DPST-85-711

ENVIRONMENTAL INFORMATION DOCUMENT

TNX BURYING GROUND

E. I. du Pont de Nemours & Co.
Savannah River Laboratory
Aiken, SC 29808

PREPARED FOR THE U.S. DEPARTMENT OF ENERGY UNDER CONTRACT DE-AC09-76SR00001

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J. K. W. DUNAWAY

W. F. JOHNSON

L. E. KINGLEY

R. V. SIMMONS

H. W. BLEDSOE

Approved by:

R. R. Fleming, Superintendent
TNX Operations Division
Savannah River Laboratory

J. C. Corey, Research Manager
Environmental Sciences Division
Savannah River Laboratory

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E. I. du Pont de Nemours & Co.
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PREFACE

This document provides environmental information on postulated closure options for the TNX Burying Ground at the Savannah River Plant and was developed as background technical documentation for the Department of Energy's proposed Environmental Impact Statement (EIS) on waste management activities for groundwater protection at the plant. The results of groundwater and atmospheric pathway analyses, accident analysis, and other environmental assessments discussed in this document are based upon a conservative analysis of all foreseeable scenarios as defined by the National Environmental Policy Act (CFR, 1986). The scenarios do not necessarily represent actual environmental conditions. This document is not meant to be used as a closure plan or other regulatory document to comply with required federal or state environmental regulations.

Technical assistance in the environmental analyses of waste-site closures was provided by Clemson University; GeoTrans, Inc.; JBF Associates, Inc.; S. S. Papadopulos & Associates, Inc.; Radiological Assessments Corporation; Rogers and Associates Engineering Corporation; Science Applications International Corporation; C. B. Shedrow Environmental Consultants, Inc.; Exploration Software; and Verbatim Typing and Editing.

SUMMARY

The TNX Burying Ground, located within the TNX Area of the Savannah River Plant (SRP), was originally built to dispose of debris from an experimental evaporator explosion at TNX in 1953. This evaporator contained approximately 590 kg of uranyl nitrate. From 1980 to 1984, much of the waste material buried at TNX was excavated and sent to the SRP Radioactive Waste Burial Grounds for reburial. An estimated 27 kg of uranyl nitrate remains buried at TNX. The TNX Burying Ground consists of three sites known to contain waste and one site suspected of containing waste material. All four sites are located within the TNX security fenceline.

Groundwater at the TNX Burying Ground was not evaluated because there are no groundwater monitoring wells installed in the immediate vicinity of this waste site.

The closure options considered for the TNX Burying Ground are waste removal and closure, no waste removal and closure, and no action. The predominant pathways for human exposure to chemical and/or radioactive constituents are through surface, subsurface, and atmospheric transport. Modeling calculations were made to determine the risks to human population via these general pathways for the three postulated closure options. An ecological assessment was conducted to predict the environmental impacts on aquatic and terrestrial biota. The relative costs for each of the closure options were estimated.

An evaluation of the environmental impacts from the TNX Burying Ground indicates that the relative risks to human health and ecosystems for the postulated closure options are low. The transport of one chemical (nitrate) and one radionuclide (^{238}U) through the environmental pathways from the TNX Burying Ground was modeled. The maximum noncarcinogenic risk for all three groundwater pathways is from exposure to nitrate (2.5E-08 ADI fraction) for all three closure options and occurs at Year 8 during the period of institutional control. The maximum radioactive risk in the groundwater pathways is from exposure to ^{238}U (9.2E-16 HE/yr) for all closure options and occurs at Year 100 immediately following the period of institutional control. The maximum radioactive risk in the reclaimed-farmland pathway is from exposure to ^{238}U (4.0E-11 HE/yr) for all closure options and occurs immediately following the period of institutional control. There are no other risks associated with any of the other exposure pathways. The ecological assessment shows that the effects of any closure activities or river water quality and wildlife would be insignificant. The cost estimates show the waste removal and closure option to be the most expensive. The cost for this option is $4,800,000. The other closure options are less expensive up to a factor of 12 for the no action option.

NATURE OF DISPOSAL

GEOGRAPHICAL LOCATION

The TNX Burying Ground consists of three areas known to contain buried waste materials and a fourth suspected burial site. The three known sites are a trapezoidal area located beneath the transformer pad near Building No. 673-T, a rectangular area beneath Building No. 711-T, and a L-shaped area beneath office trailer Building No. 676-8T. A fourth suspected burial site is located east of Building No. 673-T.

Burial Site	SRP Coordinates (ft)*		Latitude and Longitude	
Trapezoidal area	N 71426	E 17184	33.211747°N	81.760214°W
	N 71447	E 17229	33.211867°N	81.760135°W
Rectangular area	N 71388	E 17158	33.211620°N	81.760209°W
	N 71378	E 17190	33.211650°N	81.760105°W
L-shaped area	N 71193	E 17182	33.211228°N	81.759767°W
	N 71268	E 17231	33.211474°N	81.759784°W
Suspected area	N 71462	E 17295	33.212008°N	81.759992°W
	N 71472	E 17395	33.212193°N	81.759749°W

The nearest plant boundary to any of the TNX burial sites is the Savannah River, which is approximately 396 m to the west. The geographical location of the TNX Burying Ground is shown in Figure 1.

SITE DIMENSIONS

The original TNX Burying Ground was located east of the TNX Tank Farm (Building No. 671-T) and covered with approximately 4,650 m^2 of soil. Most of the buried debris has been removed, and a conservative estimate of the burial ground's present size is approximately 372 m^2. A blueprint of the area is shown in Figure 2.

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* Coordinates relative to the SRP grid, a local Department of Energy plane system whose "grid north" is approximately 36.4° west of true north at SRP.

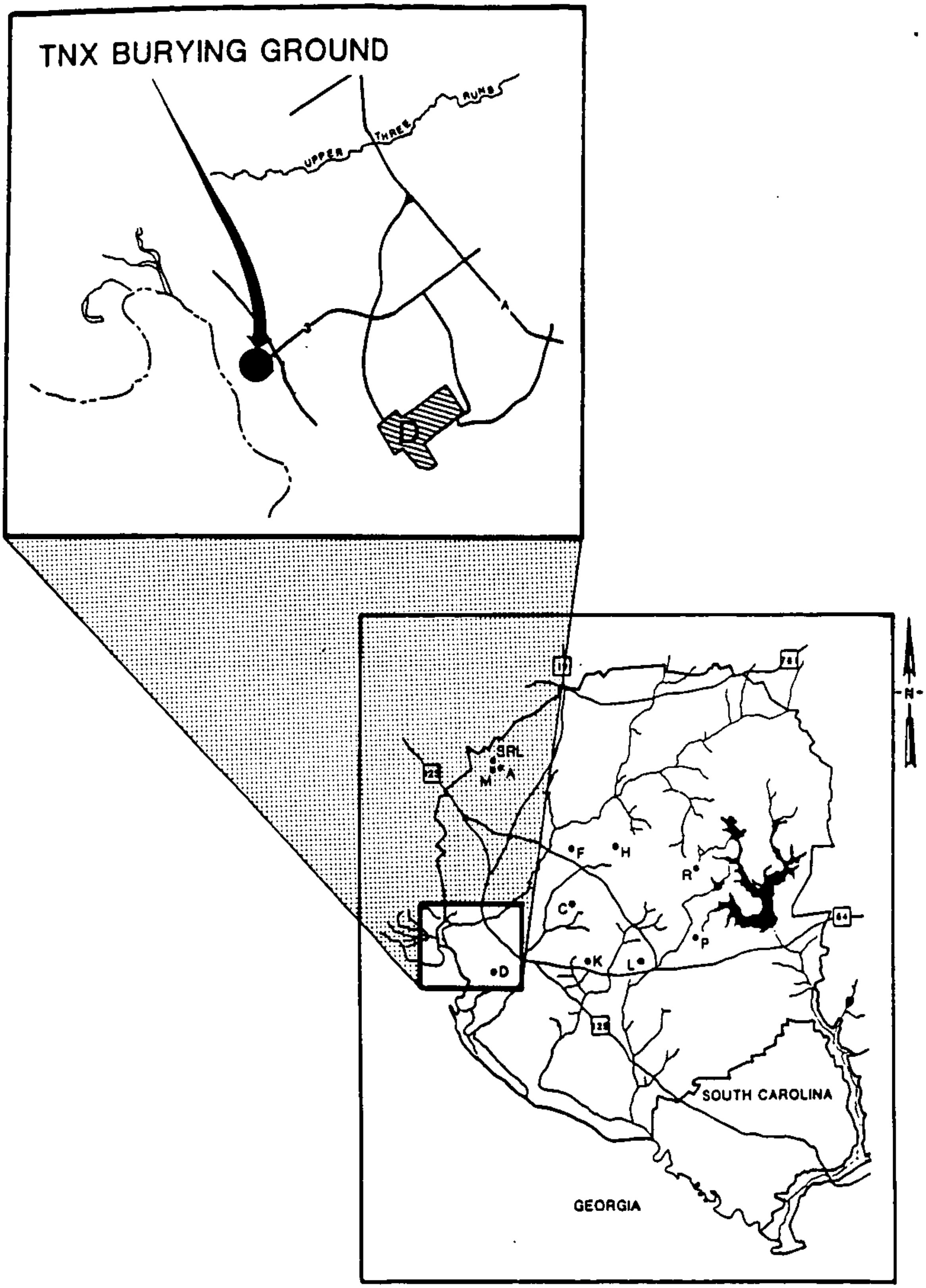


FIGURE 1. Location of the TNX Burying Ground

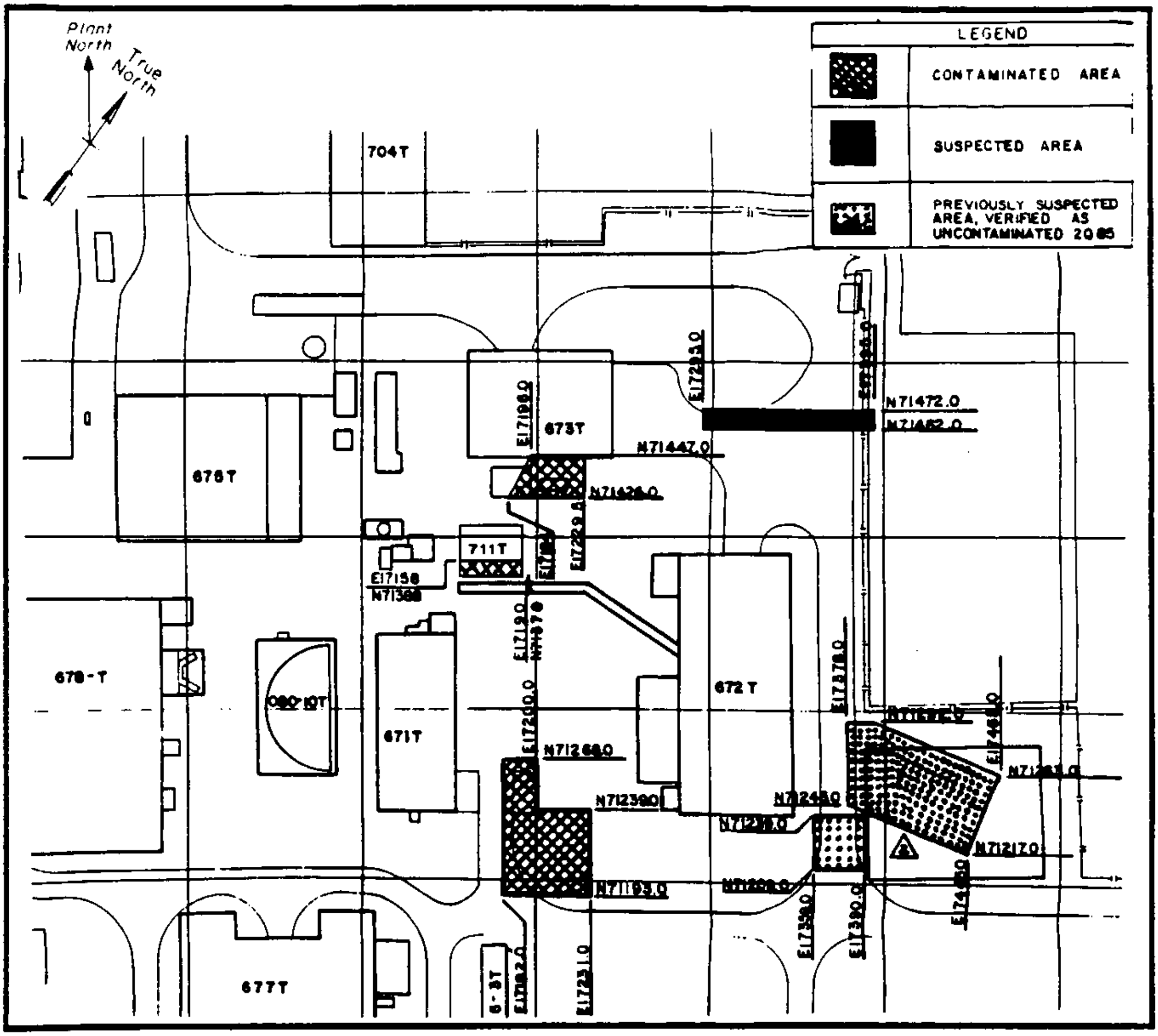


FIGURE 2. Blueprint of the TNX Burying Ground

HISTORY OF DISPOSAL

In 1953, an experimental evaporator containing approximately 590 kg of uranyl nitrate exploded at TNX. Because the SRP Radioactive Waste Burial Ground (Building No. 643-G) was not yet in operation, debris from the explosion was collected and buried at the TNX Burying Ground (Building No. 643-5T). This debris included materials such as conduit, drums, tin, and structural steel. This waste disposal site also received other waste materials, such as depleted uranium. No material was buried at the site after the SRP Radioactive Waste Burial Ground was placed into operation later in 1953.

CURRENT STATUS

Most of the material buried at TNX was excavated and sent to the SRP Burial Grounds from 1980 to 1984. The remaining waste materials lie buried beneath asphalt, buildings, and transformer pads at depths of approximately 1.8 to 2.4 m below grade. An estimated 27 kg of uranyl nitrate remains buried at the TNX Burying Ground, constituting approximately 5% of the initial inventory buried.

GEOHYDROLOGIC SETTING

PHYSIOGRAPHY

The Savannah River Plant lies mostly on the Aiken Plateau as defined by Cooke (1936). The Aiken Plateau is bounded by the Savannah and Congaree rivers (Figure 3) and slopes from an elevation of 198 m at the Fall Line to an elevation of approximately 76 m (all elevations based on mean sea level). The surface of the Aiken Plateau is highly dissected and is characterized by broad, interfluvial areas with narrow, steep-sided valleys. Relief is locally as much as 91 m (Siple, 1967). The plateau is generally well drained although small, poorly drained depressions occur. The area is underlain by a wedge of seaward-dipping unconsolidated and semiconsolidated sediments.

The TNX facility is located east of the Savannah River between two southwesterly flowing tributaries to the Savannah River, Upper Three Runs Creek and Four Mile Creek. It is located on a terrace developed by the Savannah River locally known as the Ellenton plain, the highest of three step-like topographic surfaces between the Savannah River to the west and the Aiken Plateau to the east. The site is underlain by unconsolidated and semiconsolidated sediments, including stratified gravel, sand, clay, and silt. Topographically, the TNX Burying Ground is located at an elevation of about 45 m on a bluff above the Savannah River swamp, which is at an elevation of 27 to 30 m (Figure 4).

HYDROSTATIGRAPHY

A descriptive and graphic log of the subsurface geology near the central part of the SRP site, where much of the geohydrologic data have been collected in the past, along with a tentative correlation of stratigraphic terminology, is presented in Figure 5 (Christensen & Gordon, 1983). It should be noted that recent studies have found that the sediments mapped as Tuscaloosa at SRP are geologically younger than the Tuscaloosa-type section in Alabama. Therefore, from a purely stratigraphic point of view, it is improper to continue to use the term Tuscaloosa for these sediments. However, in this report the term Tuscaloosa Formation will be retained, but "Tuscaloosa" will be placed within quotation marks to indicate that it is used as a hydrostratigraphic term and not as a formal stratigraphic term. Table 1 describes the lithologic and water-bearing characteristics of the different stratigraphic units.

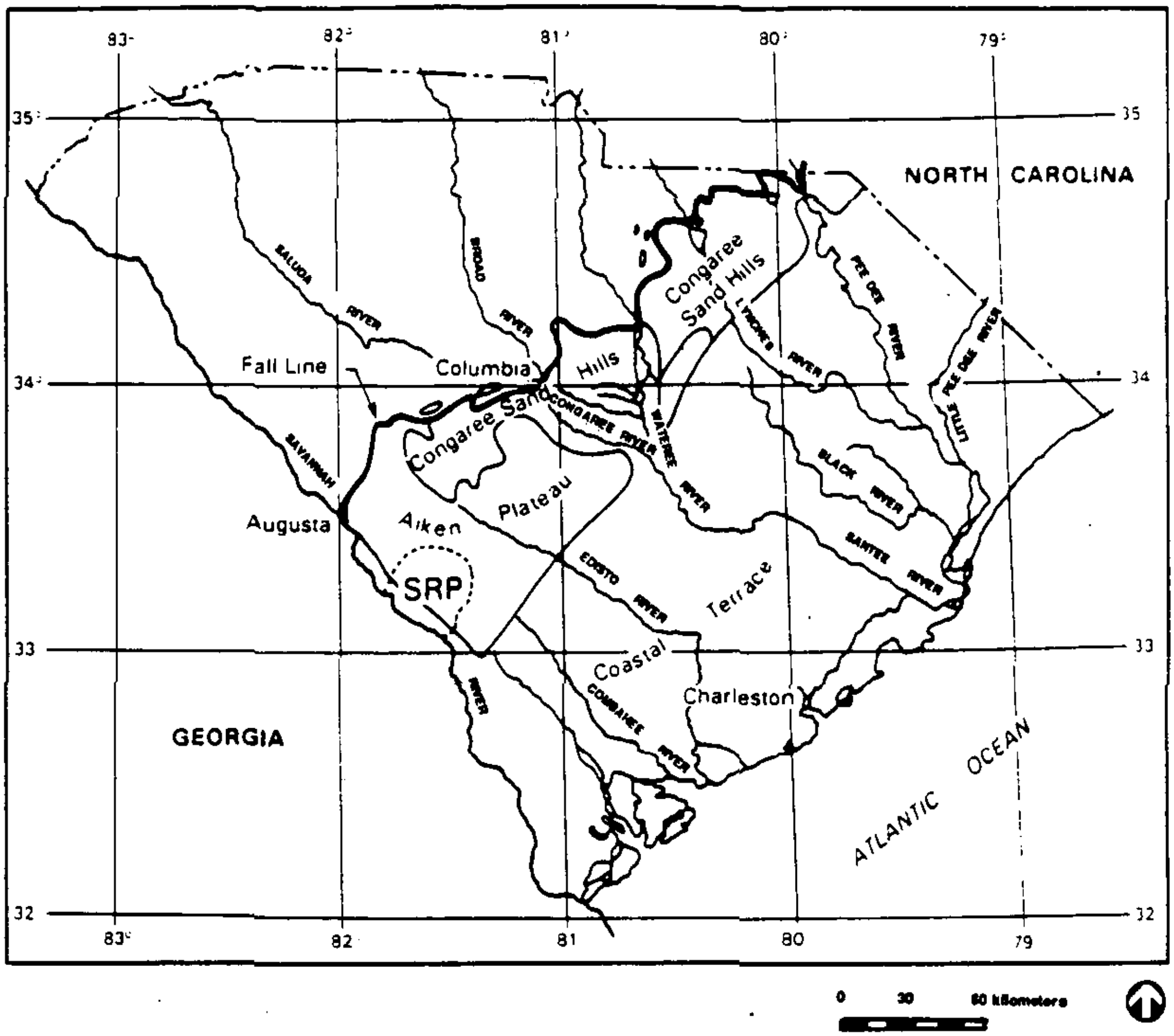


FIGURE 3. Physiography of the Savannah River Region

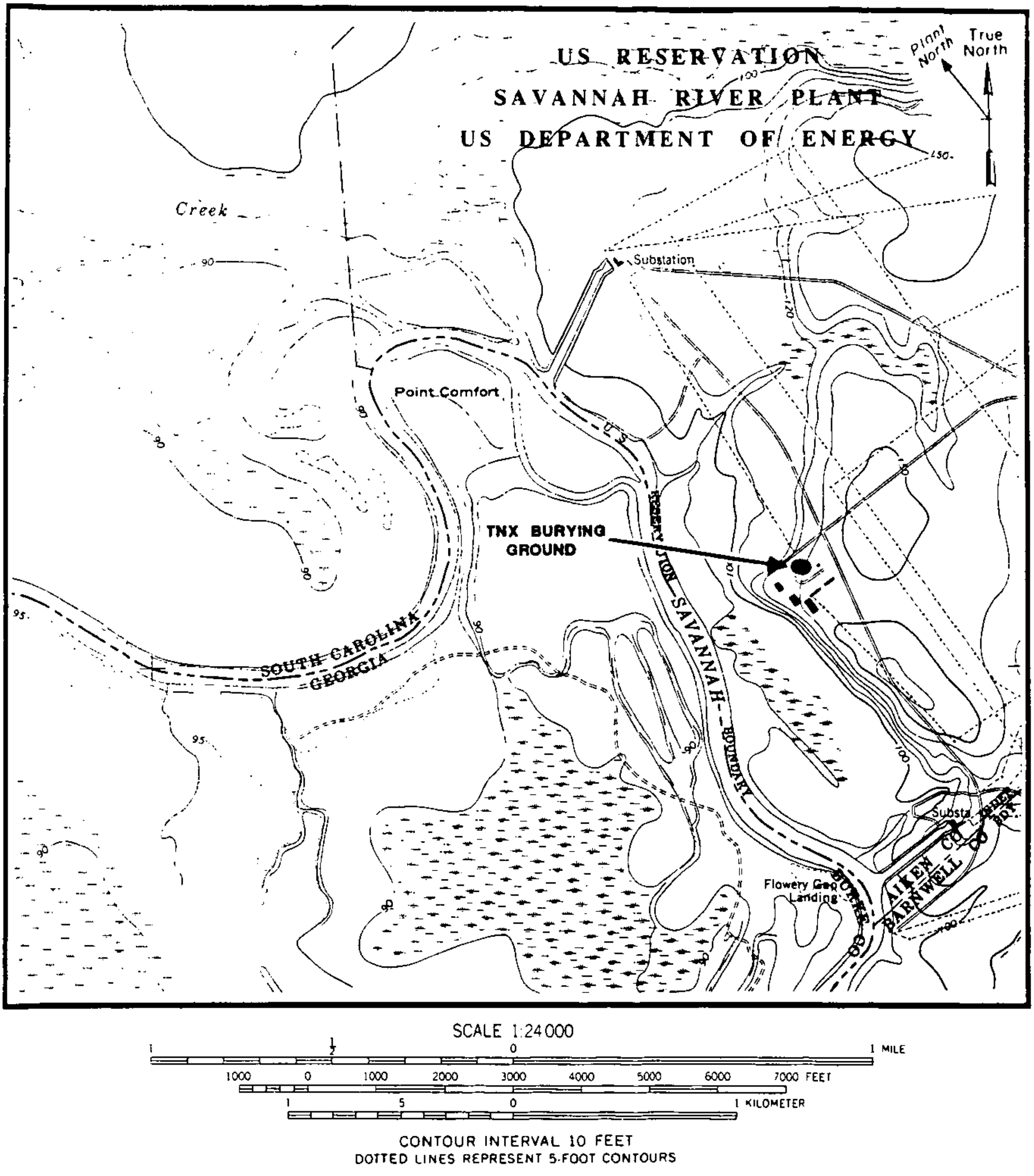


FIGURE 4. Location of the TNX Burying Ground on Shell Bluff Landing Quadrangle 7.5 Minute Series Topographic Map

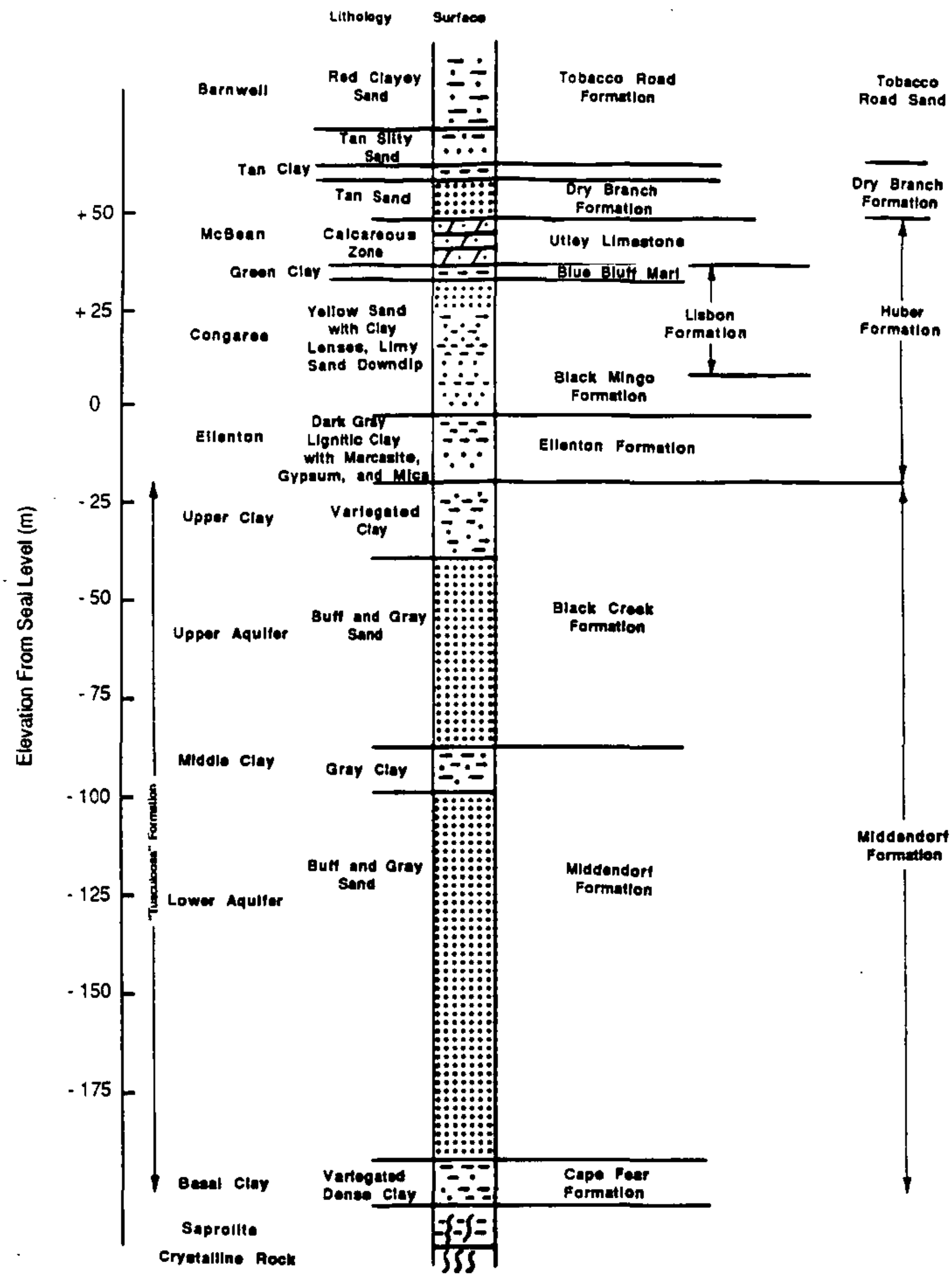


FIGURE 5. Tentative Correlation of Stratigraphic Terminology of the Southwestern South Carolina Coastal Plain

TABLE 1

Hydrostratigraphic Units Underlying the Savannah River Plant

Formation	Geologic Age	Outcrop	Description	Water Yield	Thickness (m)
Alluvium	Recent	River and creek bottoms	Fine to coarse sand, silt, and clay	Very little	0 to 9.1
Terrace Deposits	Pleistocene	In flood plains and terraces of stream valleys	Tan to gray sand, clay, silt, and gravel on higher terraces	Moderate to none	0 to 9.1
Hawthorn	Miocene	Interfluvial areas	Tan, red, and purple sandy clay with numerous clastic dikes	Little or none	0 to 24.4
Barnwell	Eocene	Large part of ground surface near streams	Red, brown, yellow, and buff, fine to coarse sand and sandy clay	Limited but sufficient for domestic use	0 to 27.4
McBean Congaree	Eocene	In banks of larger streams	Yellow-brown to green, fine to coarse, glauconite quartz sand, intercalated with green, red, yellow, and tan clay, sandy marl, and lenses of siliceous limestone	Moderate to large	30.5 to 76.2
Ellenton	Paleocene	None on plant	Dark gray to black sandy lignitic micaceous clay containing disseminate crystalline gypsum and coarse quartz sand	Moderate to large from discontinuous sand layers; higher sulfate and iron than water from other formations.	1.5 to 30.5
"Tuscaloosa"	Upper Cretaceous	None on plant	Tan, buff, red, and white; crossbedded, micaceous quartzitic and arkosic sand and gravel imbedded with red, brown, and purple clay and white kaolin	Large, up to 7.6 m^3/min soft, low in total solids	~182.9
Newark Series "Red Beds"	Triassic Period	None on plant	Dark-brown and brick-red sandstone, siltstone, and clay-stone containing gray calcareous patches; fanglomerates near border	Very little	>914.4
Basement rocks of the Slate Belt and Charlotte Group	Precambrian and Paleozoic Eras	None on plant	Hornblende gneiss, chlorite-hornblende schist, lesser amounts of quartzite; covered by saprolite layer derived from basement rock	Very little	Many thousands

Note: Modified from Siple (1967).

The near surface geology at the TNX facility is that of river terrace deposits of sand, silt, and clay, generally with a significant organic content. These sediments are, in turn, underlain by Tertiary age sediments. The Tertiary sediments, which include the McBean and Congaree formations, are difficult to distinguish. These sediments are underlain by the Ellenton Formation of Paleocene age and the "Tuscaloosa" Formation of Cretaceous age. Two geologic cross sections prepared by the Corps of Engineers (1952) are presented in Figure 6. The locations of these sections are shown in Figure 7.

In studies at SRP, the McBean and Congaree formations have been found to be separated by a confining clay layer informally called the Green Clay. In wells near the facility, PW 96G and PW 97G, a green, sandy clay was observed about 12 m from ground surface. However, if it was present in deep well XSB 3T drilled near the Old TNX Seepage Basin, it was not noted. Figure 8 illustrates the inferred stratigraphy beneath the TNX Burying Ground based on lithologic and geophysical logs developed for well XSB 3T (Simmons et al., 1985).

The water table in the vicinity of the TNX Burying Ground is found within the McBean and Congaree formations at an elevation of approximately 30 m. A detailed water-table map is not available for the site. Natural discharge for the water-table aquifer is to the Savannah River swamp. Except for the downward percolation of water in the unsaturated zone between the bottom of the basin and the water table, downward percolation to deeper groundwater levels is improbable because of the higher piezometric surface in the Congaree and "Tuscaloosa" formations.

Figure 9 presents a hydrologic section perpendicular to the Savannah River just north of the waste site area, illustrating the head relationships in the Congaree and "Tuscaloosa" formations. The diagram indicates that in the Savannah River Valley, the head in the "Tuscaloosa" is consistently above that of the Congaree and water levels in the "Tuscaloosa" in the vicinity of TNX are commonly above land surface.

The surface of the Upper "Tuscaloosa" Formation is at an elevation of approximately -24 m. The water level in well XSB 3T is above the ground surface at, or slightly above, the well casing at an approximate elevation of 48 m. The piezometric surface of the "Tuscaloosa" is shown in Figure 10 and indicates that the horizontal groundwater flow is in the direction of the Savannah River.

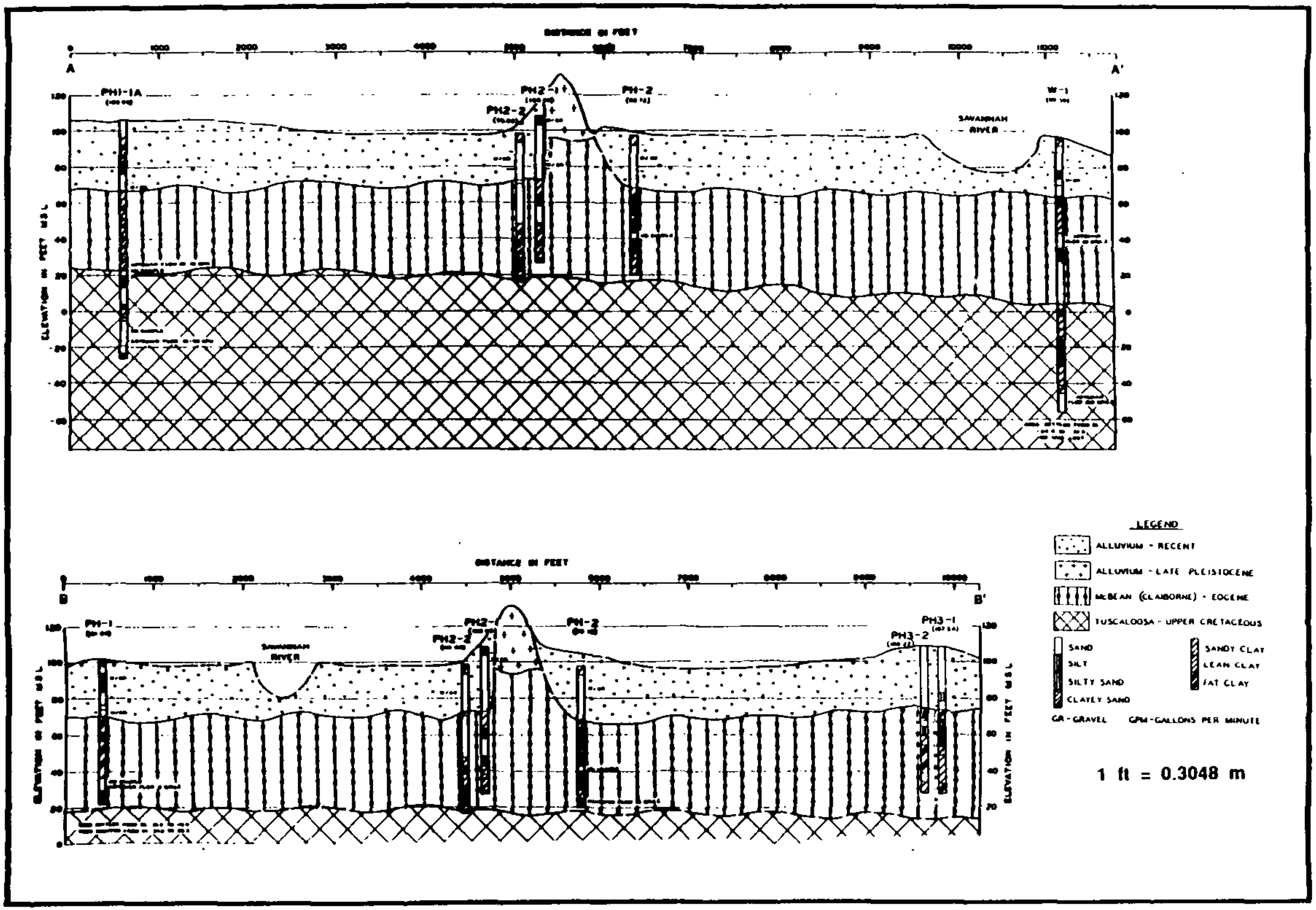


FIGURE 6. Geologic Cross Sections Near the TNX Facility

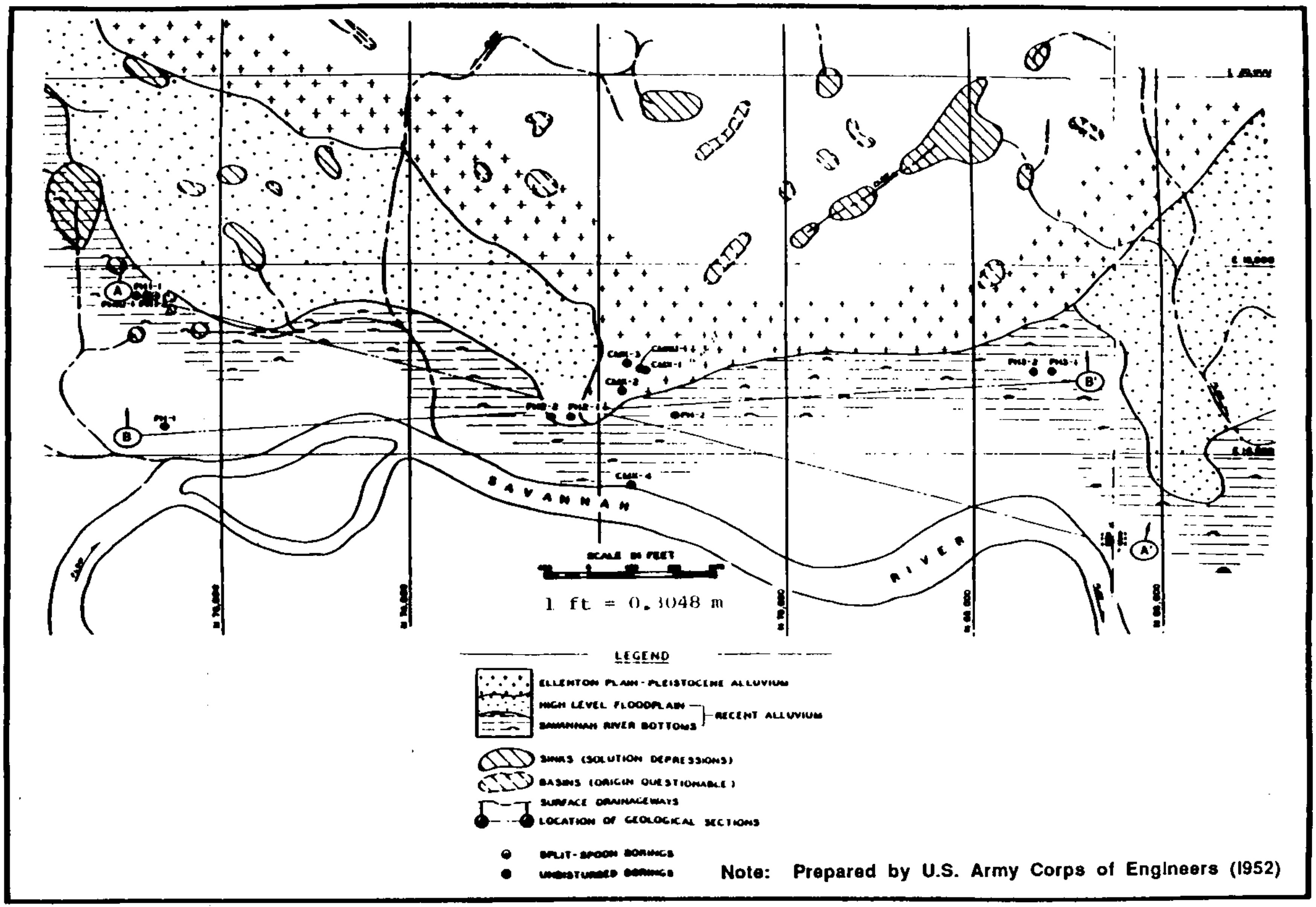


FIGURE 7. Location of Geologic Cross Sections in the Vicinity of TNX

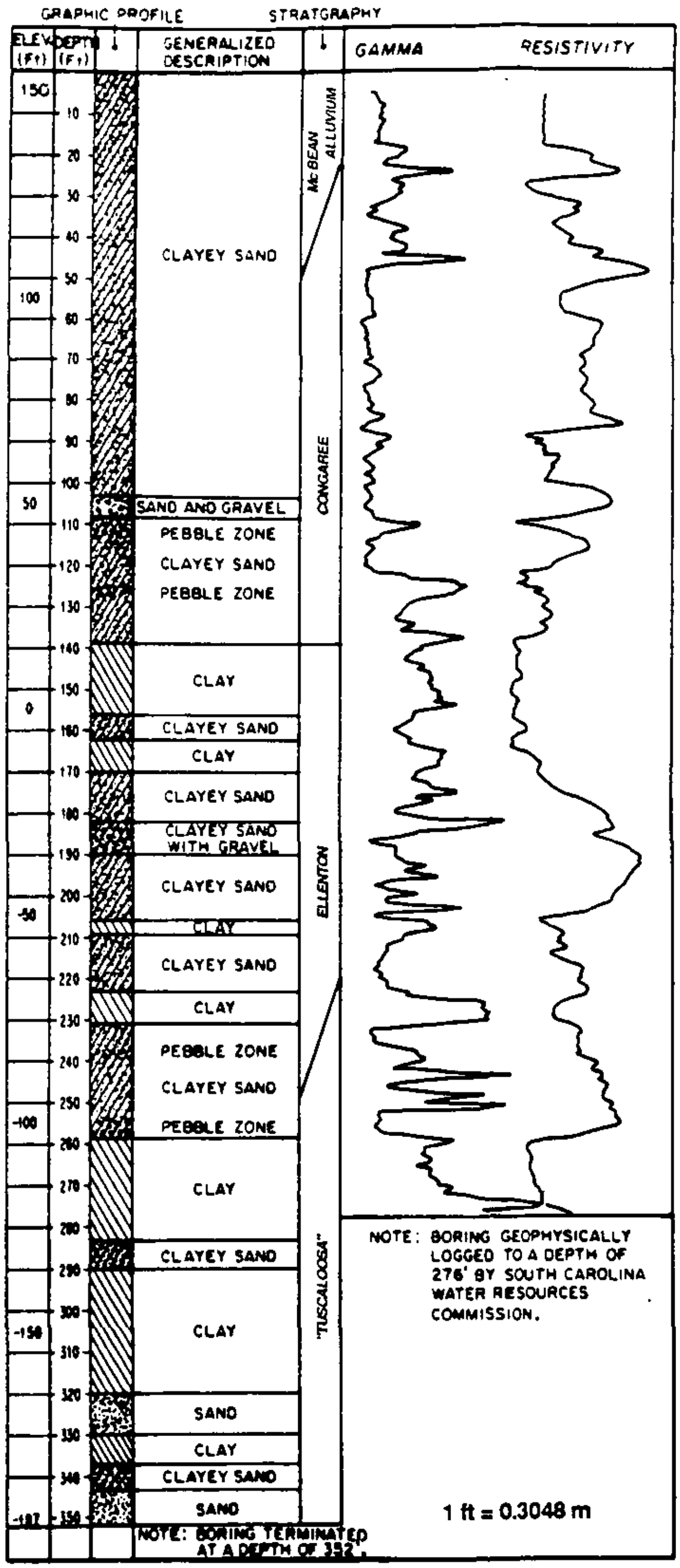


FIGURE 8. Driller's Log for Monitoring Well XSB 3T

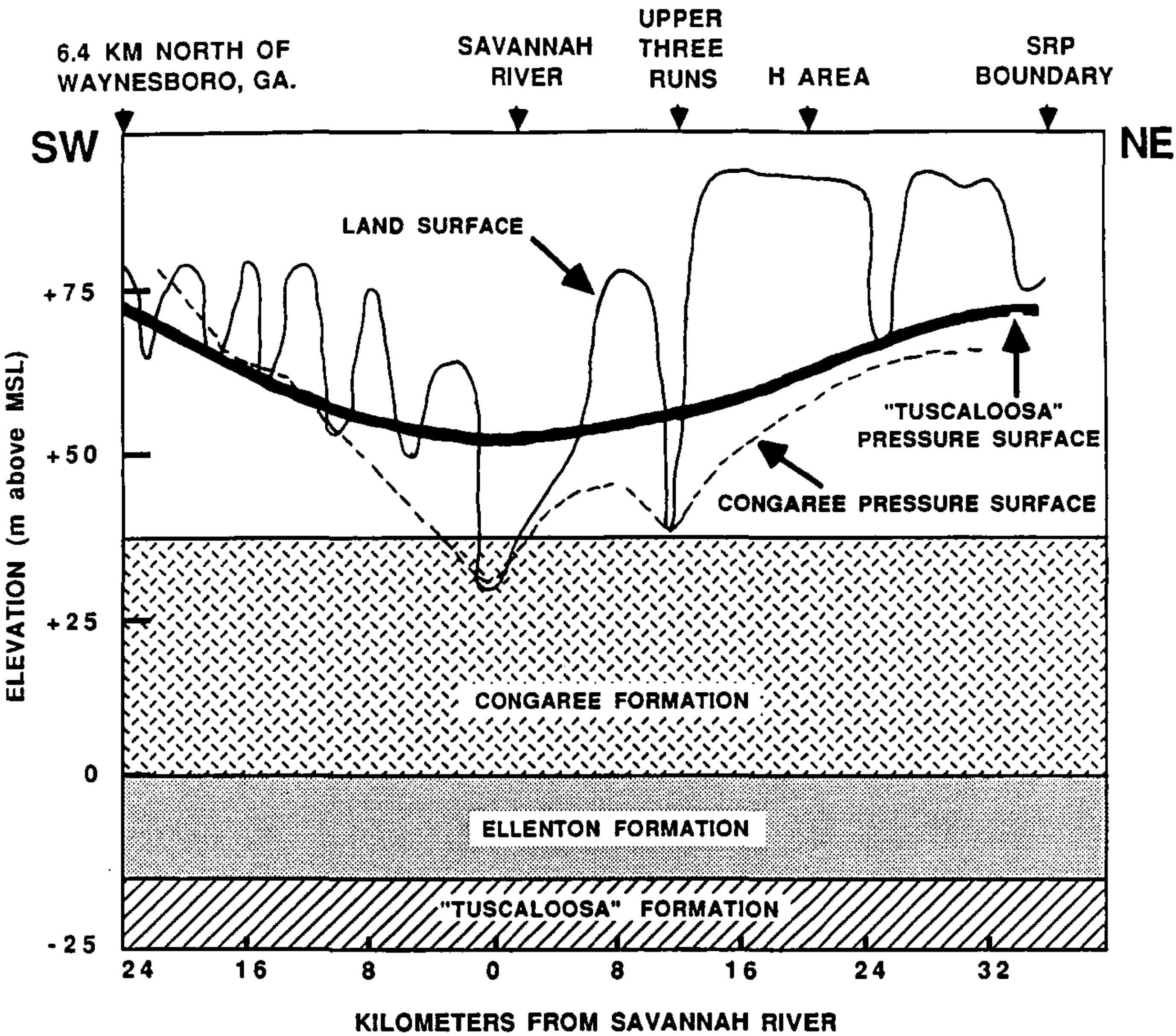


FIGURE 9. Hydrogeologic Section Perpendicular to the Savannah River Through H Area

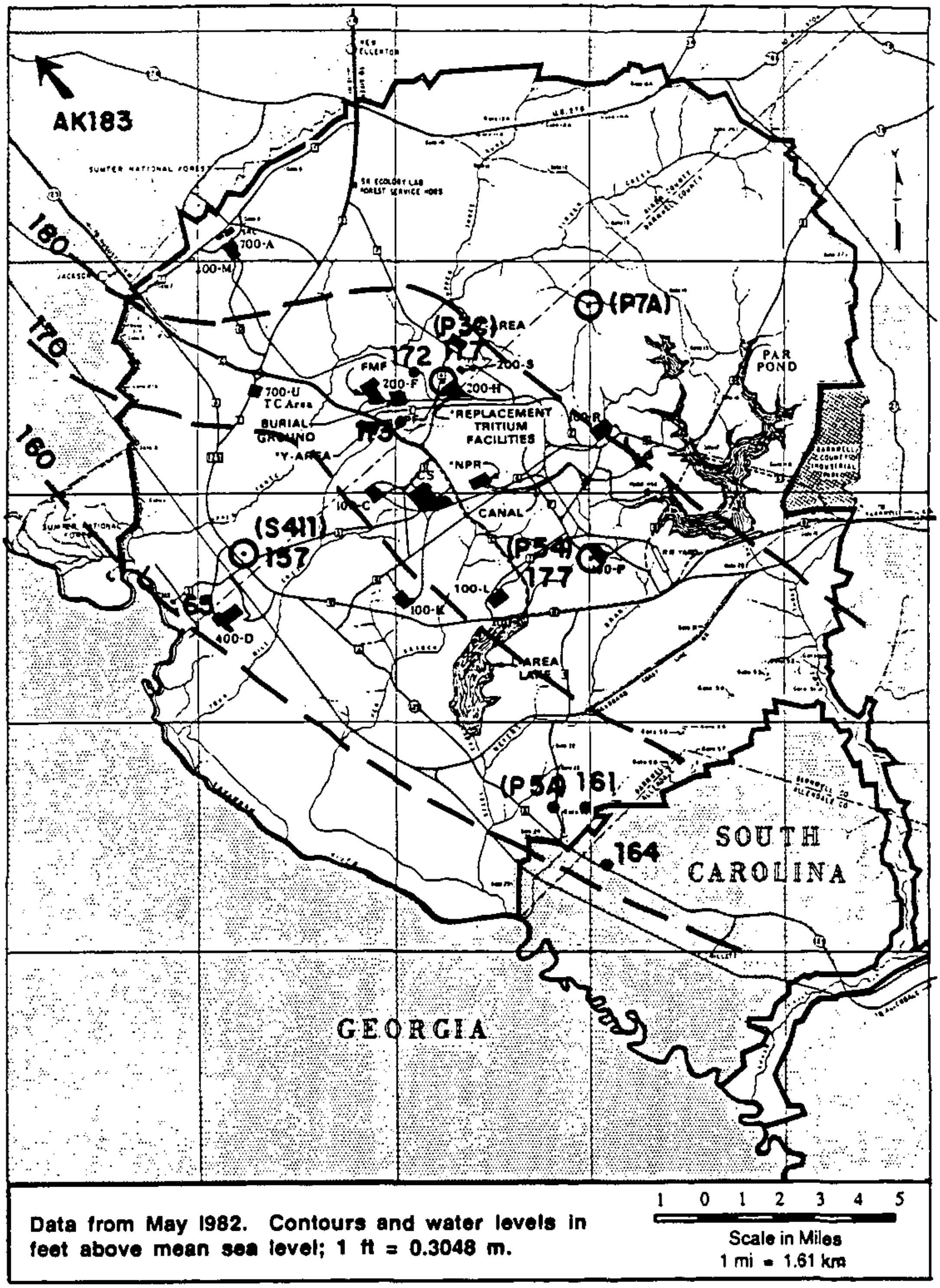


FIGURE 10. Piezometric Map of the "Tuscaloosa" Formation

HYDROLOGIC CHARACTERISTICS

The hydaulic properties of the geologic framework determine the ease and the rate at which the groundwater moves through the various formations. The properties of most importance are transmissivity/permeability, porosity, storativity, and leakance. Effective porosity and permeability (hydraulic conductivity) are the most important properties affecting the ability of geologic materials to transmit water. Effective porosity is a measure of the amount of interconnected pore space available for fluid transmission, while hydraulic conductivity is a measure of the ease with which water can be transmitted through a porous material. There are currently no data available on the hydraulic properties of the different geologic strata underlying or in the immediate vicinity of the TNX Burying Ground.

A horizontal flow velocity of 10 m/yr was assumed for the groundwater transport calculations. This value is similar to the one calculated for the Congaree Formation in the A/M Area by S. S. Papadopulos & Associates (1986).

SOIL CHARACTERIZATION DATA

No soil samples have been analyzed from the TNX Burying Ground.

GROUNDWATER MONITORING DATA

No groundwater monitoring wells exist in the immediate vicinity of the TNX Burying Ground.

IDENTIFICATION OF CONTAMINANT SUBSTANCES AND ESTIMATED INVENTORIES

Chemical constituents that have been disposed of at existing waste sites at SRP have been identified and their inventories estimated. This information is used to assess the environmental impacts and health risks associated with the various site closure options being considered. All available records have been reviewed to determine which substances were released to the waste sites during their operational histories. Where available, these records include groundwater monitoring data, waste-site characterization studies, influent waste stream measurements, and process chemical records. These inventories provide the source term information required to calculate the transport and potential risk for each material.

The concentrations of chemical constituents released to each waste site were compared to special selection criteria (Looney et al., 1987a). If the groundwater or soil concentration of a given constituent exceeded its selection criterion, the material was designated for inclusion in the transport modeling and risk assessment studies. Additionally, if large amounts of specific chemicals with a health or environmental risk were believed to have been released to a site (based upon inventory or process use), these constituents were also designated for assessment, even if the soil or groundwater characterization data did not indicate their presence.

Only one contaminant, uranyl nitrate, was selected for the environmental assessment of the TNX Burying Ground. This selection is based upon documentation indicating that uranyl nitrate is the only known contaminant disposed of in the TNX Burying Ground. It is estimated that approximately 27 kg of this material remains buried at TNX.

CLOSURE OPTIONS

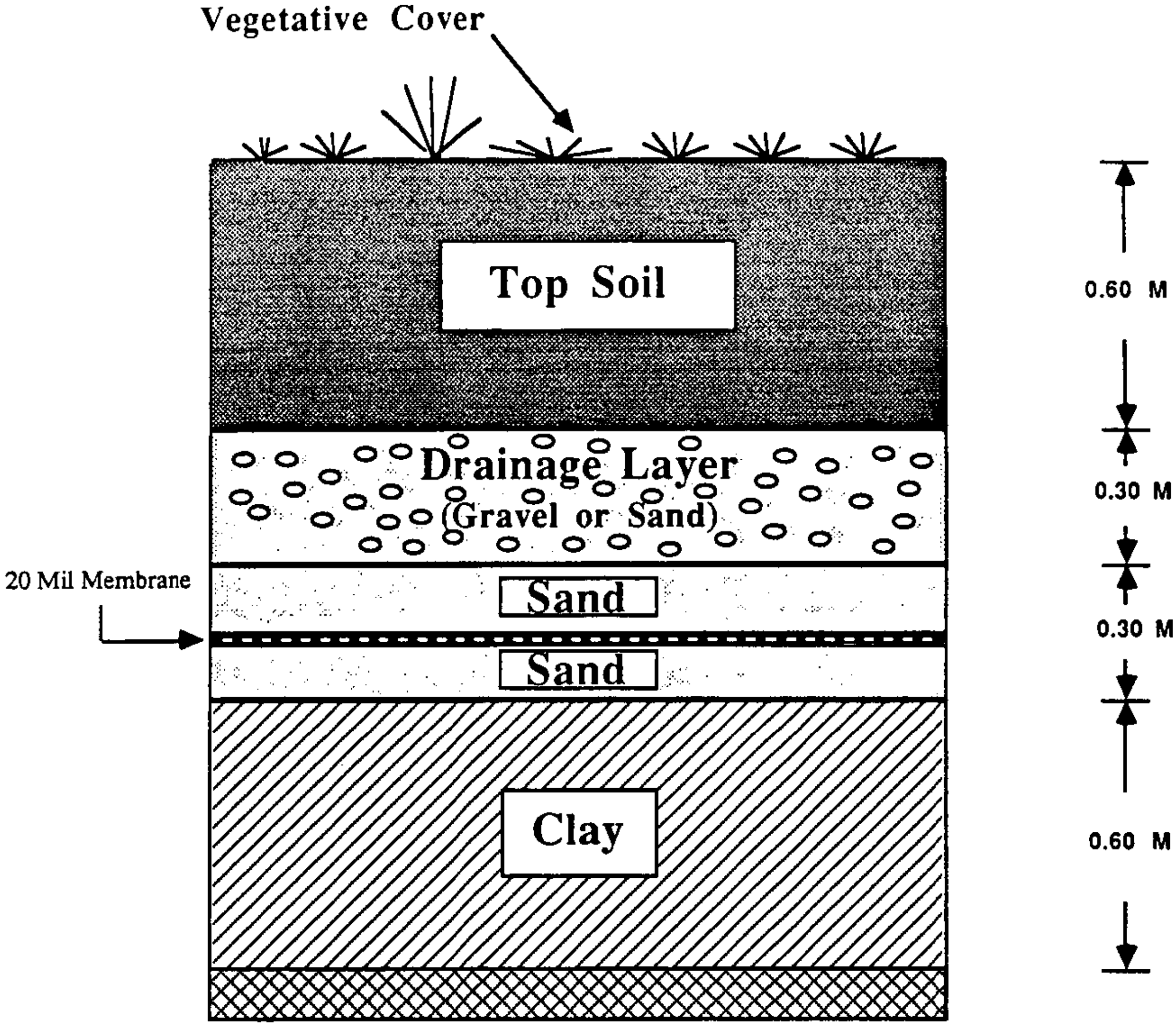
The TNX Burying Ground will be closed at some future date in accordance with all applicable state and federal regulations. Many closure options for the burying ground could be developed and evaluated for environmental soundness and cost effectiveness. To establish a range for potential environmental consequences and funding requirements for closure of the site, three basic options have been examined:

- Waste removal and closure
- No waste removal and closure
- No action

These options were not developed specifically for regulatory compliance, but to bound the potential impact of possible future closure actions. The specific details of the commitments to maintenance, monitoring, and cap design in this section were selected for the primary purpose of deriving reasonable and consistent relative cost estimates.

WASTE REMOVAL AND CLOSURE

Under the waste removal and closure option, surface structures (Building No. 711-T, trailer Building No. 676-8T, and a 13.8 kV transformer near Building No. 673-T) would be relocated, and the three known and one suspected burial sites would be excavated to a depth of 21.41 m (approximately 896 m^3). Excavated materials from the known burial sites would be packaged in metal boxes and sent to a waste storage/ disposal facility. Excavated materials from the suspected burial site would be treated in one of two ways. If they are determined by the Health Protection Department to be contaminated, they would be contained in metal boxes and transported to a waste storage/ disposal facility. If found to be clean, the material would be used as fill when the site is backfilled. All four sites would then be backfilled and covered with a low-permeability cap (Figure 11), dressed with topsoil, and seeded to prevent erosion. Sixteen new groundwater monitoring wells would be installed in the vicinity of the sites if the suspected burial site is found to be contaminated. Only 12 groundwater monitoring wells would be required if the suspected burial site is determined to be clean. These wells would be sampled and analyzed quarterly for 1 year, then annually for 29 years. Site maintenance would be provided for the entire 30-year period.



Note: Permeability of drainage layer is >1.03E-03 cm/s.
Permeability of clay is <1.0E-07 cm/s.
Infiltration reduction is 99%.

FIGURE 11. Schematic Diagram of a Low-Permeability Cap

NO WASTE REMOVAL AND CLOSURE

Under the no waste removal and closure option, the relocation of certain surface structures would be necessary as in the previous option. No waste material would be removed. The known burial sites would be covered with a low-permeability cap (Figure 11), graded, and seeded to prevent erosion. The suspected burial area would be treated in one of two ways. If soil samples from this site indicate that it is contaminated, overlying surface structures would be relocated, and it would be capped. Otherwise, the site would be left as is. Sixteen new groundwater monitoring wells would be installed in the vicinity of the sites if the suspected burial site is found to be contaminated. Only 12 groundwater monitoring wells would be required if the suspected burial site is found to be clean. Environmental monitoring and site maintenance requirements would be the same as in the waste removal and closure option.

NO ACTION

Under the no action option, all sites would be left as is. Sixteen new groundwater monitoring wells would be installed around the project area. Environmental monitoring and site maintenance requirements would be the same as in the waste removal and closure option.

ESTIMATES OF ENVIRONMENTAL IMPACTS

The environmental consequences due to closure actions at waste disposal facilities can be grouped into two categories. The first is the relative risk to human health resulting from potential exposure to waste materials transported through groundwater or atmospheric pathways. The second is the potential impact on the aquatic and terrestrial ecosystems due to transport of waste materials into these environments.

Estimates of the environmental impacts in terms of potential human health risk and ecological upsets due to the postulated closure options for the TNX Burying Ground have been completed. The results of these evaluations are given in the following sections along with the details of analysis.

Three premises are assumed in the analysis of potential environment consequences. First, it is assumed that the Department of Energy (DOE) will maintain institutional control over the SRP site for 100 years beyond 1985. This assumption is reasonable in light of current production planning and projected scheduling for site decommissioning. Second, the basic time period for the long-term analyses has been set at 1,000 years beyond 1985 because Environmental Protection Agency (EPA) and Nuclear Regulatory Commission (NRC) guidelines specify 1,000 years as a reasonable time for projected calculations. Third, it is assumed that nearly all (99%) of the current waste source is removed in the waste removal and closure option.

HUMAN HEALTH RISKS

Pathway Analysis

In a general sense, exposure of waste materials in a disposal facility to a human population can occur only as a result of transport via surface, subsurface, or atmospheric pathways. At SRP the surface and subsurface pathways of most importance are groundwater movement to water wells, groundwater movement to surface streams, erosion of waste materials and movement to a surface stream, consumption of food produced from farmland reclaimed over a waste site, consumption of crops grown from natural biointrusion into a waste site, and direct exposure to gamma radiation. The relevant atmospheric pathways for human exposure are inhalation of waste particulates or gases in air, ingestion of foodstuffs containing waste materials resulting from deposition of air particulates on the ground surface and external radiation from air particulates deposited on the ground. Computer codes for simulating transport of waste constituents through surface, subsurface, and atmospheric pathways are described briefly below and in more detail in Stephenson et al. (1987).

Surface and Subsurface Pathways

To calculate the human health risks associated with surface and subsurface transport of radioactive and nonradioactive waste materials, the PATHRAE computer code was chosen. Developed for the EPA for performance assessment calculations of low-level radioactive waste sites, the code has been modified to perform transport and risk calculations for nonradioactive waste materials as well.

The PATHRAE methodology was used to calculate the surface and subsurface pathway scenarios of interest at the TNX Burying Ground. These pathways are groundwater movement to nearby hypothetical water wells, groundwater movement to surface streams and ultimately to the Savannah River, waste erosion and movement to a surface stream and ultimately to the Savannah River, consumption of food grown on reclaimed farmland over the waste site, consumption of crops grown from natural biointrusion into the waste site, and direct gamma exposure.

For groundwater movement to nearby water wells, the pathway consists of downward migration of the modeled waste components through advection and diffusion or as a result of dissolution in percolating precipitation. The PATHRAE calculations assume that a small fraction of the cationic contaminants will be in a more highly transportable form (K_d = 0.001 mL/g) to account for chemical speciation and factors that result in high mobility of cations (low pH, organic and/or inorganic complexation). This fraction is termed the facilitated transport fraction. This assumption results in a conservative calculation of the transport of cations through the hydrologic system in the time period of interest and is in agreement with groundwater monitoring results. These waste components move downward through the unsaturated zone to the aquifer below the disposal site. They mix with water in the saturated zone of the aquifer and move to nearby wells located downgradient (in the sense of aquifer flow). Two hypothetical well scenarios are analyzed: one immediately adjacent to the waste disposal facility (at 1 m) and one downstream from the edge of the facility (at 100 m). The models for both vertical and horizontal movement of waste materials account for chemical retardation by the soils. Once withdrawn from the well, the water is assumed to be consumed directly by individuals or used to irrigate crops that are then consumed by these same individuals.

For groundwater movement to surface streams, the pathway is similar to the one described above, but the modeled waste components are assumed to continue to move through the aquifer until released to surface waters. For the purpose of analyzing the potential impacts of releases through this pathway, the release is assumed to be into nearby surface streams and ultimately into the Savannah River, with its downstream consumer populations. For modeling purposes, the waste components are assumed to be transported instantaneously to the Savannah River without further dilution and to be completely mixed with water in the Savannah River.

The scenario for erosion and movement to a surface stream involves the gradual removal of the cover over the disposed waste by erosion and eventually the slow removal of the waste itself. The time required for erosion of the total cover depth is calculated. Then erosion operates on the waste materials by removing a given amount (specific depth) from the top of the waste each year. A conservative assumption is made that the modeled eroded waste components flow over the ground surface and into the surface stream in the same year they are removed from the disposed waste volume. Once the waste components reach the surface stream, they are assumed to be transported instantaneously to the Savannah River without further dilution and to be completely mixed with water in the Savannah River.

The pathway for consumption of food grown on reclaimed farmland accounts for potential exposure of individuals to waste materials through the human food chain. This pathway assumes that reclamation activities are required to cause exposure to waste materials. The means for disturbing the waste materials are modeled as drilling wells through the waste and excavating basements for homes. A volume of waste excavated by these activities is assumed to be completely mixed with a volume of soil down to 1 m. The soil mixture then is assumed to be used to grow a representative set of edible crops and forage for milk- and meat-producing animals. Individuals are assumed to get some fraction of their food needs from contaminated crops, meat, and milk.

A slightly different pathway involves consumption of crops whose roots have grown through subsurface sediments by natural biointrusion. Vegetation roots are presumed to take up waste constituents, and these crops, contaminated by root uptake, are directly consumed by humans. The distinction here is that no reclamation activities are imposed, only crops are consumed, and then only directly.

The direct gamma exposure pathway calculates the external radiation dose to an individual standing directly over a waste site. The cover material over the waste is allowed to erode at a specified rate, so the degree of shielding provided by the cover may decrease in time. For this pathway the conservative assumption is made that no loss of contaminants occurs by leaching to the groundwater pathways. The time dependence of the source term is described solely by radioactive decay.

Atmospheric Pathway

Modeling calculations to determine potential risk to human populations due to atmospheric transport of waste materials have been made using a variety of computer codes. The pathway scenarios considered for the TNX Burying Ground are inhalation of polluted air, ingestion of contaminated foodstuffs, and exposure to direct gamma radiation.

Atmospheric source terms for the site must first be estimated from soil inventories. Atmospheric source terms account for volatilization of select contaminants (i.e., organics), dust generated by suspension of contaminated soil due to wind erosion (saltation), and dust generated as a consequence of excavation of contaminated soil from the site. The time-dependent nature of atmospheric source terms must also be estimated to account for the time period of interest in this analysis (1,000 years). SESOIL, an EPA soil layer model, is used to estimate the soil contaminant concentration profiles as a function of time. The model accounts for potential upward transport (volatilization) and downward movement (infiltration) of each contaminant for each closure option. Airborne contaminant loadings are estimated using SESOIL and MARIAH (a newly developed computer code that employs a National Oceanographic and Atmospheric Administration box model and EPA source term equations). SESOIL estimates the amount of contamination entering the atmosphere over time from the site via volatilization. MARIAH estimates suspended dust loading to the atmosphere and excavation-generated dust loading due to digging, vehicular movement, and dumping. The source term for potential atmospheric transport away from the site --the contaminant loading due to dust--is the product of the dust loading and the contaminant concentration in the top soil layer.

The transport of contaminants from a waste disposal facility to potential receptor sites through atmospheric dispersion is modeled using the XOQDOQ computer code (Sagendorf et al., 1982), an NRC model used for routine atmospheric dispersion calculations at SRP. The calculated dispersion has been verified by environmental measurements of tritium (Marter, 1984). The XOQDOQ transport code uses a modified Gaussian plume model to estimate contaminant concentration as a function of distance and direction from a waste site. Time-dependent contaminant source strength and meteorological conditions are also input parameters.

Calculation of the transport of materials from SRP by the atmosphere is based on meteorological conditions that are measured continuously at seven on-plant meteorological towers and at a 366-m television transmitting tower 30 km northwest of the geometric center of SRP. For this analysis, meteorological dispersion and deposition were calculated with meteorological measurements over a 5-year period (1975 through 1979) collected at a meteorological tower located near the center of the SRP site (H Area).

After waste contaminant concentrations at potential receptor locations are determined, the results are translated into individual and population exposures. The maximum exposed individual at the site boundary and general population exposures to airborne contaminants via inhalation, ingestion, and direct gamma radiation pathways are estimated for nonradioactive and radioactive constituents.

Nonradioactive Constituents

The CONEX computer code uses XOQDOQ transport results and local population demographics to estimate time-dependent population exposures to nonradioactive constituents. The TERREX computer code also uses XOQDOQ transport results along with local crop production data and local population demographics to estimate population exposures to contaminated foodstuffs. The population demographics used in the CONEX and TERREX codes are estimated using a population growth model. Using census data from 1980 as the initial basis, the population growth model estimates the surrounding population from 1980 to 2050. After 2050, the population is assumed to be constant. After the end of the assumed period of institutional control (2085), it is assumed that the SRP reservation is inhabited by the public. Hence, the air receptor is closer to the waste site at the end of the period of institutional control.

Risk posed to the public population from nonradioactive constituents is calculated using a newly developed computer code called MILENIUM. For each potentially airborne contaminant, the MILENIUM code translates time-dependent exposure results into a population dose and into a maximum exposed individual dose. Calculated doses are then converted to risk estimates in the MILENIUM code.

Radioactive Constituents

To calculate the human health risks associated with atmospheric transport of radioactive waste materials, transport and dosimetry models developed by the NRC and others for assessing the effects of operations of licensed commercial nuclear facilities were chosen (NRC, 1977a, 1977b; ICRP, 1978). The radioactive transport and dose models have been implemented in the computer codes MAXIGASP and POPGASP as well as XOQDOQ. MAXIGASP is a computer program to calculate maximum and average doses to offsite individuals from atmospheric releases. POPGASP is a computer program to calculate population doses from atmospheric releases. Both of these codes are SRL-modified versions of the NRC program GASPAR (Eckerman et al., 1980). The modifications are those needed to meet the requirements for input of specific SRP physical and biological data. The basic calculational methods used in the GASPAR program were not modified.

Radioactive materials released to the environment generally become involved in a complex series of physical, chemical, and biological processes. Some of these processes involve dilution while others involve physical or biological reconcentration, followed by transfer through various pathways to man.

Annual average concentration and deposition factors calculated with the XOQDOQ program are used in the MAXIGASP and POPGASP programs along with data on population distribution, vegetable crop production, milk production, and meat production to calculate offsite radiation exposure. The major exposure pathways considered in the calculation of atmospheric doses are briefly described as follows:

Pathway	Description
Plume	External dose from radioactive materials transported by the atmosphere
Ground	External dose from radioactive material deposited on the ground
Inhalation	Internal dose from inhalation of radioactive materials transported by the atmosphere
Vegetation	Internal dose from consumption of vegetable food crops that contain radioactive material deposited from the atmosphere
Milk	Internal dose from consumption of milk that contains radioactive material deposited from the atmosphere into the human food chain through livestock
Meat	Internal dose from consumption of meat products that contain radioactive material deposited from the atmosphere into the human food chain through livestock

Occupational Exposure

Risk posed to the worker involved in waste excavation activities of nonradioactive constituents is estimated using the MARIAH and MILENIUM computer codes. The MARIAH code estimates the amount of dust generated during the excavation of a waste site and the time required to complete the activity. The MILENIUM code uses these results and appropriate conversion factors to estimate worker risk. A conservative assumption built into these models is that the occupational work force would not use any special protective clothing during waste excavation operations. In actuality, operating policy and federal standards require all workers to use protective clothing. if exposure potential is present. Risks for workers would be reduced by a factor of 50 if they use standard respiratory equipment

Radiation exposure pathways are evaluated to calculate risks attributable to closure activities. Exposure from the following pathways are considered: internal dose (from inhalation) to personnel directly involved in cleanup activities; external dose to personnel directly involved in cleanup activities; and external dose to personnel involved in transportation of contaminated waste.

For the inhalation pathway, parameters such as the size of the work force, volume of waste to be excavated, and the number of work days required to excavate the waste are estimated. Concentrations of waste constituents in the air to which workers are exposed at the waste site are calculated with dust generation and resuspension models described previously and combined with work-force parameters to estimate worker inhalation exposure (no respiratory protection is assumed), dose commitment, and risk.

Exposures due to external irradiation of site workers are estimated using the DECOM computer code (Till & Moore, 1986), a pathway analysis methodology that calculates the quantity of contaminated soil that must be removed in order to keep exposures from all potential pathways below a value selected by the user. External dose rate is calculated using the dose factors of Kocher and Sjoreen (1985). The model employed in DECOM accounts for radionuclide contamination in 15-cm increments of depth and estimates exposure from the top 15 cm as well as the contribution from contaminated soil beneath the exposed layer. Worker exposure is estimated for the work crew (excluding truck drivers) by assuming workers are exposed to the external radiation field at each area for the period of cleanup required for the area. Exposure of drivers to external radiation is assumed to occur during transport of excavated waste from the site to a waste storage/disposal facility. The total time of exposure for each driver is assumed to be 4 hr/day for the period of cleanup required for the area. The exposure rate is conservatively assumed to be equal to the external exposure rate at 1 m above the ground as calculated by DECOM. No credit for shielding provided by the metal boxes is taken into account.

It is assumed there will be no release of radioactive materials from the metal boxes during routine transport. Further, because the material is being transported within the boundary of the Savannah River Plant, it is assumed there will be no exposure to the public and no significant exposure to employees on site involved in activities not related to the cleanup of this area.

Risk Assessment Procedure

Risk assessment may be divided into three major components: (1) hazard assessment, consisting of hazard identification and dose-response assessment; (2) exposure assessment; and (3) risk characterization. These fundamental steps are common to all assessments of the risk of exposure to pollutants, regardless of the substances under investigation; the species, populations, or environmental systems at risk; the medium (or media) in which exposure occurs; the route of exposure; or the adverse effects under consideration.

Hazard assessment involves the identification of waste contaminants of concern (i.e., subjects of the risk assessment) and an initial determination of the intrinsic toxicity of these contaminants under consideration (dose-response assessment). Exposure assessment is the process of measuring or estimating the intensity, duration, and frequency of exposure to these contaminants. Other elements critical to the exposure assessment are the identification of routes of exposure and the determination of human and/or nonhuman receptors at risk. The final component of the risk assessment process, risk characterization, can be defined as the process of estimating the incidence of an adverse effect under the various conditions of exposure described in the exposure assessment. Risk characterization is conducted by combining the results of the exposure and hazard (dose-response) assessments.

Risk assessment procedures for nonradioactive and radioactive constituents are briefly described below and are treated in more detail in King et al. (1987).

Nonradioactive Constituents

It is common practice to consider risk characterization for carcinogens and noncarcinogens separately because of a fundamental difference in the way organisms typically respond to these classes of compounds. For noncarcinogens, toxicologists recognize the existence of a threshold of exposure below which there is only a very small likelihood of adverse health effects in an exposed population. Exposure to carcinogenic compounds, however, is not characterized by the existence of a threshold. Rather, all levels of exposure are considered to carry a risk of adverse effects.

The procedure for calculating risk of exposure to carcinogenic compounds is well documented (EPA, 1985a; National Research Council, 1983; Rodricks, 1984). A nonthreshold dose-response model is used to calculate a unit risk value (risk per unit dose) for each chemical. The risk per unit dose (unit carcinogenic risk) is then multiplied by the estimated average daily lifetime dose experienced by the exposed individual or population to derive an estimate of risk (R) as follows:

$$R = D \times UCR$$

where D = average daily lifetime dose (mg/kg body weight/day). A 50-year exposure lifetime and 70-kg body weight are assumed.

UCR = unit carcinogenic risk estimate $[(\text{mg/kg body weight/day})^{-1}]$

The risk value is an explicit estimate of risk and will have a value between 0 and 1. In this environmental analysis, this risk is called chemical carcinogenic risk and for an exposed individual has units of health effects (HE) per lifetime; for an exposed population the units are simply health effects. In evaluating risk of exposure to more than one carcinogen, the risk values for each compound may be summed to give an overall estimate of total carcinogenic risk (EPA, 1985a; Rodricks, 1984). This summing is done for each source of environmental release, for each associated exposure pathway, and for each receptor group at risk of exposure.

The traditionally accepted practice of evaluating exposure to noncarcinogenic compounds has been to determine a no-observable-effect-level (NOEL) experimentally and to divide this level by a safety factor in order to establish an acceptable human dose. This acceptable human dose has been labeled as an acceptable daily intake (ADI) by the National Research Council (1983). The ADI is then compared to the average daily dose experienced by an exposed individual to obtain a measure of risk (R) as follows:

$$R = D/ADI$$

where D = average daily dose (mg/kg body weight/day). A one-year exposure period and 70-kg body weight are assumed.

ADI = acceptable daily intake for chronic exposure (mg/kg body weight/day)

The method of developing acceptable limits of exposure implies that the application of safety factors of various magnitudes to an experimentally derived NOEL will ensure minimal risk. The acceptable exposure levels (e.g., ADIs) are typically derived by making assumptions about the nature of dose-response relationships at low doses and drawing inferences based upon the available data (National Research Council, 1983).

The risk values derived for noncarcinogens will vary from <1 to >1. This risk is called noncarcinogenic risk, and for an exposed individual has units of ADI fraction. Unlike the estimates of R derived for carcinogens, however, R values for noncarcinogens cannot be meaningfully summed to obtain an overall estimate of noncarcinogenic risk from a given waste site for a given exposure pathway and receptor group. However, as a method of estimating the relative hazard of a mixture of noncarcinogenic chemicals, the noncarcinogenic risk values for an exposed individual will be summed and called the EPA Hazard Index (a unitless parameter). The basis for such treatment of risk results is the EPA Guidelines (EPA, 1985b) for health risk assessment of chemical mixtures, in which EPA defines a hazard index of the mixture based on the assumption of additivity. Because a threshold dose-response model is used in calculating noncarcinogenic risk, it is not meaningful to extrapolate noncarcinogenic population risks. The ADI fraction and EPA Hazard Index are not mathematical predictions of incidence of effects or severity, but are only numerical indicators of the transition between acceptable and possibly unacceptable exposure levels.

It is important to emphasize that the proposed methods for evaluating carcinogenic and noncarcinogenic hazards have been used only in evaluating the relative risk of adverse effects from postulated closure options at a given waste site or from one site to the next at the Savannah River Plant. The methods as proposed by EPA and the National Research Council are not to be assumed to be a quantitative evaluation and prediction of the incidence of adverse effects in exposed populations. The proposed methods are a tool for relative assessment of risk (i.e., comparison across sites or across closure options).

The data base (King et al., 1987) for UCRs and ADIs for inhalation and ingestion pathways was derived from the EPA Superfund Public Health Evaluation Manual (EPA, 1985a), which was designed to conform to EPA's proposed risk assessment guidelines (Federal Register, 1984; EPA 1985b) and to serve as a framework for analyzing public health risks and for developing design goals for closure options.

Radioactive Constituents

The risk associated with exposure to radioactive materials is typically characterized by a linear no-threshold model for establishing the likelihood of adverse health effects. Most scientists generally acknowledge the lack of a threshold of exposure; that is, all levels of exposure are considered to carry a finite risk of adverse effects.

Estimates of health risks associated with calculated exposures to radioactivity were made using the guidelines of the International Commission on Radiological Protection (ICRP, 1975, 1977). The detrimental health effects against which radiation protection is required are known as somatic and hereditary. Radiation effects are called somatic if they become manifest in the exposed individual and hereditary if they affect the individual's descendants. Carcinogenesis is considered to be the chief somatic risk of irradiation at low doses and, therefore, the main problem in radiation protection.

The units of radiation dose to an individual are usually expressed in millirem (mrem). To put this in perspective, an individual receives an average annual radiation dose of 93 mrem from natural sources of radiation in the vicinity of SRP. Population dose commitment is the sum of individual dose commitments in a population group and is expressed in units of person-rem.

Radiological doses are calculated with dose factors (King et al., 1987) based on methodology developed by the ICRP as reported in its Publication 30 (ICRP, 1978) and recently implemented by DOE. These dose factors relate intake of radioactive materials through ingestion and inhalation to the dose commitment received for 50 years following intake.

The procedure for determining the risk of exposure to a radionuclide requires two basic calculations. First, the radionuclide intake in a given year is multiplied by a dose conversion factor for the specific radionuclide of interest to establish a dose equivalent value. Mathematically this is represented as follows:

$$CEDE = C \times DCF$$

where CEDE = committed effective dose equivalent for a given environmental pathway (mrem/yr)

C = calculated annual intake of radioactivity for a given environmental pathway (pCi)

DCF = dose conversion factor for a given radionuclide based on ICRP guidelines (mrem/pCi)

Second, the risk of radiation exposure is found by multiplying the committed effective dose equivalent by the risk conversion factor. This equation is as follows:

$$R = CEDE \times RCF$$

where R = radioactive risk (health effects/yr of intake)

RCF = risk conversion factor (health effects/mrem)

For this environmental analysis, radioactive risk to an individual is the incremental probability of a health effect (somatic and genetic) over the 50-year lifetime of an adult male resulting from chronic intake in the first year. The units for individual radioactive risk are health effects (HE) per year of intake. Radioactive risk to the exposed population is an estimate of the projected number of incremental health effects (somatic and genetic) for the exposed population. The units for radioactive risk to a population are health effects for the receptor group during the time period of interest.

Although the frequency of effects resulting from radiation exposure is dependent on age, sex, type of radiation, and other factors, a review of reports by the Committee on the Biological Effects of Ionizing Radiation (NAS, 1980), the ICRP (ICRP, 1977), and the Office of Radiation Programs of the Environmental Protection Agency (EPA, 1985c) indicates that, for average populations, a reasonable range for the risk conversion factor is 1.65E-04 to 2.80E-04 adverse effects per rem of dose. For this assessment, a conservative value reflecting the upper limit of the above range has been chosen to convert dose to health effects for water, terrestrial, atmospheric, and occupational pathways.

The dose and health risk data should be used with caution since they are not presented for the purpose of calculating projected cancer deaths or other health-effect assessments, but are presented solely to provide a basis for evaluation and comparison of waste-site closure action alternatives. Although the codes used in the risk assessment process represent state-of-the-art technology in risk estimation, they necessarily involve numerous assumptions and generalizations that may be highly uncertain under some conditions. Hence, their application is more reliable for comparing relative risks from exposures via similar environmental pathways than for estimating absolute risks of human health effects.

Results

Surface and Subsurface Pathways

The surface and subsurface pathways for transport of waste materials, the resulting potential exposures to the human population, and the excess risk posed to human health for the postulated closure options for the TNX Burying Ground have been calculated using the PATHRAE code. Standard options in the code are used to represent both the current waste-site condition and its potential configurations covered in the closure options. The pathways modeled are groundwater movement to hypothetical water wells nearby, groundwater movement to surface streams, waste erosion and movement to a surface stream, consumption of food grown on reclaimed farmland, consumption of crops grown through natural biointrusion, and direct gamma exposure. All scenarios with the exception of groundwater movement and waste erosion to surface streams are assumed to occur immediately after the 100 years of institutional control. The groundwater movement and waste erosion pathways to surface streams may occur before the end of the assumed 100-year period of institutional control. It should be noted that the events may not occur for many hundreds of years, if at all, even without institutional control.

The TNX Burying Ground was originally constructed specifically for the disposal of uranyl nitrate from the evaporator explosion. Because there was no extended period of operation, the burying ground was considered to be a spill. Leaching into the groundwater was considered to begin in 1953, at the time of burial, and the inventory that was considered present after excavation was used for the leaching process.

Similar PATHRAE calculations were performed for the waste removal and closure and no waste removal and closure options. For the no waste removal and closure option, a low-permeability cap and backfill were added for this option. The backfill and cap serve to alter parameters defining the surface erosion, accessibility of biointrusion (roots), and uptake into food grown on the site. The low-permeability cap also greatly reduces the infiltration of water into the waste, altering the leaching, hydrology, and transport parameters.

The contaminant inventory used in the PATHRAE calculations is presented in Table 2. This inventory is based on an estimate of 27 kg of uranyl nitrate buried at the TNX Burying Ground. The general SRP site parameters used for the PATHRAE analysis are presented in Table 3. The facility parameters for the TNX Burying Ground are defined in Table 4. The parameters defining the contaminant pathways through groundwater and other environmental paths were defined from the geohydrological data presented earlier and are presented in Table 5 as they were used in the PATHRAE analyses.

The geohydrologic information presented previously indicates that the water table beneath the TNX Burying Ground is probably within the McBean Formation. The water table beneath the waste site is believed to discharge toward the bottomland wetlands to the southeast. The PATHRAE model assumes a single flow path and calculates the groundwater and outcrop concentrations along the path. The flow path assumed for this waste site is based on a groundwater outcrop into the nearby bottomland wetlands and eventual migration into the Savannah River. The groundwater flow path is shown in Figure 12.

Many of the parameters used in the PATHRAE code are specific to given chemicals or radionuclides. They are dose conversion factors (DCF), unit carcinogenic risk (UCR) factors, acceptable daily intakes (ADI), sorption coefficients (K_d), soil-plant transfer factors, solubilities, and facilitated transport fractions. Table 6 presents these parameters for the radionuclides, and Table 7 presents corresponding parameters for the chemical species.

TABLE 2

Contaminant Inventory for the TNX Burying Ground

Radionuclide	Inventory (Ci)
^{238}U	4.3E-03
Chemical	**Inventory (kg)**
Nitrate (as N)	6.7E+00

TABLE 3

General Pathway Parameters for PATHRAE Calculations

Parameter	Value
River flow rate	9.1E+09 m^3/yr
Aquifer density	1,600 kg/m^3
Aquifer porosity	0.2 (dimensionless)
Soil residual saturation	0.1 (dimensionless)
Vertical permeability of unsaturated zone	2.2 m/yr
Soil index	0.25 (dimensionless)
Plant root depth	1.0 m
Areal density of plants	1.0 kg/m^2

TABLE 4

TNX Burying Ground Facility Parameters for PATHRAE Calculations

Parameter	Value (m)
Facility length (parallel to aquifer)	20
Facility width	20
Waste thickness	1
Cover thickness	2

TABLE 5

Hydrological Pathway Parameters for PATHRAE Calculations

Parameter	Value
Distance of groundwater flow to river	400 m
Distance from bottom of burial ground to water table	10 m
Distance to wells	1 m, 100 m
Length of perforated well casing in water table	10 m
Water seepage rate	0.38 m/yr
Horizontal groundwater velocity	10 m/yr

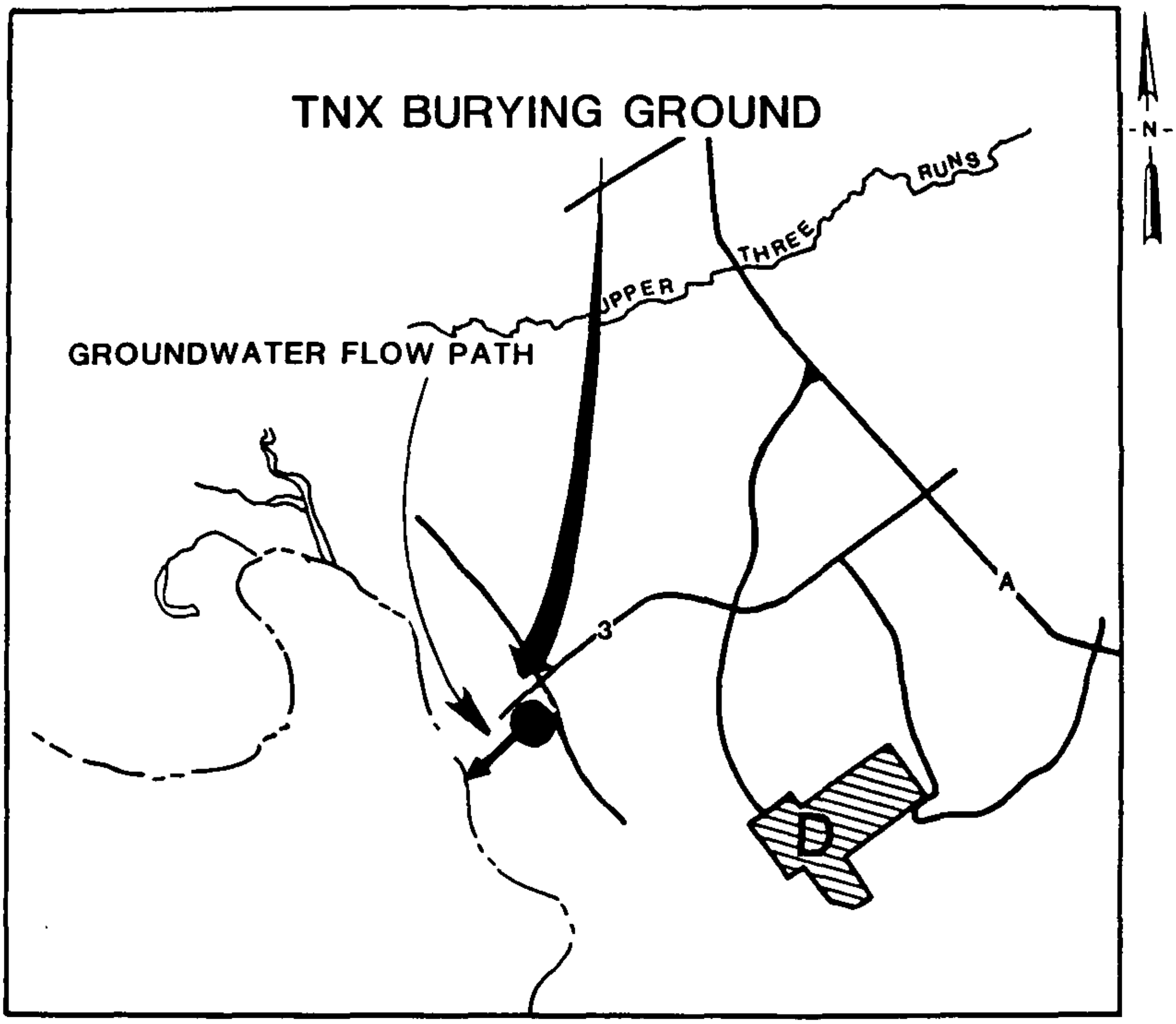


FIGURE 12. Groundwater Flow Path From the TNX Burying Ground

TABLE 6

Radionuclide-Specific Data for PATHRAE Analyses

Radio-nuclide	DCF for Ingestion* (mrem/pCi)	K_d** (mL/g)	Soil-Plant Transfer Factor*	Solubility** (moles/L)	Facilitated Transport Fraction **
^{238}U	2.3E-04	4.0E+01	2.5E-03	†	1.0E-03

* Data from King et al. (1987).
** Data from Looney et al. (1987b).
† Transport not limited by solubility.

TABLE 7

Chemical-Specific Data for PATHRAE Analyses

Chemical	ADI* (mg/kg/day)	K_d** (mL/g)	Soil-Plant Transfer Factor*	Solubility** (mg/L)
Nitrate	1.3E+00	1.0E-03	3.0E+01	†

* Data from King et al. (1987).
** Data from Looney et al. (1987b).
† Transport not limited by solubility.

One set of PATHRAE analyses was performed for each closure option for analyzing the environmental transport, exposures, and human health risks from the TNX Burying Ground. Each set consisted of four computer runs. The first run identified the times (years) at which peak doses occurred for human exposures and only addressed the groundwater pathways. The second analyzed the exposures and risks from all pathways at selected times. The third analysis calculated total releases to the Savannah River, and the fourth analysis calculated the contaminant concentrations in groundwater and fluxes at the outcrop location.

The PATHRAE concentration, dose, and risk calculations for each of the closure options are presented in the following sections. In reporting concentrations (and corresponding doses and risks) the cutoff value has been set arbitrarily at 1.0E-20. Values smaller than this are reported as zero (0.0) in the tables. Time is measured in years since (or before) 1985 in all tables. Because of the assumed period of institutional control, analysis of the pathways for groundwater to wells, reclaimed farmland, and direct gamma exposure is not applicable prior to 100 years,

All Closure Options

The evaluation of doses and risks for the no action option was sufficient for the waste removal and closure and the no waste removal and closure options because all options had similar effects on the groundwater pathways. The nitrate and ^{238}U components with high mobility are already in the groundwater and beyond any remedial action when site closure occurs. The ^{238}U component with low mobility does not appear in the groundwater within the 1,000-year period of concern. The PATHRAE analyses of the groundwater pathways for all three closure options to identify the peak doses for human exposure are summarized in Table 8. These analyses show that the risks associated with each groundwater pathway are small for all constituents. Peak concentrations of nitrate and ^{238}U for the well-water pathways occur before the start of the 1,000-year time assessment period. In addition, peak concentrations of nitrate and ^{238}U for the groundwater-to-river pathway occur within the period of institutional control of the site. Dose and risk results for the groundwater-to-river and groundwater to well pathways are presented in Tables 9 through 11 for all closure options. These doses and risks for the well-water and river pathways are small. The results of the outcrop and wetlands assessments are given in Table 12. The reclaimed-farmland pathway results are given in Table 13. The doses and risks associated with this pathway are also small.

Dose calculations were not made for the biointrusion pathway because the assumed groundcover thickness at the site is 2 m and

TABLE 8

Peak Radionuclide and Chemical Calculations for All Closure Options

Pathway	Radionuclide	Peak Concentration (Ci/m^3)	Peak Year Since 1985	Dose (mrem/yr)	Radioactive Risk (HE/yr)
Groundwater to well at 1 m	^{238}U*	7.5E-09	-27	8.2E-01	2.3E-07
Groundwater to well at 100 m	^{238}U*	9.5E-10	-21	1.0E-01	2.9E-08
Groundwater to river	^{238}U*	1.6E-17	8	1.8E-09	5.1E-16

Pathway	Chemical	Peak Concentration (mg/L)	Peak Year Since 1985	Noncarcinogenic Risk (ADI fraction)
Groundwater to well at 1 m	Nitrate	1.2E+01	-27	4.7E-01
Groundwater to well at 100 m	Nitrate	1.5E+00	-21	6.0E-02
Groundwater to river	Nitrate	2.5E-08	8	1.3E-09

* Facilitated transport fraction.

TABLE 9

Radionuclide and Chemical Results for Groundwater-to-River Pathway for All Closure Options

	Years Since 1985							
	0	100	200	300	400	500	700	1000
Concentration (Ci/m^3)								
^{238}U	1.2E-17	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dose (mrem/yr)								
^{238}U	1.3E-09	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Radioactive Risk (HE/yr)								
	3.7E-16	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Concentration (mg/L)								
Nitrate	1.8E-08	3.0E-12	1.1E-17	0.0	0.0	0.0	0.0	0.0
Noncarcinogenic Risk (ADI fraction)								
Nitrate	9.3E-10	1.5E-13	5.4E-19	0.0	0.0	0.0	0.0	0.0
EPA Hazard Index	9.3E-10	1.5E-13	5.4E-19	0.0	0.0	0.0	0.0	0.0

TABLE 10

Radionuclide and Chemical Results for Groundwater to Well at 1 m Pathway for All Closure Options

	Years Since 1985						
	100	200	300	400	500	700	1000
Concentration (Ci/m^3)							
^{238}U	3.0E-19	0.0	0.0	0.0	0.0	0.0	0.0
Dose (mrem/yr)							
^{238}U	3.3E-11	0.0	0.0	0.0	0.0	0.0	0.0
Radioactive Risk (HE/yr)							
	9.3E-18	0.0	0.0	0.0	0.0	0.0	0.0
Concentration (mg/L)							
Nitrate	4.7E-10	8.2E-16	0.0	0.0	0.0	0.0	0.0
Noncarcinogenic Risk (ADI fraction)							
Nitrate	1.9E-11	3.3E-17	0.0	0.0	0.0	0.0	0.0
EPA Hazard Index	1.9E-11	3.3E-17	0.0	0.0	0.0	0.0	0.0

Note: Analysis of this pathway is not applicable prior to 100 years because of assumed period of institutional control.

TABLE 11

Radionuclide and Chemical Results for Groundwater to Well at 100 m Pathway for All Closure Options

	Years Since 1985						
	100	200	300	400	500	700	1000
Concentration (Ci/m^3)							
^{238}U	3.0E-17	0.0	0.0	0.0	0.0	0.0	0.0
Dose (mrem/yr)							
^{238}U	3.3E-09	0.0	0.0	0.0	0.0	0.0	0.0
Radioactive Risk (HE/yr)							
	9.2E-16	0.0	0.0	0.0	0.0	0.0	0.0
Concentration (mg/L)							
Nitrate	4.7E-08	8.6E-14	2.1E-19	0.0	0.0	0.0	0.0
Noncarcinogenic Risk (ADI fraction)							
Nitrate	1.9E-09	3.5E-15	8.4E-21	0.0	0.0	0.0	0.0
EPA Hazard Index	1.9E-09	3.5E-15	8.4E-21	0.0	0.0	0.0	0.0

Note: Analysis of this pathway is not applicable prior to 100 years because of assumed period of institutional control.

TABLE 12

Radionuclide Activity and Chemical Concentration Outcrop Data for All Closure Options

	Years Since 1985							
	0	100	200	300	400	500	700	1000
Concentration in Groundwater at Outcrop (Ci/m^3)								
^{238}U	6.3E-11	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Contaminant Flux at Outcrop (Ci/yr)								
^{238}U	1.1E-07	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Concentration in Groundwater at Outcrop (mg/L)								
Nitrate	9.8E-02	1.3E-05	4.7E-11	0.0	0.0	0.0	0.0	0.0
Contaminant Flux at Outcrop (kg/yr)								
Nitrate	1.7E-01	2.7E-05	9.7E-11	0.0	0.0	0.0	0.0	0.0

TABLE 13

Radionuclide Results for Reclaimed-Farmland Pathway for the No Action Option

	Years Since 1985						
	100	200	300	400	500	700	1000
Dose (mrem/yr)							
^{238}U	1.4E-04	1.1E-04	8.0E-05	6.0E-05	4.4E-05	2.5E-05	1.0E-05
Radioactive Risk (HE/yr)							
	4.0E-11	3.0E-11	2.2E-11	1.7E-11	1.2E-11	6.9E-12	2.8E-12

Note: Analysis of this pathway is not applicable prior to 100 years because of assumed period of institutional control.

the assumed plant-root penetration depth is 1 m. Dose calculations for the direct gamma exposure pathway resulted in doses less than 1.0E-20 mrem/yr. These doses are not considered significant and are, therefore, not included here.

The waste removal and closure option has doses similar to the no waste removal and closure option for the mobile components in the groundwater pathways. This option also results in no doses from the reclaimed-farmland pathway because of the addition of a cap over the site.

For the implementation of the no waste removal and closure option, a low-permeability cap would be placed over the burial ground. The ^{238}U contaminant is grouped into two major categories: a small mobile component that moves at the same velocity as the water and a large component with very low mobility. Pathway analyses indicate that nitrate and the mobile component of ^{238}U would be entering the groundwater by the time any remedial action begins. The low mobility component of ^{238}U has peak concentrations after the 1,000-year period of concern and would not be influenced by the cap.

The no waste removal and closure option would have negligible beneficial effect upon the groundwater pathways. However, doses from the reclaimed-farmland would be essentially eliminated because of the addition of a cap over the site.

Summary

The overall transport of radionuclides from the TNX Burying Ground to the outside environment was assessed by a PATHRAE analysis of total releases to the Savannah River over a 1,000-year period. The quantities of contaminants reaching the Savannah River are the same for all closure options, being controlled mainly by the mobile components. The total chemical and radionuclide inventory released via this pathway in the first 1,000-year period is listed in Table 14 for all closure options. Assuming a downstream population of 100,000 the total releases to the Savannah River would result in a radionuclide risk of 1.5E-09 HE.

The maximum chemical risks resulting from the TNX Burying Ground from the postulated closure options are summarized in Table 15. The constituents that dominate the risk are also given along with the year in which the maximum risks occur. The dominant constituents were nitrate and ^{238}U in the groundwater pathways and ^{238}U in the reclaimed-farmland pathway for all of the closure options. The PATHRAE analyses indicate that no risks occur for the erosion, biointrusion, and direct gamma exposure pathways for any of the closure options or chemical constituents. The maximum

TABLE 14

Cumulative Release Over 1,000-Year Period to the Savannah River for All Closure Options

Radionuclide	Total Release (Ci)
^{238}U	4.3E-06

Chemical	Total Release (kg)
Nitrate	6.7E+00

TABLE 15

Comparison of Maximum Risks and Dominant Constituents

	All Closure Options			
Pathway	Peak Year Since 1985	Dominant Constituent	Radioactive Risk (HE/yr)	Noncarcinogenic Risk (EPA Hazard Index)
Groundwater to well at 1 m	100	^{238}U	9.3E-18	-
	100	Nitrate	-	1.9E-11
Groundwater to well at 100 m	100	^{238}U	9.2E-16	-
	100	Nitrate	-	1.9E-09
Groundwater to river	8	^{238}U	1.6E-17	-
	8	Nitrate	-	2.5E-08
Reclaimed farmland	100	^{238}U	4.0E-11	-

Note: Analysis of the pathways for groundwater to wells and reclaimed farmland is not applicable prior to Year 100 because of the assumed period of institutional control.

noncarcinogenic risk in all three groundwater pathways is from exposure to nitrate (2.5E-08 ADI fraction) for all three closure options and occurs at Year 8 during the period of institutional control. The maximum radioactive risk in the groundwater pathways is from exposure to ^{238}U (9.2E-16 HE/yr) for all closure options and occurs immediately following the period of institutional control. The maximum radioactive risk in the reclaimed-farmland pathway is from exposure to ^{238}U (4.0E-11 HE/yr) for all closure options and occurs immediately following the period of institutional control.

The PATHRAE analyses indicate that the site closure options with or without waste removal would have negligible effect on the groundwater pathways. The nitrate and the ^{238}U component with high mobility are already in the groundwater and beyond any remedial action when site closure occurs. The ^{238}U component with low mobility does not appear in the groundwater within the 1,000-year period of concern.

The PATHRAE analyses show that the waste removal and closure and no waste removal and closure options result in reduced risks for the reclaimed-farmland and direct gamma exposure pathways. However, risks from these pathways are small, even for the no action option. The natural biointrusion pathway is not a contributor to dose because the assumed cover thickness exceeds the maximum plant-root depth.

Atmospheric Pathway

Estimates of public risk attributable to exposure of atmospherically transported contaminants resulting from the postulated closure options at the TNX Burying Ground have been calculated. As discussed earlier, the general pathways for exposure to atmospherically dispersed chemical or radioactive constituents are inhalation of polluted air, ingestion of contaminated foodstuffs, and direct gamma radiation. The data, assumptions, and models discussed previously were used to estimate the quantities of airborne contaminants released from the waste site and to quantify public exposure and risk via the inhalation, ingestion, and gamma radiation pathways.

The chemical and radionuclide constituents selected for this environmental analysis of risk were identified by Looney et al. (1987a) as discussed previously. They are one chemical (nitrate) and one radionuclide (^{238}U). Soil inventory profiles for each closure option for the estimates of disposed mass and radioactivity were determined using a four-layer soil model (SESOIL). These concentration profiles for the TNX Burying Ground were determined for each constituent of concern for each site cleanup option. Table 16 contains these data. For the waste removal and closure

TABLE 16

Soil Inventory Profile for Radionuclide and Chemical Constituents at the TNX Burying Ground

Option	Layer Number	Thickness (m)	Constituent Inventory (Ci) Natural Uranium
Waste removal and closure	1	0.50	0.0
	2	1.30	0.0
	3	0.61	4.30E-05
	4	12.59	0.0
	Inventory excavated		4.26E-03
No waste removal and closure	1	0.50	0.0
	2	1.30	0.0
	3	0.61	4.30E-03
	4	12.59	0.0
No action	1	0.50	0.0
	2	1.30	0.0
	3	0.61	4.30E-03
	4	12.59	0.0

Option	Layer Number	Thickness (m)	Constituent Inventory (kg) Nitrate (as N)
Waste removal and closure	1	0.50	0.0
	2	1.30	0.0
	3	0.61	6.67E-02
	4	12.59	0.0
	Inventory excavated		6.60E+00
No waste removal and closure	1	0.50	0.0
	2	1.30	0.0
	3	0.61	6.67E+00
	4	12.59	0.0
No action	1	0.50	0.0
	2	1.30	0.0
	3	0.61	6.67E+00
	4	12.59	0.0

Note: The waste removal and closure option includes excavating 896 m^3 of contaminated soil.

option, the table also lists the volume of soil and mass of each constituent that would be excavated from the site.

Nonradioactive Constituents

For each of the three options considered, nitrate was analyzed to estimate public exposure and risk attributable to atmospheric contaminant releases from the TNX Burying Ground. Because nitrate has only noncarcinogenic properties, public exposure and risk were estimated for noncarcinogens only.

Twenty-four 1-year risk assessments were performed spanning a 1,000-year period. Analyses were performed for every year for the period 1986-1990, for every 5th year for the period 1990-2035, and for every 100th year for the period 2085-2985. Doses and risks for the population and for a maximum exposed individual were estimated.

Table 17 shows noncarcinogenic risks associated with nitrate for three selected years--1, 100, and 1,000. The noncarcinogenic risks are not plotted because, with the exception of the waste removal and closure option in Year 1, all risks are zero. In Year 1, there is some risk for the waste removal and closure option attributable to waste excavation activities. For all years after Year 1, the risks for the waste removal and closure option are zero (0.0). Also, for all years the risks for the no waste removal and closure option and the no action option are zero (0.0).

Radioactive Constituents

Atmospheric dust terms were estimated for depleted uranium for each of the closure options at the TNX Burying Ground. The results are presented in Table 18. Nonzero source terms were calculated for the site in only the first year of the waste removal and closure option. The source of material is the excavation operation, giving rise to suspended contaminated dust covered with asphalt and contains no volatile radioactive material. No atmospheric releases were projected under the other options.

The dose to the maximum exposed individual at the SRP boundary, as a consequence of contaminated dust moving from the TNX Burying Ground, is presented in Table 19. These calculations include inhalation of suspended dust and radionuclides deposited on the ground entering the human food chain.

The total maximum dose from the waste removal and closure option is 8.37E-05 mrem during the first year. No further dose is expected because of the backfilling of the site and the nonvolatile

TABLE 17

Risks Due to Atmospherically Released Noncarcinogens for Years 1, 100 and 1,000 for the Closure Options

Constituent	Noncarcinogenic Risk (ADI fraction) Waste Removal and Closure	No Waste Removal and Closure	No Action
	Year 1		
Nitrate	1.01E-12	0.0	0.0
EPA Hazard Index	1.01E-12	0.0	0.0
	Year 100		
Nitrate	0.0	0.0	0.0
EPA Hazard Index	0.0	0.0	0.0
	Year 1,000		
Nitrate	0.0	0.0	0.0
EPA Hazard Index	0.0	0.0	0.0

TABLE 18

Radionuclide Atmospheric Source Terms Used to Assess Public Risk for Years 1, 100, and 1,000 for the Closure Options

	Waste Removal and Closure			No Waste Removal And Closure			No Action		
	1	100	1000	1	100	1000	1	100	1000
Radionuclide (Ci/yr)									
Depleted uranium	3.83E-07	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 19

Summary of Public Risk from Atmospheric Transport of Radionuclides for Years 1, 100, and 1,000

	Dose								
	Waste Removal and Closure			No Waste Removal and Closure			No Action		
	1	100	1000	1	100	1000	1	100	1000
Maximum individual (mrem)	8.37E-05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Population (person-rem)	2.93E-05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	Radioactive Risk								
	Waste Removal and Closure			No Waste Removal and Closure			No Action		
	1	100	1000	1	100	1000	1	100	1000
Maximum individual (HE/yr)	2.34E-11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Population (HE)	8.20E-09	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

nature of the radionuclides. The corresponding radioactive risk is small (2.34E-11 HE/yr) to the maximum exposed individual due to the small dust source term.

The dose calculations and an estimate of total health effects to the exposed population surrounding the Savannah River Plant for the closure options are also presented in Table 19. In no case do the incremental health effects to the exposed population exceed 8.20E-09 (based on an incremental dose of 2.93E-05 person-rem). This is an extremely small calculated absolute health effect to the affected population of about 585,000 (1986 estimate) in the vicinity of the Savannah River Plant. The population results can be placed into proper perspective relative to exposure to background radiation. For the exposed population of 585,000 (1986 estimate) surrounding the Savannah River Plant, the average individual receives 93 mrem of background radiation corresponding to a population dose of 5.42E+04 person-rem of radiation exposure, resulting in an estimate of 15 absolute adverse health effects to the exposed population over a lifetime due to natural background radiation.

The calculated health effects are zero for the no waste removal and closure and no action options, due to the presence of the backfill in the basin and the absence of excavation-related activities. For radionuclide atmospheric pathways, the risk of offsite exposure does not exceed acceptable criteria for any of the closure options for the TNX Burying Ground.

Occupational Exposure

Cleanup of the site under the waste removal and closure option would expose workers to the airborne nonradioactive contaminant nitrate. Approximately 896 m^3 of soil would be excavated if the waste removal and closure option is selected. Therefore, the site excavation would require approximately 5 days (Table 20). Approximately 129 kg of contaminated dust would be generated as a result of excavation activities. Calculation of risks due to inhalation assumes no respiratory protection.

Nonradioactive Constituents

The calculated nonradioactive risks for the waste removal and closure option, assuming an average individual works at the site for 8 hr each day, are summarized in Table 21. (Note that the average worker and maximum exposed worker are the same in this model at worker risk.)

For the noncarcinogenic contaminant nitrate, the average worker is exposed to a noncarcinogenic risk of 4.36E-06 ADI fraction. Thus, the EPA Hazard Index due to excavation operations for the average worker is 4.36E-06.

TABLE 20

Parameters for the Assessment of Occupational Exposure

Work crew composition	One supervisor One health physics technician One crane operator One loader operator Two handlers Three truck drivers
Work day	8 hours for crew 4 hours for drivers
Truck volume	12 metal boxes per trip 2 m^3 per box
Loading rate	8 truckloads (192 m^3/day)
Volume of material removed	896 m^3
Exposure time	5 work days
Distance waste is transported	16 km (one way)
Transport speed	32 km/hr

TABLE 21

Occupational Risk Due to Atmospherically Released Noncarcinogens for the Waste Removal and Closure Option

Constituent	Source Term ($g/m^2/s$)	Inhalation Dose (mg/kg/day)	Exposure Time (days)	Noncarcinogenic Risk (ADI fraction)
Nitrate	7.65E-08	1.25E-06	5	4.36E-06
EPA Hazard Index				4.36E-06

Radioactive Constituents

For each of the three closure options considered (no action, no waste removal and closure, and waste removal and closure), the radioactive constituent natural uranium was analyzed to estimate occupational exposure and risk attributable to closure activities for the TNX Burying Ground. Radiation exposures from the following pathways were considered: internal dose (from inhalation) to personnel directly involved in cleanup activities, external dose to personnel directly involved in cleanup activities, and external dose to personnel involved in transportation of contaminated waste. For the inhalation pathway, parameters such as the size of the work force, volume of waste to be excavated, and the number of work days required to excavate the waste were estimated (Table 20). Concentrations of waste constituents in the air to which workers are exposed at the waste site were calculated with dust generation and resuspension models described previously and combined with work-force parameters to estimate worker inhalation exposure (no respiratory protection is assumed) and dose commitment (Table 22). Each crew worker could receive 0.044 mrem via inhalation of dust during excavation.

Worker exposure is estimated for the work crew (excluding truck drivers) by assuming workers are exposed to the highest external radiation field at each area for the period of cleanup required for the area. The maximum dose rate a 1 m above the ground calculated by DECOM for cleanup of the TNX Burying Ground is 6.4E-03 mrem/hr. For a cleanup period lasting 4 work days, each crew member would receive a total external dose of 0.26 mrem (Table 23).

Exposure of drivers to external radiation is assumed to occur during transport of excavated waste from the site to the disposal facility. The total time of exposure for each driver is assumed to be 4 hr/day for the period of cleanup. The exposure rate was conservatively assumed to be equal to the highest external exposure rate at 1 m above the ground as calculated by DECOM (6.4E-03 mrem/hr). This value is below the allowable Department of Transportation limit for exposure in the occupied cab of 2 mrem/hr unless the driver is wearing dosimeters under a radiation protection program (CFR, 1984). No credit for shielding provided by the metal boxes is taken into account. The total dose due to external exposure for each driver while involved in excavation (5 work days) would be 0.13 mrem (Table 23).

It is assumed there will be no release of radioactive materials from the metal boxes during routine transport. Further, since the material is being transported within the boundary of the Savannah River Plant, it is assumed there will be no exposure to of the public and no significant exposure to employees on site involved in activities not related to the cleanup of this area.

TABLE 22

Internal Dose to Each Crew Worker Due to Inhalation

Radionuclide	Inhalation Dose Factor (mrem/μCi)	Air Concentration (μCi/m^3)	Total Intake (μCI)	Dose Commitment (mrem)
^{234}U	1.3E+05	3.7E-09	1.8E-07	2.3E-02
^{235}U	1.2E+05	1.6E-10	7.5E-09	9.0E-04
^{238}U	1.2E+05	3.4E-09	1.6E-07	2.0E-02
Total				4.4E-02

TABLE 23

Summary of Occupational Exposure and Risk for the Waste Removal and Closure Option

Worker	Internal Dose Due to Inhalation (mrem)	External Dose (mrem)	Total Dose (mrem)
Supervisor	0.044	0.26	0.304
Health physics	0.044	0.26	0.304
Crane operator	0.044	0.26	0.304
Loader	0.044	0.26	0.304
Handler #1	0.044	0.26	0.304
Handler #2	0.044	0.26	0.304
Driver #1	0	0.13	0.13
Driver #2	0	0.13	0.13
Driver #3	0	0.13	0.13
Total			2.214

Note: Radioactive risk = 2.214 mrem x 2.8E-07 health effects/mrem
= 6.2E-07 health effects.

ECOLOGICAL ASSESSMENT

Surface Water Quality Impacts

Nitrate and ^{238}U were identified earlier in this report as contaminant substances of potential environmental concern in the assessment of closure options for the TNX Burying Ground. Groundwater beneath the TNX Burying Ground ultimately outcrops to the Savannah River. Dilution modeling of instream water chemistry in the Savannah River and outcropping of nitrate and ^{238}U gives a result of no calculated adverse environmental impacts on Savannah River water quality for all closure options through 1,000 years following 1985.

Simple dilution modeling of nitrate and ^{238}U in groundwater associated with the TNX Burying Ground closure options with existing Savannah River water chemistry was completed according to

$$C_3 = \frac{Q_1 C_1 + Q_2 C_2}{Q_1 + Q_2}$$

where

C_1 = instream water chemistry data (stream reach)

C_2 = outcrop water chemistry data (influent)

Q_1 = instream flow rate

Q_2 = influent flow from outcrops

C_3 = resultant mixed concentration (calculated mixture)

The groundwater migrating from the TNX Burying Ground is assumed to outcrop into the Savannah River near the southwestern boundary of SRP. The mean Savannah River flow rate is estimated at 9.1E+09 m^3/yr. The groundwater flux into the river within the flow path is estimated at 1.7E+03 m^3/yr. The rates and concentrations of nitrate and ^{238}U outcropping into the Savannah River have been calculated using the PATHRAE code.

Calculated concentrations of nitrate and ^{238}U in the Savannah River after mixing with the groundwater outcrop from beneath the burying ground are shown in Table 24 for all closure options. Year 0 following 1985 was chosen for dilution modeling because,

TABLE 24

Savannah River Water Quality Impacts for All Closure Options

Parameter	Units	Stream Reach	Calculated Mixture	Comparison Criterion	Criterion Exceeded
Nitrate	µg/L	260	260	NS	-
^{238}U	pCi/L	<0.2	<0.2	24	No

Note: This model run represents Year 0 after 1985. NS = no standard.

of the years assessed, this year represents the time at which outcropping of nitrate and ^{238}U to the Savannah River would approach or reach a maximum concentration. The comparison criterion for nitrate is based on EPA ambient water quality criteria documents or upstream unimpacted measurements (whichever are greater). The water quality comparison criterion for ^{238}U is based on the activity of ^{238}U that yields a dose of 4 mrem/hr.

Results of the calculations in Table 24 indicate that the existing water chemistry of the Savannah River is not adversely affected by any of the closure options. Because influent concentrations for both contaminants are so low, no change in existing Savannah River water quality is expected. Calculated mixtures indicate that none of the contaminants exceed their respective comparison criteria.

A summary of instream water quality effects associated with the closure options for the TNX Burying Ground for eight time scenarios up to 1,000 years following 1985 is given in Table 25. No degradation of existing Savannah River water quality is evidenced for either nitrate or ^{238}U under all years and closure options.

Aquatic and Terrestrial Impacts

For the aquatic and terrestrial impacts assessment, four pathways through which waste-site constituents can reach the environment were identified: (1) biointrusion, (2) surface erosion of waste constituents due to water and subsequent transport to surface waters, (3) movement of waste constituents through the unsaturated zone to the groundwater and subsequent transport to a surface outcrop, and (4) consumption of contaminated basin waters and, at some sites, aquatic plants.

The exposure concentrations were screened by comparing them to various ecological benchmark criteria. The first benchmark for each constituent, a lower screening level, represents an ecologically protective concentration (SAIC, 1987) and is based on EPA Water Quality Criteria for the Protection of Aquatic Life or equivalent numbers from the technical literature. Any constituent that exceeded the lower screening level by more than a factor of 10 was compared to additional ecological benchmarks to define further the extent (if any) of the potential ecological effects. These additional benchmarks are based on either (1) LC-50s and EC-50s for of taxa specific to the SRP ecosystem to assess effects on the aquatic community; (2) the EPA National Interim Primary Drinking Water Standards (DWS) and, if the DWS are exceeded, chronic no-effect concentrations of metals and organics (except volatile solvents) in mammalian diets to screen for possible effects from consumption

TABLE 25

Instream Ecological Effects in the Savannah River for All Closure Options

Parameter	Units	Existing Savannah River Concentration*	Incremental Increase in Concentration for Years Since 1985							
			0	100	200	300	400	500	700	1000
Nitrate	µg/L	260	1.9E-05	3.0E-09	1.1E-14	0.0	0.0	0.0	0.0	0.0
^{238}U	pCi/L	<0.2	1.2E-08	0.0	0.0	0.0	0.0	0.0	0.0	0.0

* In vicinity of outcrop (Looney & Holmes, 1987).

of surface waters by terrestrial wildlife; or (3) dietary concentrations shown to be toxic to birds and mammals to assess consumption of contaminated aquatic biota. For those waste sites with radionuclide constituents, EPA National Interim Drinking Water Standards were used as first-level benchmarks for comparison of potential exposure concentrations in surface waters. For tritium, known no-effect concentrations in fish were used as second-level benchmarks. Benchmarks for soil are based on the Department of Energy's Threshold Guidance Limits (DOE, 1985) as presented in Looney et al. (1986). These soil and water criteria are based on human health concerns and so are conservative. The various quotients (comparing calculated concentrations to benchmarks) form the basis for quantification of potential ecological impacts from each waste site.

Because the TNX Burying Ground has already been backfilled and covered with buildings and asphalt, the only pathway ecological concern is the groundwater to surface water pathway.

Analysis of the PATHRAE-generated groundwater outcrop concentrations indicates that no first-level ecological benchmarks are exceeded. Therefore, no adverse impacts are expected to the aquatic communities of the Savannah River and adjacent wetlands or to wildlife utilizing these habitats to drink and feed under any of the closure options.

Although the waste material is buried relatively close to the soil surface (i.e., 1.8 to 2.4 m), the presence of a cap under the waste removal and closure and no waste removal and closure options and buildings, asphalt, etc. under the no action option should render the biointrusion pathway insignificant.

Based on the results of the ecological assessment, no aquatic or terrestrial impacts attributable to contaminants from the TNX Burying Ground are anticipated.

Endangered Species

No endangered species have been identified in the vicinity of the TNX Burying Ground from previous surveys at SRP. The habitats in the vicinity of this waste site are not suitable for any federally endangered species that have been identified at SRP, including the American alligator, the red-cockaded woodpecker, the wood stork, and the short-nose sturgeon (Dukes, 1984; Gladden et al., 1985). Therefore, none of the actions postulated for this site would have any effect on endangered species or their critical habitats.

Wetlands

Wetlands found within 1,000 m of the TNX Burying Ground are summarized in Table 26 (Mackey et al., 1985; Shields et al., 1982). The wetland communities occur primarily along the Savannah River and its floodplain south and southeast of this waste site (Figure 13). These wetlands are sufficiently removed from the waste site so that no effect would be expected to them from any of the closure options postulated for this site. However, remedial actions should use appropriate erosion control techniques to eliminate potential runoff and sedimentation to small drainages and tributaries.

TABLE 26

Wetlands Within 1,000 m of the TNX Burying Ground

Type of Wetlands (acres)	Distance to Wetlands (m) 0-200	201-400	401-600	601-800	801-1000
Open water	0	0	1.5	23.9	15.6
Cypress/tupelo	0	0	23.6	39.4	29.1
Emergent marsh	0	0	0	0	0
Scrub/shrub	0	0	0	0	0
Bottomland hardwood	0	7.8	19.8	18.9	11.9
Total	0	7.8	44.9	82.2	56.6

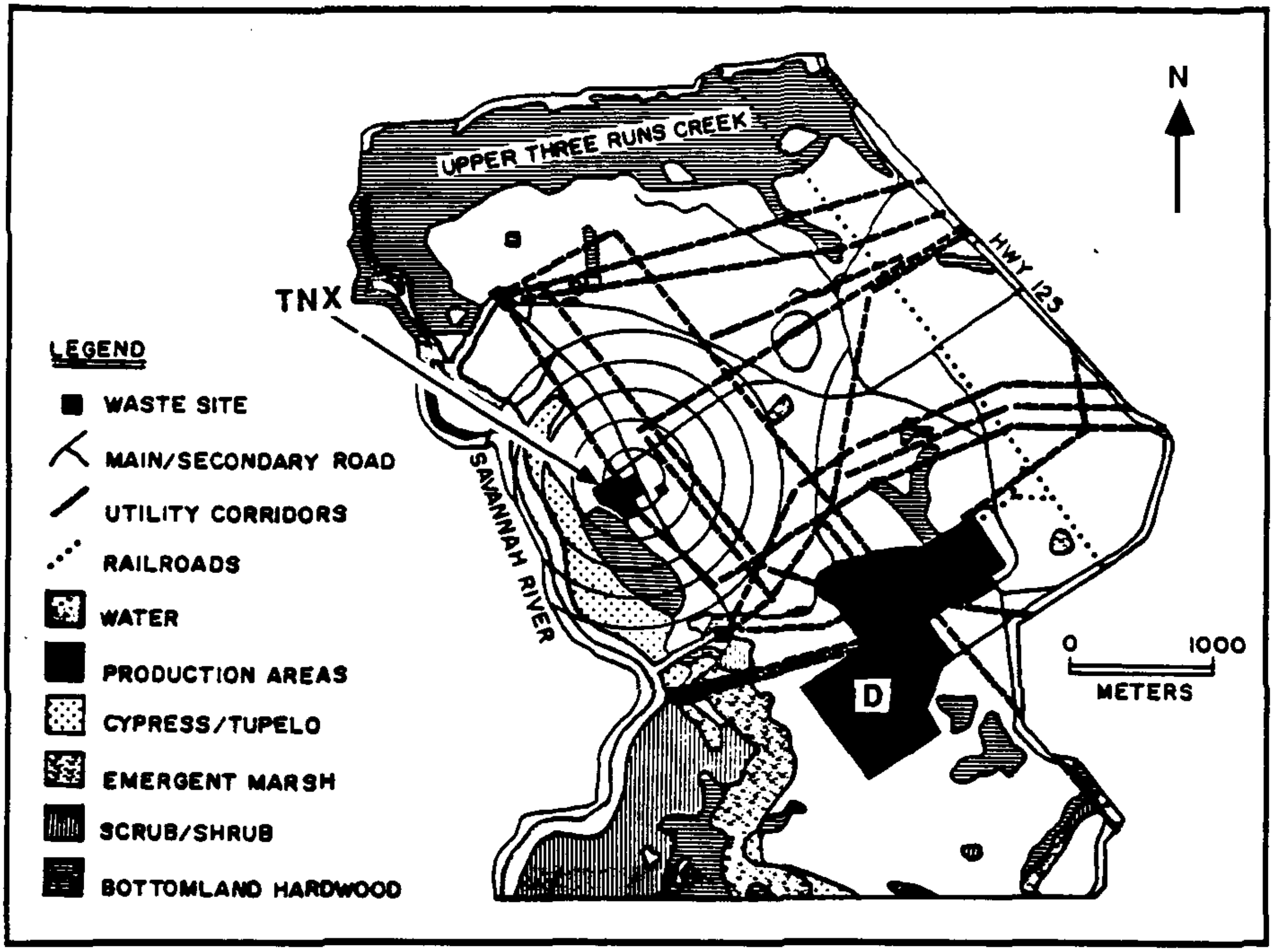


FIGURE 13. Location of Wetlands Within 1,000 m of the TNX Burying Ground

ACCIDENT ANALYSIS

The environmental impacts and risks of potential accidents occurring during the closure options for the TNX Burying Ground have been analyzed. The selected closure option would be implemented in such a manner that the risk to the public and to workers from accidental releases of or exposure to site materials/contaminants would be minimal.

Pertinent environmental and safety documents were reviewed to identify potential accidents. The potential accidents and consequences associated with each waste-site closure action are related to the materials at the site. The potential accident scenarios are based on the hazards associated with these materials. The TNX Burying Ground was used for the disposal of debris resulting from a 1953 experimental evaporator explosion. Wastes buried in this area included conduit, drums, tin, and structural steel. Use of this site ceased in 1953 when the SRP Radioactive Waste Burial Grounds was placed into service. From 1980 to 1984, much of the material at the TNX Burying Ground was excavated and sent to the SRP Radioactive Waste Burial Grounds. The TNX Burying Ground is presently covered with asphalt and surface structures such as buildings, trailers, and transformer pads. An estimated 27 kg of uranyl nitrate remains at the burying ground site.

The accidents considered for the closure options are natural events such as earthquakes, tornadoes, and straight winds and industrial accidents such as injuries, fires, cave-ins, and container spills. The natural events were analyzed using historical data on probability and severity. Industrial accidents were analyzed using man-hour estimates based on construction industry cost-estimating handbooks and industrial accident rate tabulations. The number of construction labor man-days required to accomplish the postulated options was estimated. This estimate was used to calculate the frequency of each potential accident. The contaminants considered in the accident analysis are those selected for this site in Looney et al. (1987a).

Tables 27 through 29 identify the potential accidents germane to the site. The frequencies for the closure options of waste removal and no waste removal are based on events per closure operation to facilitate comparison among the various sites and options. The highest frequency for an accident to occur at the TNX Burying Ground would be for falls or equipment-related mishaps resulting in personnel injury. Further explanation of the methodology, analyses, and appropriate calculations of consequences is supplied in separate documentation (Palmiotto & Comiskey, 1986).

TABLE 27

Accident Analysis for the Waste Removal and Closure Option

Initiator	Accident	Frequency	Consequence
Natural Events			
Tornado	High winds disperse soil during excavation.	4.69E-06	Dispersion of soil off waste site but not beyond SRP boundary.
Straight winds	High winds disperse soil during excavation.	3.38E-05	Dispersion of wet soil off waste site but not beyond SRP boundary.
Earthquake	Failure of walls.	N/A	N/A
Industrial Events			
Container puncture	Waste containers in site punctured.	N/A	N/A
Equipment collision	Mobile equipment collides. Possible puncture of waste boxes.	1.47E-03	Potential for serious injury to personnel. Releases confined to the immediate area of the site.
Large equipment toppling	Failure of equipment.	7.76E-04	Potential for serious injury to personnel. Dispersion of waste material at site.
Employee injury	Falls/equipment-related injuries.	3.13E-02	Potential for serious personnel injury.
Contamination	Inadvertent chemical contamination to workers at site.	1.34E-02	No personnel injury.
Drop & breach	Waste box dropped and puncture or lid opening occurs.	2.66E-04	Potential for minor injury to personnel. Release of waste at site. Cleanup initiated.

Note: N/A = not applicable due to the nature of the closure option or the waste site.

TABLE 27, Contd

Initiator	Accident	Frequency	Consequence
Equipment fire	Fuel or hydraulic fluid catches fire.	3.61E-04	Onsite fire team response. Potential for minor injury to personnel. Some equipment damage.
Cave-in	During excavation of material with equipment in basin.	2.52E-05	Potential for serious injury to personnel.
Waste truck accident and fire	Accident resulting in fire.	4.46E-06	Onsite fire department response. Potential for serious injury to personnel. Damaged equipment.
Waste truck accident and spill	Truck accident during transport. Waste container damaged and breached.	2.66E-04	Waste release confined to accident site. Cleanup initiated.
Waste truck accident and fatality	Truck accident while in transit to disposal area.	1.42E-04	Fatality to driver.
Waste box falls off truck	Rigging or driving error results in spillage of waste container contents.	7.08E-04	Release of waste at site of accident. Cleanup initiated.
Fill truck accident	Truck with fill and another vehicle collide, or single vehicle accident occurs.	2.04E-03	Potential for serious injury to personnel. Fill material released at accident site. Cleanup initiated.
Fatal construction accident	Construction accident resulting in fatality.	2.29E-06	Fatality.

TABLE 28

Accident Analysis for the No Waste Removal and Closure Option

Initiator	Accident	Frequency	Consequence
Natural Events			
Tornado	High winds disperse soil during excavation.	5.33E-07	Minimal dispersion of soil at waste site.
Straight winds	High winds disperse soil during excavation.	3.84E-06	Minimal dispersion of wet soil at waste site.
Earthquake	Failure of walls.	N/A	N/A
Industrial Events			
Container puncture	Waste containers in site punctured.	N/A	N/A
Equipment collision	Mobile equipment collides. Possible puncture of waste boxes.	6.90E-04	Potential for serious injury to personnel.
Large equipment toppling	Failure of equipment.	3.37E-04	Potential for serious injury to personnel. Damage to equipment.
Employee injury	Falls/equipment-related injuries.	1.88E-02	Potential for serious injury to personnel.
Contamination	Inadvertent chemical contamination to workers at site.	1.53E-03	No injury likely.
Drop & breach	Waste box dropped and puncture or lid opening occurs.	N/A	N/A

Note: N/A = not applicable due to the nature of the closure option or the waste site.

TABLE 28, Contd

Initiator	Accident	Frequency	Consequence
Equipment fire	Fuel or hydraulic fluid catches fire.	2.17E-04	Potential for minor injury to personnel. Damage to equipment.
Cave-in	During excavation of material with equipment in basin.	N/A	N/A
Waste truck accident and fire	Accident resulting in fire.	N/A	N/A
Waste truck accident and spill	Truck accident during transport. Waste box damaged and breached.	N/A	N/A
Waste truck accident and fatality	Truck accident while in transit to disposal area.	N/A	N/A
Waste box falls off truck	Rigging or driving error results in spillage of waste box contents.	N/A	N/A
Fill truck accident	Truck with fill and another vehicle collide, or single vehicle accident occurs.	2.07E-03	Potential for serious injury to personnel. Release of fill at accident site. Cleanup initiated.
Fatal construction accident	Construction accident resulting in fatality.	1.37E-06	Fatality.

Note: N/A = not applicable due to the nature of the closure option or the waste site.

TABLE 29

Accident Analysis for the No Action Option

Initiator	Accident	Frequency	Consequence
Natural Events			
Tornado	High winds disperse sediments in basin.	N/A	N/A
Straight winds	High winds disperse soil in basin.	N/A	N/A
Earthquake	Failure of walls.	N/A	N/A
Industrial Events			
Container puncture	Waste containers in site punctured.	N/A	N/A
Equipment collision	Mobile equipment collides. Possible puncture of waste boxes.	N/A	N/A
Large equipment toppling	Failure of equipment.	N/A	N/A
Employee injury	Falls/equipment-related injuries.	N/A	N/A
Contamination	Inadvertent contamination to workers at site.	N/A	N/A
Drop & breach	Waste box dropped and puncture or lid opening occurs.	N/A	N/A
Equipment fire	Fuel or hydraulic fluid catches fire.	N/A	N/A
Cave-in	During excavation of material with equipment in basin.	N/A	N/A

Note: N/A = not applicable due to the nature of the closure option or the waste site.

TABLE 29, Contd

Initiator	Accident	Frequency	Consequence
Waste truck accident and fire	Accident resulting in fire.	N/A	N/A
Waste truck accident and spill	Truck accident during transport. Waste box damaged and breached.	N/A	N/A
Waste truck accident and fatality	Truck accident while in transit to disposal area.	N/A	N/A
Waste box falls off truck	Rigging or driving error results in spillage of waste box contents.	N/A	N/A
Fill truck accident	Truck with fill and another vehicle collide, or single vehicle accident occurs.	N/A	N/A
Fatal construction accident	Construction accident resulting in fatality.	N/A	N/A

Note: N/A = not applicable due to the nature of the closure option or the waste site.

ARCHEOLOGICAL AND HISTORICAL SURVEY

Archeological surveying and testing of the TNX Burying Ground have been performed by the University of South Carolina's Institute of Archeology and Anthropology (Brooks, 1986). The area was surveyed by surface inspection and its condition documented by two general area photographs. One hundred percent of the subject area was found to be disturbed by construction-related activity. The survey located no archeological or historical sites. Therefore, no further archeological work is warranted or required as part of the closure actions for the TNX Burying Ground. It is recommended that a request be made to the South Carolina State Historic Preservation Officer for concurrence with this determination of no effect.

UNAVOIDABLE/IRREVERSIBLE IMPACTS

Environmental impacts that cannot be avoided by reasonable mitigation measures are described in this section. These impacts are based upon the alternative closure options developed for the TNX Burying Ground. Also assessed are the irreversible and irretrievable commitments of resources, short-term land uses, and long-term environmental implications for the alternative closure options considered.

Many of the unavoidable adverse impacts expected from the closure of the TNX Burying Ground have been experienced during past use of the land. One impact is the loss of alternative land uses while the subject area (approximately 372 m^2) remains under the control of the Department of Energy. Application of the no action option would require some future action (i.e., site preparation) before alternative land uses such as agriculture could be implemented. Other adverse environmental impacts may include minimal wildlife habitat loss during revegetation of the site and temporary air pollution associated with activities such as field work (i.e., excavation, backfilling, grading) and transportation of materials to and from the site.

Energy, raw materials, and other resources would be used for the closure of this site. Resources that would be irreversibly or irretrievably committed during closure actions include (1) materials that cannot be recovered or recycled (i.e., backfill material) and (2) materials consumed or reduced to unrecoverable forms (i.e., energy).

Closure of the site would involve land area already committed. Disposal of soils and other materials from the site (approximately 896 m^3) would require use of additional land at a waste storage/disposal facility. Other committed resources would include backfill and capping materials, clean topsoil, and packaging materials (i.e., metal boxes). Irretrievable energy loss would result from the use of machinery to work the site, transport materials, and process wastes at the disposal facility. Continued grounds maintenance and groundwater monitoring of the subject area would require a 30-year commitment of manpower and other resources.

In the short term, implementation of site closure options would minimally affect local wildlife habitat and natural productivity. However, the long-term impact of these effects would be no greater than the impacts of existing land use.

CONTROL AND SECURITY

Access to the Savannah River Plant site is controlled at primary roads by permanently manned barricades. Other roads entering the site are closed to traffic by gates or other barriers. The plant, except along the Savannah River, is fenced. Additionally, the site is posted against trespass under South Carolina and federal statutes. Operating areas are separately fenced and continuously patrolled by armed security personnel.

The TNX Burying Ground is located within the confines of the TNX-Area complex. The complex itself is protected by a high chain link security fence that is locked after normal working hours. Access to the known and suspected burial sites is extremely limited due to the presence of overlying surface structures and pavement. The TNX Area is frequently patrolled by plant security personnel. The TNX Operations Division is responsible for the care and maintenance of the TNX Burying Ground.

COST ANALYSIS

The relative costs for each of the postulated closure options for the TNX Burying Ground have been estimated. The Du Pont Engineering Department has prepared Venture Guidance Appraisal (VGA) cost estimates for each option.

SCOPES OF WORK

Scopes of work based upon the various closure options described earlier in this document have been developed and are detailed below. The specific details of the commitments to maintenance, monitoring, and cap design in this section were selected for the primary purpose of deriving reasonable and consistent relative cost estimates.

Waste Removal and Closure

Under the waste removal and closure option, surface structures (Building 711-T, trailer Building 676-8T, and a 13.8 kV transformer near Building 673-T) would be relocated, and the three known and one suspected burial sites would be excavated. An estimated excavation volume of 1,220 m^3 was assumed for cost estimating purposes. Excavated materials from the known burial sites would be packaged in metal boxes and sent to a waste storage/disposal facility. Excavate from the suspected burial site would be treated in one of two ways. If determined by the Health Protection Department to be contaminated, it would be containerized in metal boxes and transported to a waste storage/disposal facility. If found to be clean, it would be used as fill material when the site is backfilled. After backfilling, all four sites would then be covered with a low-permeability cap, dressed with topsoil, and seeded to prevent erosion. Sixteen new groundwater monitoring wells would be installed around the project area if the suspected burial site is found to be contaminated. Only 12 groundwater monitoring wells would be required if the suspected burial site is found to be clean. These wells would be sampled and analyzed quarterly for 1 year, then annually for 29 years. Site maintenance would be provided for the entire 30-year period.

No Waste Removal and Closure

Under the no waste removal and closure option, the relocation of certain surface structures would be necessary as in the previous option. No waste material would be removed. The known burial sites would be covered with a low-permeability cap, graded, and seeded to prevent erosion. The suspected burial area would be treated in one of two ways. If soil samples from this site indicate that it is contaminated, overlying surface structures would be relocated, and it would be capped. Otherwise, the site would be left as is. Sixteen new groundwater monitoring wells would be installed around the project area if the suspected burial site is found to be contaminated. Only 12 groundwater monitoring wells would be required if the suspected burial site is found to be clean. Environmental monitoring and site maintenance requirements would be the same as in the waste removal and closure option.

No Action

All sites would be left as is under the no action option. Sixteen new groundwater monitoring wells would be installed around the project area. Environmental monitoring and site maintenance requirements would be the same as in the waste removal and closure option.

VENTURE GUIDANCE APPRAISAL COST ESTIMATES

Cost estimates are provided below for the site closure options previously described (Moyer, 1987). The costs are in fourth quarter 1985 dollars.

	Closure Option Costs ($ Millions)		
Estimate Categories	Waste Removal and Closure	No Waste Removal and Closure	No Action
Site preparation and waste treatment	0.69	0.25	-
Waste disposal*	3.70	-	-
Monitoring and maintenance	0.38	0.38	0.38
Total	4.77	0.63	0.38

* Based on $\$3,000/m^3$ of waste disposed to a storage/disposal facility.

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