005%)	1.161 (~100%)	---
$^{210}_{84}Po$	Radium F	138.4d	5.305 (100%)	---	0.803 (0.0011%)
$^{206}_{81}Tl$	Radium E"	4.19m	---	1.571 (100%)	---
$^{206}_{82}Pb$	Radium G	Stable	---	---	---

FIGURE D.1.1 URANIUM 238 DECAY SERIES

occurring radionuclides which are deposited inside the body via the ingestion and inhalation pathways. Exposure to man-made sources results primarily from medical exposures (e.g., diagnostic x-rays), with minor contributions from sources such as airline travel, atmospheric weapons tests, the nuclear industry, consumer products, and technologically enhanced natural radiation.

Medical usage of radiation is responsible for the highest contribution to man's radiation exposure, accounting for approximately 50 percent of man's total radiation exposure. Other man-made contributors, including airline travel, atmospheric weapons tests, the nuclear industry, and consumer and industrial products together account for approximately five percent. The remaining 45 percent of man's total radiation exposure results from exposure to natural radiation sources.

D.2 METHOD OF ANALYSIS

Radiation and its associated health effects have been studied more thoroughly than health effects from other carcinogenic agents. The evaluation of health effects caused by low-level radiation is, however, a difficult task, and many uncertainties are associated with the estimation of risks from radiation. The traditional approach for estimating risks from low-level radiation exposures is to extrapolate from effects observed at high radiation exposures using a linear dose-response and no threshold assumptions.

There are five principal pathways which could potentially result in exposure of man to radiation from the tailings pile. These are: (1) inhalation of radon daughters; (2) direct exposure to gamma radiation emitted from the contaminated area; (3) inhalation and ingestion of airborne radioactive particulates; (4) ingestion of ground and surface water contaminated with radioactive materials; and (5) ingestion of contaminated foodstuff produced in areas contaminated by tailings.

For detailed calculations of health effects in this appendix, only the most significant radiation exposure pathways are considered; they are inhalation of radon daughters and direct exposure to gamma radiation. Discussions are presented which estimate radiation exposures and health impacts to the general public and remedial action workers from the air particulate pathway and to the general public from the drinking water ingestion pathway. When risk estimates are calculated for various remedial action alternatives, the following means of handling significant figures will be used to facilitate comparison of alternatives. Any results that may be used in further calculations, such as summations of risk, will be rounded to two significant figures. Final results, such as total risk estimates for alternatives, will be rounded to one significant figure.

Analyses of excess health effects due to air particulates have been performed (DOE, 1985a, 1984, 1983) with results indicating that inhalation of suspended particulates from the tailings pile results in relatively small radiation exposures for workers on the pile and negligible exposures to the general public. To control airborne radioactive particulate releases during remedial action, mitigating measures would include surficial wetting of the materials and haul roads, and protective clothing such as dust masks or respirators would be provided to remedial action workers.

A health effects calculation for ingestion of contaminated drinking water was done using the maximum concentrations of radionuclides measured in water samples collected from beneath and downgradient of the tailings pile. The calculation resulted in a conservative individual risk estimate that is 5.3 percent of the individual risk calculated for inhalation of radon daughters and gamma exposure within 0.5 mile from the pile perimeter. Under existing conditions, no one would be exposed to the radionuclide concentrations used because the wells from which the radionuclide concentrations were monitored are not used as a source of drinking water and dilution with distance from the pile was not taken into account.

Excess health effects resulting from the ingestion of plant material that has been "dusted" with windblown tailings or the ingestion of animal food products (i.e., meat, milk, eggs) from animals that have ingested such plant material have been calculated at other Uranium Mill Tailings Remedial Action (UMTRA) Project sites (DOE, 1985a,b). The radiation dose resulting from the contaminated food pathway to the hypothetical, maximally exposed adult individual was calculated for remedial action at the Riverton, Wyoming, UMTRA Project site using conservative assumptions. These assumptions included that the individual consumed foodstuff produced only on contaminated soil, that washing and cooking vegetables removed only half of the radioactive contamination, and that the individual lived 50 meters downwind of the tailings pile from the prevailing wind direction. Under these hypothetical conditions, the risk of excess health effects was found to be negligible. Although the mass of air particulates generated during either remedial action alternative at the Tuba City site would exceed that generated at the Riverton, Wyoming, site, the excess health risk to a member of the general public from this pathway is judged to be insignificant because there is no agricultural land in the vicinity of the tailings pile, there are no residences within 0.25 mile of the tailings pile, and the grazing land in the vicinity of the tailings site does not produce enough food for human consumption to have an appreciable effect on the Tuba City population.

The health effects estimations made in this appendix are primarily based on data and models presented in the BEIR-III report (NAS, 1980). Quantitative risk estimation of somatic effects (e.g., cancer) for various organs of the body can be obtained using available human radiation exposure data. The manifestation of a cancer caused by radiation exposure would occur after a latent period of up to 25 years or more, depending on the type of cancer and the age of the person exposed. The risks from radiation vary with adult age and sex but are presented here as average values assuming that the variation due to adult age and sex is small. No data are available that indicate whether risk estimates for adults are appropriate for radiation exposure during childhood. Because the BEIR-III report did not always make firm recommendations for application of the data, health risk estimates in this appendix also make use of recommendations published in scientific journals.

D.2.1 HEALTH EFFECTS OF EXPOSURE TO RADON DAUGHTERS

The health effects of radon diffusion from tailings arise from the inhalation of short-lived radon daughters which deposit alpha energy in the lung. For radiation protection purposes, the International Commission on Radiological Protection (ICRP, 1977) proposed an individual lung cancer risk factor of 20×10^{-6} per rem, or 20 excess fatal cancers where one million individuals each receive a one-rem lung dose equivalent commitment from radon daughters.

Health effects from radon daughter inhalation can also be expressed as excess risk of lung cancer based on the lung collective dose equivalent commitment in person working-level months (person-WLM). The unit of working level (WL) is defined as any combination of short-lived radon daughters in one liter of air, which, on complete decay, results in a total emission of 1.3×10^5 million electron volts (MeV) of alpha energy. One WL is equivalent to 100 pCi of radon per liter of air, with the short-lived radon daughters in 100 percent equilibrium. At equilibrium levels less than 100 percent, the WL corresponding to a given radon concentration is reduced. The working level month (WLM) is a unit defined as the exposure resulting from the inhalation of air with a concentration of one WL of radon daughters for 170 working hours. The total dose of one or more persons is the product of the number of persons and the average dose they receive; the unit of measurement of such a population dose is the person-WLM.

Following are estimates of excess fatal lung cancers given in terms of person-WLM. The United Nations Scientific Committee on the Effects of Atomic Radiation quoted a range of 200 to 450 x 10^{-6} fatal cancers per person-WLM (UNSCEAR, 1977), while the NRC in its environmental impact statement on uranium milling quoted 360 x 10^{-6} fatal cancers per person-WLM (NRC, 1980a). The BEIR-III report formulated an age-dependent model for predicting the risk of lung cancer based on several studies of uranium and fluorspar miners. Evans et al. (1981) reviewed the BEIR-III study, lung cancer risk estimates published by other authors, and epidemiological evidence. They concluded that the most defensible upper bound to the lifetime lung cancer risk for the general public is 100 x 10^{-6} fatal cancers per person-WLM. The BEIR-III committee reported a conversion factor of one WLM approximately equal to a five-rem dose equivalent commitment to the lung. The risk estimate of 100 x 10^{-6} deaths per person-WLM is therefore equivalent to the ICRP risk estimate stated previously. For conservatism, the value of 300 x 10^{-6} deaths per person-WLM is used in this appendix for calculating health effects due to exposure to radon daughters.

D.2.2 HEALTH EFFECTS OF EXPOSURE TO GAMMA RADIATION

Tailings piles emit gamma radiation that delivers an external exposure to the whole body of a person near the pile. The BEIR-III report contains several models for estimating cancer risk resulting from exposure to gamma radiation. Health effects estimates in this appendix for excess fatal cancers due to gamma radiation use a risk factor of 120 x 10^{-6} fatal cancers per person-rem (NAS, 1980; Cohen, 1981). This is equivalent to 120 excess fatal cancers in an exposed population for each 1,000,000 person-rems of collective dose equivalent. A person-rem is the product of the radiation dose commitment multiplied by the number of people receiving that dose.

Health effect estimates for gamma radiation exposure were calculated for remedial action workers and for the general public within 0.3 mile from the tailings site. The contribution from the tailings pile to gamma radiation levels becomes negligible beyond approximately 0.3 mile from the tailings pile perimeter. A health effects analysis was done for the general public and remedial action workers to determine gamma radiation effects during transportation of tailings in the relocation alternatives.

For gamma radiation, one rem is approximately equal to one roentgen (R) which is the unit for measuring gamma radiation intensity in air. A microroentgen (microR) is one-millionth of a roentgen, and typical environmental gamma radiation levels are expressed in microR per hour (microR/hr).

The health effects attributed to a gamma radiation dose are categorized into two general types: somatic and genetic. Somatic effects are manifested in the exposed individual (e.g. cancer) and genetic effects are manifested in the descendants of the exposed individual. The ICRP (1977) reported that the average risk estimate for genetic effects, as expressed in the first two generations and considered genetically significant, is 40×10^{-6} per rem. For all subsequent generations, the risk is estimated to be equal to that expressed in the first two generations. The total genetic risk (all generations) is, therefore, 80×10^{-6} per rem. Measures taken to reduce the somatic effects would also reduce the genetic effects, thus the calculations in this appendix reflect only the somatic risk.

D.3 CALCULATIONS OF HEALTH EFFECTS

The computation of excess health effects begins by determining the "additional amount" of radiation that a tailings site contributes to an area. Only this "additional amount" is used to estimate excess health effects. For each radiation type, there is a risk factor that associates an effect (e.g., cancer) with a specific amount of that radiation (e.g., rem). Multiplying together the additional amount of radiation in an area, the time spent in that area, the number of people in that area, and the risk factor for the radiation of concern gives the estimated number of extra cancers that might occur in the group being exposed to the "additional radiation." This estimated number of extra cancers is the number of cancers that might occur due only to the radiation from the tailings.

D.3.1 STABILIZATION IN PLACE

General public health effects from radon daughter exposure

The population distribution in the vicinity of the Tuba City tailings site was used as a basis to calculate the health effects to the general public during stabilization in place. There are approximately 115 people living within a three-mile radius of the tailings pile and approximately 7020 people living within a six-mile radius of the tailings pile, distributed by sector as shown in Table D.3.1 (TAC, 1985). An average of five occupants per household was used to calculate the population estimate (DOC, 1980). It was assumed that people spend 75 percent of their time in the immediate vicinity of their residences (25 percent outdoors and 50 percent indoors), and 25 percent of their time beyond a distance from the site where radon daughter health effects become negligible.

The remedial action for stabilization in place would take 18 months. Disturbance and exposure of the tailings would occur for a maximum of 12 months, during which time radon releases would be increased.

To develop the radon source term during stabilization in place, the radon flux was calculated using the RAECOM model (NRC, 1984), assuming that no cover exists. The stabilization in place alternative involves the excavation of 222 acres of windblown contamination (windblown includes road berms of 26 acres or 41,500 cubic yards), 28 acres of contamination in the mill yard and ore storage area, and 6.5 acres of contamination in the former emergency spill ponds. These contaminated materials would be placed on the 25-acre tailings pile and 27.5 acres of the emergency spill ponds. Therefore, the site radon source term was calculated using the sum of the four separate source terms.

The tailings pile was divided into 15 layers at 2.5-foot increments (76.0 cm). Input parameters for each layer are shown in Table D.3.2. A diffusion coefficient of 0.027 square centimeters per second (cm^2/s) for the tailings pile (Nielson, 1984a) and an emanation fraction of 0.21 (Nielson, 1984b) were used. For this calculation,

Table D.3.1 Tuba City estimated 1985 population distribution[a]

	Radius (miles from the tailings pile edge)																
Direction	0.25	0.5	0.75	1.0	1.25	1.5	1.75	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	Total
N	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25
NNE	0	0	10	0	0	0	0	0	0	15	0	0	0	0	0	0	25
NE	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	10
ENE	0	0	0	0	0	0	0	0	0	10	5	0	0	0	0	0	15
E	0	0	0	0	0	10	0	0	0	0	0	0	5	0	0	5	20
ESE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SW	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	15
WSW	0	0	0	0	0	0	0	0	0	0	0	0	5	5	1600	0	1610
W	0	0	5	0	0	5	0	0	0	20	15	65	30	15	5045	0	5200
WNW	0	0	5	0	0	0	0	0	0	0	0	0	10	15	30	15	75
NW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	5
NNW	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	10	20
Total	0	25	20	0	0	25	0	0	0	45	20	80	60	35	6680	30	7020

[a]An average of five occupants per household was used to calculate the population estimate (DOC, 1980).

Table D.3.2 RAECOM model radon flux calculatio. .or the Tuba City tailings pile

Layer no.	Thickness (cm)	Ra-226 (pCi/g)	Radon diffusion coefficient (cm^2/s)	Emanating fraction	Porosity fraction	Bulk density (g/cm^3)	Moisture fraction
1 (bottom)	76	15	0.027	0.21	0.49	1.40	0.13
2	76	15	0.027	0.21	0.49	1.40	0.13
3	76	23	0.027	0.21	0.49	1.40	0.13
4	76	42	0.027	0.21	0.49	1.40	0.13
5	76	73	0.027	0.21	0.49	1.40	0.13
6	76	162	0.027	0.21	0.49	1.40	0.13
7	76	312	0.027	0.21	0.49	1.40	0.13
8	76	438	0.027	0.21	0.49	1.40	0.13
9	76	517	0.027	0.21	0.49	1.40	0.13
10	76	554	0.027	0.21	0.49	1.40	0.13
11	76	734	0.027	0.21	0.49	1.40	0.13
12	76	894	0.027	0.21	0.49	1.40	0.13
13	76	1011	0.027	0.21	0.49	1.40	0.13
14	76	1059	0.027	0.21	0.49	1.40	0.13
15 (top)	76	1052	0.027	0.21	0.49	1.40	0.13

the average Ra-226 concentration by 2.5-foot layers was used based on field data (BFEC, 1984; MSRD, 1982) and computer modeling which generated a profile of tailings pile contamination distribution. The radon flux calculation resulted in an annual average radon flux of 705 picocuries per square meter per second (pCi/m^2s) from the tailings pile.

The 479,400 cubic yards of windblown contamination were determined to have a radon flux of 33.8 pCi/m^2s based on an average radon concentration of 33.8 pCi/g multiplied by one pCi/m^2s per picocurie per gram (pCi/g) Ra-226 (NRC, 1979). The remaining excavated material (mill yard, ore storage area, and emergency spill ponds) was similarly determined to have a radon flux of 84.7 pCi/m^2s.

The radon flux from the pile and emergency spill pond areas will decrease as it is covered with the remaining contaminated material. This reduction in radon flux, however, was not included in the site flux. For conservatism, the 25-acre pile flux was assumed to remain at 705 pCi/m^2s for the duration of remedial action, and the 27.5 acres of emergency spill ponds were assumed to have a radon flux of 84.7 pCi/m^2s. The 6.5 remaining acres (2.63×10^4 square meters) of emergency spill ponds were assumed to be removed at a uniform rate, and the area would be reduced linearly from $2.63 \times 10^4 m^2$ to zero during the 12 months of remedial action. The resulting radon source term would be calculated with the following equation:

Equation D.3.1

$$[(25\ ac)(705\ pCi/m^2s) + (27.5\ ac)(84.7\ pCi/m^2s)] \times [(4048\ m^2/ac)(3.15 \times 10^7 s)] +$$

$$(84.7\ pCi/m^2s) \int_0^{3.15x10^7} 2.63 \times 10^4 m^2 - \frac{2.63 \times 10^4 m^2}{3.15 \times 10^7 s}\ t\ \ dt = 2579.5\ Ci.$$

It was also assumed that the windblown material would be excavated at a uniform rate, and therefore the area of contamination would decrease linearly from 248 acres ($1.004 \times 10^6 m^2$) to zero during the 12 months of disturbance of the tailings and other contaminated materials. Since the windblown material has a radon flux of 33.8 pCi/m^2s, this contribution to the total source term can be calculated with the following equation:

$$(33.8\ pCi/m^2s) \int_0^{3.15x10^7} 1.004 \times 10^6 m^2 - \frac{1.004 \times 10^6\ m^2}{3.41 \times 10^7 s}\ t\ \ dt = 534.5\ Ci.$$

Similarly, the radon source term for the ore storage/mill yard area would be reduced linearly from 28 acres ($1.133 \times 10^5 m^2$) to zero during the 12-month remedial action period. The radon flux from this area is 84.7 pCi/m^2s and therefore would contribute to the total radon source as follows:

$$(84.7\ pCi/m^2s) \int_0^{3.15x10^7} 1.133 \times 10^5 m^2 - \frac{1.133 \times 10^5\ m^2}{3.15 \times 10^7 s}\ t\ \ dt = 151\ Ci.$$

An additional radon release from the soil interstitial pore spaces would occur during remedial action excavation of contaminated materials. Assuming the radon to be in secular equilibrium with Ra-226, the total activity of radon in the 479,400 yd^3 of windblown contamination, 51,500 yd^3 of material in the ore storage/mill yard areas, and the 19,600 yd^3 of material consolidated from the emergency spill ponds is:

$$[(479{,}400\ yd^3)(33.8\ pCi/g) + (51{,}500\ yd^3)(84.7\ pCi/g) + (19{,}600\ yd^3)(84.7\ pCi/g)] \times [(1.6 g/cm^3)(7.646 \times 10^5 cm^3/yd^3)(Ci/10^{12}\ pCi)] = 27\ Ci.$$

Using an emanation fraction for radon of 0.22, the radon puff release from soil interstitial pore spaces would be six Ci.

The total site radon source term for the stabilization in place alternative would be the sum of the above terms, or 3271 Ci.

The radon concentration on the site was determined by summing the radon concentrations from the tailings pile, ore storage area, emergency spill ponds, mill yard area, and windblown tailings area. An average wind velocity of 4.0 meters per second was used. This value was calculated by weighting each wind speed by its frequency of occurrence. An area radius of 180 meters for the tailings pile, 283 meters for the emergency spill pond/mill yard/ore storage, and

565 meters for the windblown tailings was used in each determination of radon concentrations.

For calculation purposes, a conservative distribution of stability classes was used based upon meteorological data from Winslow, Arizona (NOAA, 1983), and the respective area geometries were assumed to be circular. The radon concentration at the center of each circular area was conservatively estimated by using the frequency of occurrence of the stability class and integrating the functional form of sigma Z as function of distance from the area centers back to the area edges, ignoring crosswind spreading. This is similar to assuming that the center of the area is always at the edge of an infinite strip of area source, with the width equal to the area radius. The sum of the resulting radon concentrations for all three areas was calculated to average 8.56 pCi/l.

To estimate the radon concentration and working level downwind from the tailings pile, annual average radon concentrations and working levels as a function of distance from the pile were calculated using a sector average form of the Gaussian diffusion equation (Turner, 1969) and a calculation of the ingrowth of radon daughters as a function of time (Evans, 1980). The area source (final size of stabilized pile) was treated as a point source at the pile center with the same source strength as the site (3271 Ci per year per 48 acres or 534 pCi/m^2s). The calculated radon concentration is a function of wind speed and stability class for each distance downwind. A conservative distribution of wind speed and stability class based on the joint frequency distribution between wind speed and wind direction data for a conservative sector from Winslow, Arizona, was assumed that would result in maximum radon and radon daughter concentrations downwind for a sector as summarized in Table D.3.3. This bivariate joint frequency distribution was then used to time-weight the radon concentration calculated at a given downwind distance according to the percent of the time that each wind speed and stability class pair occurs. Similarly, the percent ingrowth of daughters at a given downwind distance was calculated based on the transit time of the radon from the area source center. The working level due to the pile at varying distances from the pile is dependent on the percent ingrowth of radon daughters. Between a transit time of one minute and 40 minutes, the WL grown into 100 pCi/l of radon can be represented within plus five percent by the approximate analytical expression (Evans, 1980):

Equation D.3.2

$$WL = 0.023\ T^{0.85}$$

where:

WL = working level.
T = transit time in minutes.

The working level for each wind speed and stability class was also time-weighted using the assumed joint frequency distribution.

The use of the sector average model, with the area source replaced by a point source, generally overpredicts the concentrations at distances close to the source. At distances greater than several

Table D.3.3 Joint frequency distribution between wind speed and stability class for a conservative sector from Winslow, Arizona

Stability class	Wind speed (miles per hour) 0-3	4-7	8-12	13-18	19-24	>25	Total
A	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B	0.0	0.007020	0.0	0.0	0.0	0.0	0.007020
C	0.0	0.003159	0.007020	0.0	0.0	0.0	0.010179
D	0.0	0.005967	0.014976	0.007020	0.0	0.0	0.027963
E	0.016965	0.007020	0.013923	0.0	0.0	0.0	0.037908
F	0.016965	0.017082	0.0	0.0	0.0	0.0	0.034047

Note: The distribution of frequencies in the table refers to the percentage of time that wind blew for each class from the conservative sector. A total of 13.3 percent of calms was not assigned a direction during the observation program. To include this significant fraction of occurrence which produces the largest concentrations, it was estimated that a full 50 percent of the calms were associated with drainage conditions, and that the drainage was limited to only two 22.5 degree sectors. Thus, 3.4 percent of the calm percentage was divided equally between the E and F stability classes. This resulted in the stability class distribution provided in the table above.

source diameters from the edge of the source, the model is reasonably accurate; however, overprediction can be up to a factor of two at distances less than several source diameters. To estimate radon concentrations within one mile of the pile edge, interpolation was done on a log-log basis between the previously calculated on-pile radon concentration and the modeled radon concentrations beyond one mile. Similarly, the working-level exposures within one mile of the pile edge were calculated by extrapolating on a semi-logarithmic basis from the modeled working levels beyond one mile.

For the general public health effects calculations, assumptions were made which resulted in a conservative estimate of working levels as a function of distance from the pile edge. A wind direction frequency in the conservative sector of 11.7 percent was used. Table D.3.3 shows that the maximum measured wind direction frequency from any direction was 11.7 percent. All of the population was assumed to live in this conservative sector of interest. These assumptions provide a reasonable upper bound for the general public health effects estimates.

The radon concentration and working levels due to the pile at varying distances from the pile edge are presented in Table D.3.4. The percent ingrowth formula used to derive working levels assumed that no daughter products are removed from the air by plate-out. Plate-out occurs when the electrically-charged radon daughters attach to walls or other surfaces and are removed from the air, thereby reducing the percent equilibrium of radon daughters in the air inhaled. To account for plate-out in health effects calculations for outdoor conditions, the working level in inhaled air was assumed to be one-half of that calculated from the ingrowth formula; that is, 50 percent plate-out was assumed. For indoor working levels, the outdoor radon concentration as a function of distance was multiplied by a 50 percent equilibrium factor for radon daughters.

Table D.3.4 Radon daughter health effects to the general population during remedial action for stabilization in place

Distance from pile edge (miles)	Population	Radon concentration (pCi/l)	Modeled outdoor working level $\times 10^{-4}$	$WLM(r) \times 10^{-4}$	Excess health effects $\times 10^{-4}$
0.5	25	0.90	15.2	2417.0	18
0.75	20	0.50	15.2	1386.0	8.3
1.5	25	0.19	11.30	312.6	2.3
3.0	45	0.07	5.69	123.3	1.7
3.5	20	0.05	4.64	99.4	5.9
4.0	80	0.04	3.90	82.6	2.0
4.5	60	0.04	3.35	70.2	1.3
5.0	35	0.03	2.94	60.8	0.6
5.5	6680	0.03	2.60	53.4	110
6.0	30	0.03	2.34	47.5	0.4
Total	7020				150

For each distance, the number of working-level months per person exposed was calculated using the equation:

Equation D.3.3

$$WLM(r) = \left(\frac{R(r)}{100} \times I + WL(r) \times O\right)\left(\times \frac{H}{170\ (hr/WLM)} \times T\right)$$

where:

$WLM(r)$ = working-level months (WLM) per person exposed at distance r.
$R(r)$ = radon concentration at distance r (pCi/l).
$WL(r)$ = working level at distance r (WL).
O = fraction of time spent outdoors multiplied by the radon daughter plate-out factor (0.25 x 0.5).
I = fraction of time spent indoors multiplied by the radon daughter equilibrium factor (0.5 percent x 0.5).
H = hours per year (8760 hours).
T = duration of exposure (years).

The results of the above calculations are presented in Table D.3.4. The health effects were calculated by multiplying the working-level months by the population at each distance and by the conversion factor of 300 x 10^{-6} effects per person-WLM. Health effects were then summed over the distances.

The estimated number of excess health effects due to the 12-month tailings pile disturbance for the general public within six miles of the Tuba City tailings pile was calculated as 0.0148 excess health effects for stabilization in place.

General public health effects from gamma exposure

The general public living or working within 0.3 mile of the tailings pile edge will be exposed to gamma radiation from the tailings as well as to radon daughters. The contribution from the tailings pile to gamma radiation levels is negligible beyond approximately 0.3 mile from the tailings pile perimeter. A predictive model (Yuan et al., 1983) which plots the ratio of direct gamma exposure rate divided by tailings Ra-226 concentration (microR/hr per pCi/g) as a function of distance from a tailings pile edge was used to estimate gamma radiation exposure rates contributed by the tailings to the general public. This model assumes that no cover exists on the tailings pile. The measured average Ra-226 concentration of 959 pCi/g was multiplied by the ratio at each distance to determine the gamma exposure rate. Input parameters and health effects results due to the 12-month tailings pile disturance are shown in Table D.3.5. Since individuals are assumed to spend 75 percent of their time at home, the period of exposure is 0.75 x 12 months, or 6570 hours. Using the risk factor mentioned in Section D.2.2, the estimated number of excess health effects in the general public living within 0.3 mile of the pile edge due to gamma radiation from the tailings is 0.0000095 excess health effects. The number 0.0000095 is the increased number of cancers that might occur in the exposed population from gamma radiation originating from the tailings. This number is intended to be interpreted per the time of remedial action when the tailings are uncovered, in this case, approximately one year.

Table D.3.5 General public health effects from gamma exposure during stabilization in place

Distance from pile edge (miles)	Population	Individual hours exposed	Excess gamma exposure rate (microR/hr)	Excess health effects x 10^{-6}
0.3	25[a]	6570	0.48	9.5

[a]The 25 individuals located between 0.26 and 0.5 mile were conservatively assumed to reside within the 0.3-mile range.

Remedial action worker health effects from radon daughter exposure

An average of approximately 48 workers would be required during the 12-month remedial action for stabilization in place. To estimate an upper bound for excess health effects to remedial action workers, it was assumed that each worker would spend eight hours per day, 16.7 days per month over 12 months (1603 hours) outside on the pile, and be exposed to a radon concentration of 8.56 pCi/l as calculated previously for the 12-month period when the pile is uncovered. The radon daughter percent equilibrium on the pile was conservatively assumed to be 20 percent based on percent equilibrium measurements made near the Grand Junction uranium tailings pile (Borak and Inkret, 1983). From a calculation similar to Equation D.3.2, the estimated excess health effects to site workers due to the 12-month remedial action are (8.56 pCi/l/100 pCi/l-WL) (0.2 equilibrium fraction) (1603 hours) (1 WLM/170-WL-hours) (48 persons) (300 x 10^{-6} health effects/person WLM), which equals 2.3 x 10^{-3}.

Remedial action worker health effects from gamma exposure

Remedial action workers on the pile would be exposed to gamma radiation from tailings, as well as to radon daughters. The estimated gamma exposure rate on the pile in microR/hr is 2.5 times the Ra-226 concentration in pCi/g (Schiager, 1974), or 2400 microR/hr based on the measured average Ra-226 concentration of 959 pCi/g. It should be noted that this is a highly conservative estimate and represents an upper bound which, in practice, is not expected to be reached. On a partially reclaimed portion of the tailings pile, the exposure rate would be reduced by a factor of 10 for each foot of cover material. The majority of workers would be enclosed in cabs of earthmoving equipment which would provide shielding from the tailings, where one inch of steel reduces gamma-ray transmission by a factor of 10. A more realistic average gamma radiation exposure rate to remedial action workers would therefore be a factor of 10 below 2400 microR/hr, or approximately 240 microR/hr. Based on 240 microR/hr, the external gamma radiation exposure that a worker could be expected to receive from working 1603 hours over a 12-month period would be 0.38 rem, which is within the standard limit of five rem per year for occupational exposure (NRC, 1980b). For 48 remedial action workers, the estimate for excess health effects due to gamma radiation is 2.2 x 10^{-3}.

The total estimated health effects to remedial action workers during stabilization in place from radon daughter inhalation and gamma radiation is 5 x 10^{-3} excess health effects.

Remedial action worker and general public exposures to particulates

Occupational exposures for remedial action workers breathing dust in the vicinity of earthmoving equipment have been estimated for comparison to the combined radon daughter exposure and gamma radiation exposure at other UMTRA Project sites. A method proposed by NRC (1981) was used at the Riverton, Wyoming, UMTRA Project site to estimate doses from inhalation of particulates. These doses would be to the worker's lung from inhalation of respirable particulates (<10 microns in size) that contain trace amounts of U-238, Th-230, and Ra-226. The calculated 50-year dose commitments to the lungs from Ra-226, Th-230, and U-238 from excavation at the Riverton site resulted in a total 50-year dose commitment to the lung of 6.2 mrem.

Using the ICRP lung cancer risk factor of 20 x 10^{-6} per rem which is equivalent to the risk of 300 x 10^{-6} per WLM used for radon daughter exposure, the risk from a 50-year dose commitment of 6.2 mrem at Riverton was found to be 1.2 x 10^{-7}. The calculations showed that for workers in the stabilization in place alternative at Riverton, Wyoming, the risk from inhalation of particulates was 0.2 percent of that from the sum of the risks from exposure to gamma rays and radon daughters. The amount of particulates generated at the Tuba City site will be greater than at the Riverton site; however, the resulting excess health effects would be greater but still negligible with respect to the risk due to gamma and radon daughter exposure.

For persons off the pile, the particulate component of total dose becomes even smaller. Based on this, it was also concluded for the Riverton site that since particulate doses would be negligible for remedial action workers, then particulate doses to the general public that result from remedial actions would be negligible as well. Similarly, the radiation doses to the general public at Tuba City would not be significantly increased through the inhalation of airborne particulates.

D.3.2 NO ACTION

General public health effects from radon daughter exposure

The estimated population distribution (see Table D.3.1) was used as a basis to calculate the health effects to the general public if remedial action did not occur. For this analysis it was assumed that people spend 75 percent of their time in the immediate vicinity of their residences; 25 percent outdoors, 50 percent indoors, and 25 percent of their time beyond a distance from the site where radon daughter health effects become negligible. The population distribution as a function of distance from the pile is presented in Table D.3.6, which also presents additional input parameters as well as results for this health effects calculation.

The radon flux source term under no action conditions was calculated using the RAECOM model (NRC, 1984). The total source term was calculated by summing the source terms from the 25-acre tailings piles, the 62-acre ore storage area, mill yard and evaporation ponds, and the 248 acres contaminated by windblown tailings.

The pile area was divided into 15 layers at 2.5-foot increments (76.0 cm). Input parameters for each layer are shown in Table D.3.2. The method of calculating a tailings pile radon source term for no action conditions was as described under the stabilization in place alternative. The calculation resulted in an annual average radon flux of 705 pCi/m^2s from the uncovered tailings pile. Using a pile surface area of 25 acres, the radon flux of 705 pCi/m^2s for no action conditions is equivalent to a tailings pile source term of 2247 Ci/year.

Table D.3.6 Radon daughter health effects to the general population for no remedial action

Distance from pile center (miles)	Population	Modelled outdoor radon concentration (r) (pCi/l)	Modelled outdoor working level (r) x 10^{-4}	Calculated WLM (r) x 10^{-4} per year of exposure	Excess health effects x 10^{-4} per year
0.5	25	1.11	16.3	1535.0	12
0.75	20	0.63	16.3	917.0	5.5
1.5	25	0.23	11.7	372.0	2.8
3.0	45	0.082	6.94	150.4	2.0
3.5	20	0.066	5.66	121.2	0.7
4.0	80	0.054	4.76	100.7	2.4
4.5	60	0.046	4.09	85.6	1.5
5.0	35	0.040	3.58	74.2	7.8
5.5	6680	0.035	3.18	65.2	130.6
6.0	30	0.030	2.85	58.0	0.5
Total	7020				170

The area including the former emergency spill ponds, ore storage areas, and mill yard was determined to have an average Ra-226 concentration of 84.7 pCi/g soil. In order to calculate the radon flux from this area, the NRC (1979) radon flux to radium concentration conversion factor was used. For wet tailings, a concentration ratio of 0.35 pCi/m^{2}s: 1 pCi/g Ra-226 is appropriate, and for dry tailings a ratio of 1.2 pCi/m^{2}s: 1 pCi/g Ra-226 is correct. The NRC, however, suggests using the generic value of 1 : 1 for this conversion. Therefore, since the average Ra-226 concentration in this 62-acre area is 84.7 pCi/g, the average radon flux may be estimated to be 84.7 pCi/m^{2}s and is equivalent to a source term of 670 Ci/year.

The large 248-acre area contaminated with windblown tailings has an average Ra-226 concentration of 33.8 pCi/g of soil, and therefore has an estimated radon flux of 33.8 pCi/m^{2}s. The source term for the windblown tailings area is therefore estimated to be 1069 Ci per year.

The total source term for the Tuba City site may be determined by summing the source terms for the three different areas resulting in a value of 3986 Ci radon per year.

The radon concentration on the site was determined by summing the radon concentrations from the tailings pile, ore storage area, emergency spill ponds, mill yard area, and windblown tailings area. An average wind velocity of 4.0 meters per second was used. This value was calculated by weighting each wind speed by its frequency of occurrence. An area radius of 180 meters for the tailings pile, 283 meters for the emergency spill pond/mill yard/ore storage area, and 565 meters for the windblown tailings was used in each determination of radon concentrations.

For calculation purposes, a conservative distribution of stability classes was used based upon meteorological data from Winslow, Arizona (NOAA, 1983), and the respective area geometries were assumed to be circular. The radon concentration at the center of each circular area was conservatively estimated by using the frequency of occurrence of the stability class and integrating the functional form of sigma Z as a function of distance from the area centers back to the area edges, ignoring crosswind spreading. This is similar to assuming that the center of the area is always at the edge of an infinite strip of area source, with the width equal to the area radius. The sum of the resulting radon concentrations for all three areas was calculated to average 8.56 pCi/l.

To estimate the radon concentration and working levels downwind from the site, annual average radon concentrations and working levels as a function of distance from the site were determined as described under the stabilization in place alternative. The area sources (tailings pile, emergency spill ponds/ore storage area/mill yard, and windblown tailings area) were treated as a total point source at the site center. The source strength (93.3 pCi/m^2s) was determined by calculating the area weighted radon flux for all three areas (Equation D.3.4).

Equation D.3.4

$$\frac{(25\ ac)(705\ pCi/m^2s)+(62\ ac)(84.7\ pCi/m^2s)+(248\ ac)(33.8\ pCi/m^2s)}{25+62+248\ ac}$$

A conservative distribution of wind speed and stability class was assumed that would result in maximized radon and radon daughter concentrations downwind for a sector (Table D.3.3).

This bivariate joint frequency distribution was then used to time-weight the radon concentration calculated at a given downwind distance according to the radon concentration according to the percent of the time that each wind speed and stability class pair occurs. Similarly, the percent ingrowth of daughters at a given downwind distance was calculated based on the transit time of the radon from the area source center. The working level due to the pile at varying distances from the pile is dependent on the percent ingrowth of radon daughters. Between a transit time of one minute and 40 minutes, the WL grown into 100 pCi/l of radon can be represented within plus five percent by the approximate analytical expression (Evans, 1980) given in Equation D.3.2. The working level for each wind speed and stability class was also time-weighted using the assumed joint frequency distribution.

The use of the sector average model, with the area source replaced by a point source, tends to overpredict the concentration at distances close to the source. At distances greater than several source diameters from the edge of the source, the model is reasonably accurate. At distances less than several source diameters, however, overprediction can be up to a factor of two.

The area of the source including the tailings pile, emergency spill ponds, mill yard, ore storage areas, and windblown tailings area is large, and therefore the model is inappropriate and overpredicts radon concentrations at distances closer than 2.5 miles from the edge of the site.

To estimate radon concentrations close-in to the pile edge, interpolation was done on a log-log basis between the previously calculated on-pile radon concentration (8.56 pCi/l) and the modeled radon concentrations beyond 2.5 miles.

For the general public health effects calculations, assumptions were made which resulted in a conservative estimate of working levels as a function of distance from the pile edge. A wind direction frequency in the conservative sector of 11.7 percent was used as provided in Table D.3.3. All of the population was assumed to live in this conservative sector of interest. These assumptions provide an upper bound for the general public health effects estimates.

The radon concentration and working level due to the pile at varying distances from the pile edge are presented in Table D.3.2. The percent ingrowth formula used in the model to derive working level assumed that no daughter products were removed from the air by attaching themselves to non-respirable particles or to other surfaces (plate-out). Table D.3.6, therefore, presents modeled outdoor working levels assuming zero-percent plate-out of radon daughters. For indoor working levels, the outdoor radon air concentration as a function of distance was multiplied by a 50 percent equilibrium factor for radon daughters; no ingrowth factor was applied. These factors are applied in Equation D.3.3 for outdoors and inhalation to determine working-level-month exposures. For each distance, the number of working-level months was therefore calculated using Equation D.3.3.

The results of the above calculation for no action are presented in Table D.3.6. The health effects were calculated by multiplying the working-level months by the population at each distance and by the conversion factor of 300×10^{-6} deaths per person-WLM. Health effects were then summed over the distances.

The estimated number of yearly excess health effects under no action conditions for the general population within six miles of the Tuba City tailings pile was 0.016 excess lung cancer deaths per year of exposure.

<u>General public health effects from gamma radiation</u>

The general public living or working within 0.3 mile of the tailings edge will be exposed to gamma radiation from the tailings as well as the radon daughters. The contribution from the tailings pile to gamma radiation levels is negligible beyond approximately 0.3 mile from the tailings pile perimeter. Using the same calculational approach as in Section D.3.1, the estimated excess health effects due to gamma radiation in the general public living within 0.3 mile of the tailings pile edge is 9.5×10^{-6} per year or 0.0000095 excess health effects per year of no action (Table D.3.7).

Table D.3.7 General population health effects from gamma exposure for no remedial action

Distance from pile edge (miles)	Population	Individual hours exposed/yr	Excess gamma exposure rate (microR/hr)	Excess health effects $\times 10^{-6}$ per year
0.3[a]	25	6570	0.48	9.5

[a]The 25 individuals located between 0.26 and 0.5 mile were conservatively assumed to reside within the 0.3-mile range.

General public health effects from ingestion of contaminated drinking water

The following discussion is an assessment of the radiological risk to individuals living in the vicinity of the Tuba City tailings pile who use the unconfined sandstone aquifer monitoring wells as their source for drinking water. Radionuclides from the tailings can seep into the ground water and migrate downgradient to hydrologic monitoring wells installed beneath and downgradient of the tailings pile. This health effects calculation is based upon a radiological assessment prepared by Millard and Baggett (1984), which concluded that the risk from inhalation of radon daughters dominated the health effects analysis compared to the estimated risk from the water ingestion pathway for people living in the vicinity of an operating uranium mill.

For the no action alternative, the maximum concentrations of radionuclides in samples drawn from hydrologic monitoring wells in the unconfined sandstone aquifer directly beneath or downgradient of the ponds were used to calculate health effects. The maximum concentrations were 95 pCi/l for U-238 and 122 pCi/l for U-234. Maximum Ra-226, Th-230, and Pb-210 concentrations were measured at 2.0 pCi/l, 0.1 pCi/l, and 0.9 pCi/l, respectively (Appendix B, Water). These concentrations were found under existing conditions and were used to maximize estimated health effects from the ingestion of drinking water.

In the calculation, 50-year dose commitments were determined per year of exposure for all pertinent organs, which include total bone, endosteum, liver, kidney, and lung. An F_1 uptake to blood factor for U-238 and U-234 of 0.05 (ICRP, 1981) was used. The F_1 factors used for other radionuclides are: Ra-226 (0.2), Th-230 (0.0002), and Pb-210 (0.08) (Dunning, 1981; ICRP, 1981, 1959). The average daily water intake for an individual was assumed to be one liter per day. Dose conversion factors (DCF) in rem per microCi were taken from the report by Dunning (1981) and are summarized in Table D.3.8 for each target organ, using a radiobiological effectiveness factor (RBE) of 20 for alpha emitters.

Table D.3.8 Dose conversion factors for target organs (rem per microCi)

Target organ	U-238	U-234	Ra-226	Th-230	Pb-210
Total bone	7.0	7.8	43.0	1.2	21.0
Endosteum	2.8	3.6	20.0	16.0	9.6
Liver	0.013	0.016	0.60	0.22	1.4
Kidney	1.5	1.7	0.60	0.0043	0.94
Lung	0.015	0.017	0.60	0.0046	0.30

Table D.3.9 presents the 50-year dose commitments (DC-50) per year of consumption for each target organ, as calculated using the following equation:

Equation D.3.6

$$\text{DC-50} = (\text{concentration pCi/l}) \times \frac{(1\ \text{liter})}{\text{day}} \times \frac{(365\ \text{days})}{\text{year}} \times \frac{(1\ \text{microCi})}{10^6\text{pCi}} \times (\text{DCF}) \times \frac{(1000\ \text{mrem})}{\text{rem}} = \frac{\text{mrem}}{\text{yr}}$$

Table D.3.9 Fifty-year dose commitments per year of consumption of radionuclides in drinking water (mrem/yr)

Target organ	U-238	U-234	Ra-226	Th-230	Pb-210	Total
Total bone	243	347	31.4	0.044	6.90	628
Endosteum	97.1	169	14.6	0.584	3.15	276
Liver	0.451	0.712	0.438	0.008	0.460	2.07
Kidney	52.0	75.7	0.438	0.0002	0.309	128
Lung	0.520	0.757	0.438	0.0002	0.099	1.81

Table D.3.10 presents the lifetime risk coefficients used for each target organ (NAS, 1980) and also the resulting risk estimates from ingestion of the ground water in terms of individual organ risk per year of consumption. The individual organ risk was determined by multiplying the 50-year dose commitment per year of consumption times the lifetime risk coefficient. The total organ risk for an exposed individual was 2.5 x 10^{-6} per year of consumption, or 0.00025 percent.

This is 5.5 percent of the individual risk that was calculated [illegible] inhalation of radon daughters by a person within 0.[illegible] mile from the [illegible] under no action conditions.

It should be noted that conservative assumptions were used [illegible] calculations, and no people would be exposed [illegible] centrations used because the wells from which [illegible] trations were monitored are not [illegible] dilution with distance from the [illegible] more realistic estimate of the [illegible] drinking water ingestion pathway [illegible] tions of radionuclides found [illegible]

The maximum concentration [illegible] monitoring well[illegible] in the unconfined [illegible] 0.[illegible] and 1.6 pCi/[illegible] for U-[illegible] Th-230, and 0.[illegible] pCi/l for Pb-210. Using the [illegible] described in the previous calculations, the [illegible] excess health risk from drinking water with [illegible] radionuclides is [illegible] x 10[illegible] [illegible] 0.000[illegible] percent [illegible] 0.20 percent of the excess health risk from the [illegible] daughters by a person within 0.[illegible] mile from the pile under no action conditions, and indicates that the drinking water ingestion pathway would have an insignificant impact on the general public.

Table D.3.10 Summary of drinking water health effects analysis

Target organ	Lifetime risk coefficient (risk/10^6 person-rem)	Individual organ risk per year of consumption (excess health effects x 10^-6 per year)
Total bone[a]	0.95	[illegible]
Endosteum	0.95	0.52[illegible]
Liver	15	0.06[illegible]
Kidney	2.75[b]	0.[illegible]
Lung	30[c]	0.[illegible]
Total		2.[illegible] x 10[illegible]

[a]Total bone and endosteum risk coefficients were taken from the BEIR III report (NAS, 1980) for a 7000-gram bone and modified to give average skeletal doses for a 5000-gram bone by multiplying BEIR coefficients by 5000/[illegible].

[b]The risk coefficient for kidney was obtained by taking a ratio of [illegible] risk rate coefficients reported in the BEIR III report and multiplying by the high LET risk coefficient for liver. The linear energy transfer (LET) is defined as the local rate of energy deposition along a radioactive particle track. A radiation with a large LET value (such as an alpha particle or other heavy charged particles) will result in greater biological damage.

[c]This risk coefficient was taken from Evans et al. (1981) and is equivalent to the lifetime risk coefficient of 300 x 10^-6 deaths per person-WLM, where one WLM is approximately equal to a fifteen-rem dose equivalent commitment to the lung.

D.3.3 DISPOSAL AT THE FIVEMILE WASH SITE

General public health effects from radon daughter exposure

The remedial action for relocation and stabilization of the tailings at the Fivemile Wash site is expected to take 24 months. Disturbance and exposure of the tailings would occur for a maximum of 19 months, during which time radon releases would be increased.

For radon daughter health effects estimations, it was assumed that the contaminated materials from the Tuba City site would be removed at a uniform rate, and therefore the radon flux would be reduced linearly during the 19 months of remedial action. In addition to the source term for the Tuba City site, a source term was also developed for the contamination as it is deposited at the Fivemile Wash site. At the alternate disposal site, the radon flux would be increased linearly as the contaminated materials are relocated. The radon flux would then be decreased as the radon cover is placed.

For the general public health effects estimations, wind speed and direction assumptions were made which resulted in conservative estimates of working level much the same as for the stabilization in place alternative. In addition, the population distribution in the Fivemile Wash vicinity was assumed to be equivalent to the population in the vicinity of the processing site up to a distance of five miles. A large population is not located five miles from the Fivemile Wash site as it is at the Tuba City tailings site, and therefore the five- to six-mile population was not considered. For health effects calculations at the Tuba City site for the relocation alternative, the population as provided in Table D.3.1 was used directly.

The reduced population at the Fivemile Wash site would result in fewer health effects to the general public due to radon daughter exposure. However, the extended period of remedial action would result in a greater number of health effects to the general public. The total number of excess health effects to the general public at both locations due to radon daughter exposure during tailings relocation and stabilization at the Fivemile Wash site is therefore estimated to be approximately equal to the excess health effects under the stabilization in place alternative.

General public health effects from gamma exposure

Assuming the population distribution at Fivemile Wash to be approximately equivalent to the population at the Tuba City site, the health effects due to exposure to gamma radiation may be estimated to be proportional for the stabilization in place and alternate disposal site alternatives, according to the time required for remedial action. Since the total activity of the contaminated material remains the same, and the contaminated material would be relocated to the Fivemile Wash site at a uniform rate, it can be assumed that the gamma exposure rate levels would decrease and increase linearly at the respective sites over 19 months. Therefore, the health effects due to gamma exposure for the two sites are estimated to be slightly greater than the number of excess health effects due to gamma exposure for the stabilization in place alternative by a factor of 19/12.

Remedial action worker health effects from radon daughter exposure

An average of approximately 82 workers would be required during the 19-month remedial action for tailings relocation. To estimate an upper bound for excess health effects to remedial action workers, it was assumed that each worker would spend eight hours per day, 27.5 days per month over 19 months outside on the pile, and be exposed to a radon concentration of 8.56 pCi/l, as calculated previously for the 19-month period when the pile is relocated. Due to the extended period of remedial action, and an increase in the number of remedial action workers, it is estimated that the excess health effects to workers would exceed the number for the stabilization in place alternative by approximately a factor of two.

Remedial action worker health effects from gamma exposure

Remedial action workers would be exposed to gamma radiation from tailings, as well as to radon daughters. For the 82 remedial action workers during the 19-month relocation to Fivemile Wash, the estimate for excess health effects due to gamma radiation would be slightly increased over the calculated value for stabilization in place.

Remedial action workers and general public exposure to particulates

Estimates of excess health effects resulting from exposure to particulates were determined to be negligible for remedial action workers and the general public under the stabilization in place alternative. For health effects estimations, the volume of airborne particulates resulting from the relocation of tailings to the Fivemile Wash site may be estimated to be approximately twice the volume for stabilization in place since all contaminated materials would be moved. This alternative would take 19 months rather than 12 months for stabilization in place. Therefore, the health effects to workers due to air particulates may be estimated to be increased by a factor of two to three, but still considered negligible as would be the number of health effects for the general public.

Health effects from transportation during tailings relocation

During implementation of the Fivemile Wash alternative, there would be potential for increased gamma radiation exposure to the general public and to remedial action workers as a result of transportation of the tailings to the disposal site.

The exposure rate for people living along a transportation route during normal transport conditions was calculated for the Riverton, Wyoming, UMTRA Project site according to accepted analytical methods (DOE, 1985a). Based on conservative assumptions, the collective dose rate and total excess health effects for the general public were determined. The results indicated that the gamma health effects to the general public during relocation of the tailings were negligible, primarily because few people live along the proposed transportation route. Although the population density along the proposed transportation route for relocation of the tailings at Tuba City is greater than that at Riverton, Wyoming, the total excess health effects to the general public from transportation of the tailings to the Fivemile Wash site are considered to be negligible.

A transportation accident involving an overturned truck and spillage of tailings onto the roadbed is possible, but the magnitude of the radiation exposure to the general public and subsequent health effects associated with such an accident would be minimal (DOE, 1984). The cleanup of the road bed would be done promptly and the exposure of the cleanup crew would be small compared to the estimated 19-month exposure of remedial action workers in the Fivemile Wash alternative. This exposure pathway is therefore not addressed further in this document.

The maximum dose equivalent for a truck driver would be approximately eight microrems per loaded truck mile, based on 10 miles per hour and 80 microR/hr, which accounts for the shielding effect of the truck and the distance from the cab to the enclosed tailings. This exposure has been determined to be negligible from calculations performed for the Riverton, Wyoming, site (DOE, 1985a). There would be no radon daughter exposure to truck drivers or to the general public along the transportation route, since all radon is assumed to be released from the tailings pore spaces during handling at the existing tailings site.

D.3.4 EXPOSURES AFTER REMEDIAL ACTION

The only radiation exposure pathway of significance after remedial action would be that due to inhalation of radon daughters from the stabilized tailings pile. Following remedial action, there would be essentially no gamma radiation exposure, and the general public gamma health effects are considered to be zero for both remedial action alternatives.

Independent of which alternative was chosen, the EPA standard for the final stabilized tailings pile established an upper limit for radon flux of 20 pCi/m^2s or an upper limit for the radon concentration at the pile edge of 0.5 pCi/l above background. Table D.3.11 gives maximum radon and radon daughter concentrations downwind and calculated increases in health effects for stabilization in place following remedial action. Values are based upon the radon flux rate of 20 pCi/m^2s and a final pile surface area of 48 acres. The excess health effects to the general public within six miles of the tailings site following stabilization in place were calculated to be 5×10^{-4} per year, which is a factor of 34 lower than the health effects estimated for the no

Table D.3.11 Radon daughter health effects to the general public after remedial action for stabilization in place

Distance from pile edge (miles)	Population	Modeled outdoor radon concentration (pCi/g)	Modeled outdoor working level (r) x 10^{-4}	Calculated annual WLM (r) x 10^{-4}	Excess health effects x 10^{-4} per yr
0.5	25	0.036	0.71	50.9	0.38
0.75	20	0.020	0.63	29.8	0.18
1.5	25	0.007	0.42	11.7	0.09
3.0	45	0.003	0.21	4.6	0.06
3.5	20	0.002	0.17	3.7	0.02
4.0	80	0.002	0.15	3.1	0.07
4.5	60	0.001	0.13	2.6	0.05
5.0	35	0.001	0.11	2.3	0.02
5.5	6680	0.001	0.10	2.0	4.0
6.0	30	0.001	0.09	1.8	0.02
Total	7020				5

action alternative. The excess health effects for the Fivemile Wash alternative following remedial action would be smaller than that for stabilization in place due to a significantly smaller population between five and six miles from the Fivemile Wash site.

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APPENDIX E

PERMITS, LICENSES, APPROVALS

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LIST OF TABLES

E.1 INTRODUCTION

This appendix contains a listing of the permits, licenses, and approvals that would be required for various aspects of the proposed remedial action at the Tuba City, Arizona, uranium mill tailings site. Relocation of the tailings to the Fivemile Wash site may require additional permits, licenses, and approvals that are not identified in this appendix.

In most cases, regulatory permits, licenses, and approvals would be obtained by the Remedial Action Contractor or the U.S. Department of Energy, whichever is appropriate.

E.1.1 Permits, licenses, and approvals for remedial action at the Tuba City, Arizona, site

Permit, license, or approval	Granting or approving agency	Statute or regulation	Activity
NRC License	U.S. Nuclear Regulatory Commission	Public Law 95-604, Section 104(f)	Surveillance and maintenance at the disposal site after completion of the remedial action.
Threatened and Endangered Species Consultation	U.S. Fish and Wildlife Service with review by the Navajo Nation, Hopi Tribe, and Bureau of Indian Affairs	Endangered Species Act of 1973, Section 7.16	Any action which might affect threatened or endangered species.
Cultural Resource Clearance	Bureau of Indian Affairs, Navajo Nation, Hopi Tribe, Arizona State Historic Preservation Officer	National Historic Preservation Act, 36 CFR Part 800	Any action which might affect historic or cultural resources.
National Pollutant Discharge Elimination System (NPDES) Permit	U.S. Environmental Protection Agency	Clean Water Act of 1977	Controlled surface discharge of waste water.
Sand and Gravel Permit	Bureau of Indian Affairs	25 CFR Part 216	Extraction of earth and rock borrow materials.
Revocable Use Permit	Bureau of Indian Affairs	25 CFR Part 162	Temporary surface disturbing activities.
Right-of-Way Permit	Bureau of Indian Affairs	25 CFR Part 169	Construction of access roads.

E.1.1 Permits, licenses, and approvals for remedial action at the Tuba City, Arizona, site (Concluded)

Permit, license, or approval	Granting or approving agency	Statute or regulation	Activity
Approval of Borrow Site Excavations	Navajo Nation, Environmental Protection Administration; Hopi Tribe, Division of Economic and Natural Resources	General Surface Restoration Requirements for Sand and Gravel Operations; Hopi Tribe Contract Regulation	Extraction of rock and earth borrow materials.
Water Purchase Contract/Water Use Permit	Navajo Nation, Division of Water Resources; Hopi Tribe, Division of Economic and Natural Resources	Navajo Nation Water Code; Hopi Tribe Contract Regulation	Use of surface or ground water.
Water Well Drilling Permit	Navajo Nation, Division of Water Resources; Hopi Tribe, Division of Economic and Natural Resources	Navajo Nation Water Code; Hopi Tribe Contract Regulation	Drilling water wells.
Approval of Well Sealing and Abandonment	Navajo Nation, Division of Water Resources; Hopi Tribe, Division of Economic and Natural Resources	Navajo Nation Water Code	Sealing and abandonment of water wells.
Highway Right-of-Way	Arizona Department of Transportation	Arizona Revised Statutes 28-1870 and 28-1871	Construction activities on a state highway or highway right-of-way.