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GEOHYDROLOGY OF THE PROPOSED WASTE ISOLATION PILOT PLANT SITE, LOS MEDAÑOS AREA, SOUTHEASTERN NEW MEXICO

By Jerry W. Mercer

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 83-4016

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CONVERSION FACTORS

In this report figures for measurements are given in inch-pound units only. The following table contains factors for converting to International System (S.I.) units.

Multiply inch-pound units	By	To obtain S.I.units
foot	0.3048	meter
foot per mile	0.1894	meter per kilometer
foot per day	0.3048	meter per day
foot squared per day	0.0929	meter squared per day
gallon per minute	0.06309	liter per second
ton (short)	0.09072	megagram
pound per square inch	0.07031	kilogram per square centimeter
mile	1.609	kilometer
square mile	2.590	square kilometer
inch	25.4	millimeter

Chemical concentrations are given only in metric units--milligrams per liter, micrograms per liter, picocuries per liter, or milliequivalents per liter. Liquid densities are given only in metric units--grams per cubic centimeter.

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level." NGVD of 1929 is referred to as sea level in this report.

GEOHYDROLOGY OF THE PROPOSED WASTE ISOLATION PILOT PLANT SITE, LOS MEDAÑOS AREA, SOUTHEASTERN NEW MEXICO

By Jerry W. Mercer

ABSTRACT

Geohydrologic data have been collected in the Los Medaños area at the U.S. Department of Energy's proposed Waste Isolation Pilot Plant (WIPP) site in southeastern New Mexico since 1975 as part of a study evaluating the feasibility of storing defense-associated nuclear wastes within the bedded salt of the Salado Formation of Permian age. Drilling and hydrologic testing have identified three principal water-bearing zones above the Salado Formation and one below that could potentially transport wastes to the biosphere if the proposed facility were breached. The zones above the Salado are the contact between the Rustler and Salado Formations and the Culebra and Magenta Dolomite Members of the Rustler Formation of Permian age. The zone below the Salado Formation consists of channel sandstones in the Bell Canyon Formation of the Permian Delaware Mountain Group.

Determinations of hydraulic gradients, directions of flow, and hydraulic properties were hindered because of the negligible permeability of the water-bearing zones. Special techniques in drilling, well completion, and hydraulic testing have been developed to determine the hydrologic characteristics of these water-producing zones.

Data collected from drill-stem tests in test wells penetrating the Bell Canyon Formation indicate that the brines associated with the unit usually occur in relatively isolated channel sandstones that are permeable (hydraulic conductivities ranging from 7×10^{-3} to 5×10^{-2} foot per day) but grade vertically and laterally into siltstones and shales with little permeability. Potentiometric-surface maps (as equivalent freshwater heads) show flow in the Bell Canyon Formation to be laterally across the basin to the northeast, but the movement probably is extremely slow. The dissolved ions in the brines of the Bell Canyon are predominantly sodium and chloride with dissolved-solids concentrations ranging from 180,000 to 270,000 milligrams per liter.

The Rustler Formation contains the principal water-bearing zones identified at the WIPP site, and thus were the most extensively studied. Calculations from pumping, slug, and pressure-pulse tests indicate that the transmissivities of the individual units vary laterally within as well as between the individual beds. The Culebra Dolomite Member is the most persistent and productive hydrologic unit in the WIPP site area and also has the greatest variability of hydraulic properties. This variability results from the size and number of fractures, which in turn are related to the degree of evaporite dissolution within the Rustler Formation. Transmissivities calculated for the Culebra in Nash Draw immediately west of the WIPP site range from 18 to 1,250 feet squared per day, whereas they range from 1×10^{-3} to 140 feet squared per day at the WIPP site. Potentiometric-surface maps (as equivalent freshwater heads) indicate flow in the Culebra Dolomite Member of the Rustler Formation at the WIPP site to be southerly, eventually flowing southwestward to Nash Draw. Determination of flow directions, however, may be affected significantly by directional differences in permeability along fractures. The dominant dissolved ions are sodium and chloride, with calcium, magnesium, potassium, and sulfate being other major ions present. Hydrochemistry studies indicate an increase of mineralization of water from west to east along with a decrease in circulation of the flow system. The dissolved-solids concentrations range from 2,950 to 239,000 milligrams per liter.

The Magenta Dolomite Member is the uppermost hydrologic unit. Water in this unit either occurs in thin silt beds and silty dolomite or in fractures where extensive evaporite dissolution has occurred in the Rustler Formation. Transmissivities calculated for the Magenta in Nash Draw range from 53 to 375 feet squared per day, whereas they range from 4×10^{-3} to 1×10^{-1} foot squared per day at the WIPP site. Potentiometric-surface maps (as equivalent freshwater heads) indicate flow in the Magenta to be westward toward Nash Draw where the flow direction is then controlled by the evaporite dissolution in the Rustler. The water is brackish to briny. The dominant dissolved ions are sodium and chloride with calcium, magnesium, potassium, and sulfate being other major ions. Dissolved-solids concentrations range from 5,000 to 261,000 milligrams per liter.

The least productive water producing zone is at the contact between the Rustler and Salado Formations where brine occurs either in an evaporite residuum or in clays along bedding planes. The residuum is concentrated along Nash Draw and is most extensive between Malaga Bend on the Pecos River 10 miles southwest of the proposed WIPP site and Salt Lake where transmissivities are as large as 8,000 feet squared per day. North of Salt Lake in Nash Draw the transmissivities range from 2×10^{-4} to 8 feet squared per day; transmissivities at the WIPP site range from 3×10^{-5} to 5×10^{-2} foot squared per day. Potentiometric surface maps (as freshwater equivalent heads) indicate flow in the contact zone to the southwest across the WIPP site toward Nash Draw. The dissolved solids in the brines at the Rustler-Salado contact are predominantly sodium chloride with dissolved-solids concentrations ranging from 41,500 to 412,000 milligrams per liter. Large potassium and magnesium ion concentrations in the eastern part of the site may indicate restricted circulation of the brines.

The relative static heads or formation pressures of the hydrologic units in the Rustler decrease with depth; that is, static heads are the highest in the Magenta and the lowest at the contact zone between the Rustler and Salado. In the WIPP site area, the presence of relatively impermeable interbeds of halite and anhydrite probably restricts vertical movement between units. The Rustler Formation is probably recharged in Bear Grass Draw about 20 miles northwest of the WIPP site and in Clayton Basin which is about 12 miles northwest of the WIPP site. The major discharge occurs at Malaga Bend on the Pecos River.

INTRODUCTION

The U.S. Geological Survey, at the request of the U.S. Department of Energy, is investigating the geohydrology of the proposed Waste Isolation Pilot Plant (WIPP) site in an area known as Los Medaños, 30 miles east of Carlsbad, New Mexico (fig. 1). Geohydrologic data have been collected from this area by the U.S. Geological Survey intermittently since 1972 and on a continuous basis since 1975.

The WIPP is a project of the Department of Energy and is proposed as a radioactive-waste storage facility to be placed at a depth of approximately 2,150 feet in the bedded salts of the Permian Salado Formation. The WIPP is planned to demonstrate disposal technology for transuranic wastes. After a period of "pilot" operation in a waste retrievable mode, it is expected WIPP will be converted into a facility for permanent storage of transuranic wastes (Powers, 1981, p. 119).

The characteristics of the regional geohydrologic systems associated with the WIPP site need to be defined because of the potential for transport of radionuclides to the biosphere by ground water in the event the storage facility is breached. Another equally important aspect of the WIPP site is the geologic stability of the formation in which the wastes will be placed. Because the formation of concern is easily dissolved halite, the inherent stability of the formation is directly related to the hydrologic regime within and around the formation and needs to be studied in detail.

At the WIPP site, water-bearing zones above and below the salt section could affect stability as well as potentially transport radionuclides. Because some of these water-bearing zones are more likely to be involved than others, the degree of certainty required in the definition of flow paths, velocity of ground water, quality of water, and other characteristics is different for some zones than others.

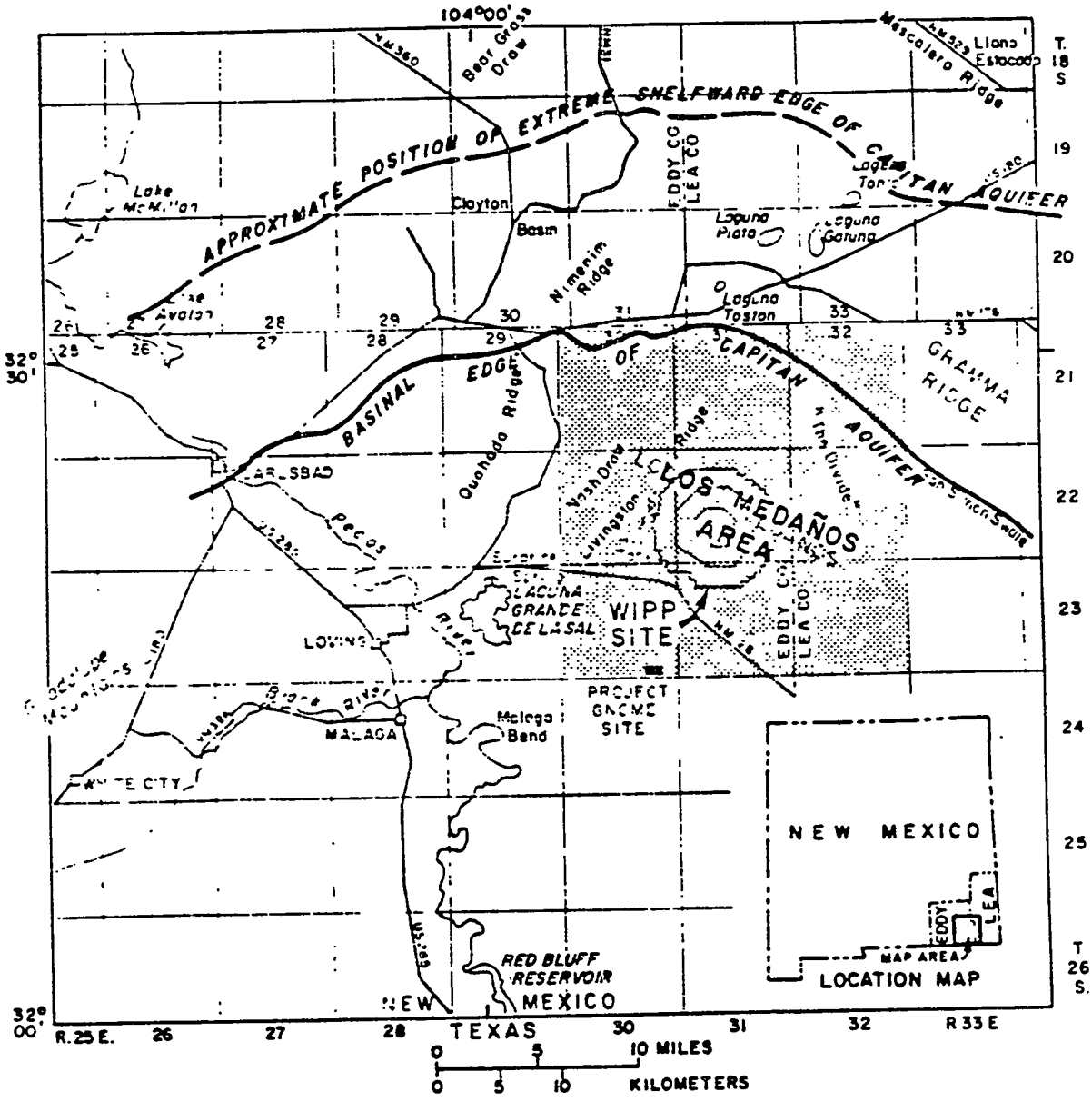


Figure 1.--Location of Los Medaños area and the proposed Waste Isolation Pilot Plant (WIPP) site.

Purpose and scope

This report discusses the ground-water systems and the interpretation of test results in the water-bearing zones above and below the proposed facility. Hydrologic data used in these analyses were collected during 7 years beginning in 1975 and were from 33 test holes drilled for, or converted to, hydrologic test holes. The study included: the determination of potential ground-water flow boundaries; potentiometric heads; ground-water chemistry; and hydraulic properties obtained through pumping, slug, pressure-pulse, and tracer tests.

The hydrologic investigation is part of a comprehensive study related to site characterization and validation conducted on behalf of the U.S. Department of Energy by Sandia National Laboratories. The hydrologic studies were conducted by the U.S. Geological Survey and were designed to supplement the technical site-characterization program performed by Sandia.

Location and areal extent

The study area of approximately 800 square miles is located within the northern part of the Delaware Basin in eastern Eddy and western Lea Counties, New Mexico and includes all or part of Tps. 20-24 S., Rs. 29-33 E. (fig. 1). The WIPP site is approximately in the center of the study area and covers about 54 square miles, encompassing almost all of T. 22 S., R. 31 E. (fig. 1). It is outlined in figure 1 by a proposed exclusion boundary, or buffer zone, surrounding the area of the proposed facility.

The WIPP site is in an area referred to as Los Medaños. Los Medaños is part of a gently sloping terrain that rises eastward from the Pecos River to the "caprock" of the Llano Estacado. The topographic relief generally is less than 50 feet with the surface area covered with sand dunes. Vegetation consists of mesquite, scrub oak, and other plants typical of the northern Chihuahuan desert. The average annual precipitation is 11 to 13 inches, while evaporation from surface water exceeds 98 inches per year. The primary land use is cattle grazing. Potash is being mined in the area to the north and west; petroleum exploration and development recently has become quite intensive.

The major topographic features in the area include two depressions called Nash Draw and Clayton Basin. Nash Draw is the larger, being 4 to 6 miles wide and 15 to 18 miles long, extending southward through the western part of the area (fig. 1). These features are believed to be formed by solution-subsidence and collapse, having then been extensively modified by erosion. Neither Nash Draw nor Clayton Basin have external surface drainage.

Los Medaños area is drained by the Pecos River, the only perennial stream in the region. The Pecos drainage system trends southeastward through the western margin of the study area and is at its closest point 10 miles from the WIPP site.

Laguna Grande de la Sal (Great Salt Lake), a large salt lake in the southern end of Nash Draw, contains water most of the time. Numerous small lakes and playas contain water only after intense rains, whereas small permanent tailing ponds, resulting from potash mining, occupy several of the smaller closed depressions.

Previous investigations

The Delaware Basin geology in southeastern New Mexico has been studied extensively during the past 40 years, especially since the increase in oil and gas exploration. Prior to the establishment of the WIPP project, however, relatively little study was devoted to the Permian formations (above the Bell Canyon Formation), which include the evaporites of concern. Lang (1937) was one of the first to discuss these rock units and topographic features in the area; however, the most intensive geologic work prior to the WIPP project was done by C. L. Jones and others in connection with the U.S. Geological Survey's study of the potash deposits of the Carlsbad area. Reports were prepared by Jones (1954, 1959, 1972), Jones and Madsen (1959), and Jones, Bowles, and Bell (1960). The other significant geologic studies concentrating on this sequence of rocks were related to the Gnome experiment (an underground nuclear test) and include work by Vine (1963), Cooper (1960, 1961, 1962a, and 1962b), and Gard (1968). Numerous recent geologic papers concerned with the WIPP site investigations have been published and are included as references in this report and also are included in a report published by Sandia National Laboratories (Powers and others, 1978).

The first detailed hydrologic work in the area was conducted by Robinson and Lang (1938) during studies of the occurrence of brine springs in the Malaga area during 1937-38. Additional work was performed in the Malaga Bend area from 1938 to 1941; the results of this work, particularly that of Theis and Sayre (1942), was published in the "Reports of the participating agencies, the Pecos River Joint Investigation." Further detail on the Malaga Bend saline problem was added by Hale (1945a, 1945b, 1961), Hale and Clebsch (1958), Hale, Hughes, and Cox (1954), Cox and Kunkler (1962), Cox and Havens (1965), and more recently, Havens and Wilkins (1980) and Kunkler (1980). The regional occurrence of ground water in the area was discussed in Hendrickson and Jones (1952) and Nicholson and Clebsch (1961). Hiss (1976) made an extensive contribution to the hydrology of the Capitan Reef in a dissertation prepared while working with the U.S. Geological Survey. Others that made contributions to an understanding of the Capitan Reef include Bjorklund and

Motts (1959), Halpenny and Greene (1966), and Motts (1968). Associated with the Project Gnome investigations, contributions by Cooper (1961, 1962a, 1962b), Cooper and others (1962), and Cooper and Glanzman (1971) have greatly added to an understanding of the geohydrology of the Rustler Formation.

Recent investigations related to hydrologic characteristics of the WIPP site began with a review of the geology and hydrology of the Carlsbad potash area (Brokaw, Jones, Cooley, and Hays, 1972) and a review of the Los Medanos area (Jones, Cooley, and Bachman, 1973). A review of the regional hydrology of the WIPP site area was presented by Mercer and Orr (1977), while detailed hydrologic studies are included in an interim data report by Mercer and Orr (1979) and in a paper by Mercer and Gonzalez (1981).

The dissolution in the WIPP area is complex and has been considered in studies of the Cenozoic history of the area by Bachman (1973, 1974, 1976, 1980, and 1981). These studies added greatly to an understanding of the hydrologic systems in the area. Additional interpretations of dissolution have been prepared by Lambert (1982) and Anderson (1978, 1981).

Method of investigation

The objective of the hydrologic program was to define the hydrologic characteristics of the flow path of the ground-water system that could potentially transport wastes to the biosphere. Hydrologic information required to define the flow-path characteristics included static heads or reservoir pressures, the magnitude and direction of ground-water flow, and the chemical characteristics of the water that may have an effect on dissolution or on chemical interactions with rocks along the flow path.

The lack of very permeable rocks and the consequent lack of existing wells within the WIPP study area necessitated the development of a comprehensive drilling and testing program. This program included test holes for both site-specific geohydrologic studies and regional studies. Seventy-one test holes were drilled during WIPP studies; of these, 26 were specifically for hydrologic testing (H series) and 13 of the 45 geologic test holes were later used or converted for hydrologic testing (table 1, fig. 1A). These holes range in depth from 154 to 4,910 feet. Because the water-producing zones had little permeability and consequently would require months of recovery time and testing, special techniques in drilling, well completion, and hydraulic testing were developed to determine the hydrologic characteristics of the water-producing zones (Basler, 1983).

The air-rotary method was used to drill two types of holes specifically designed for hydrologic testing: (1) Holes were drilled, cased, cemented, and then perforated at the selected test zone; (2) three closely spaced holes were drilled in a complex, each cased down to a specific test interval. Each of these holes in the second type then was completed by coring to total depth

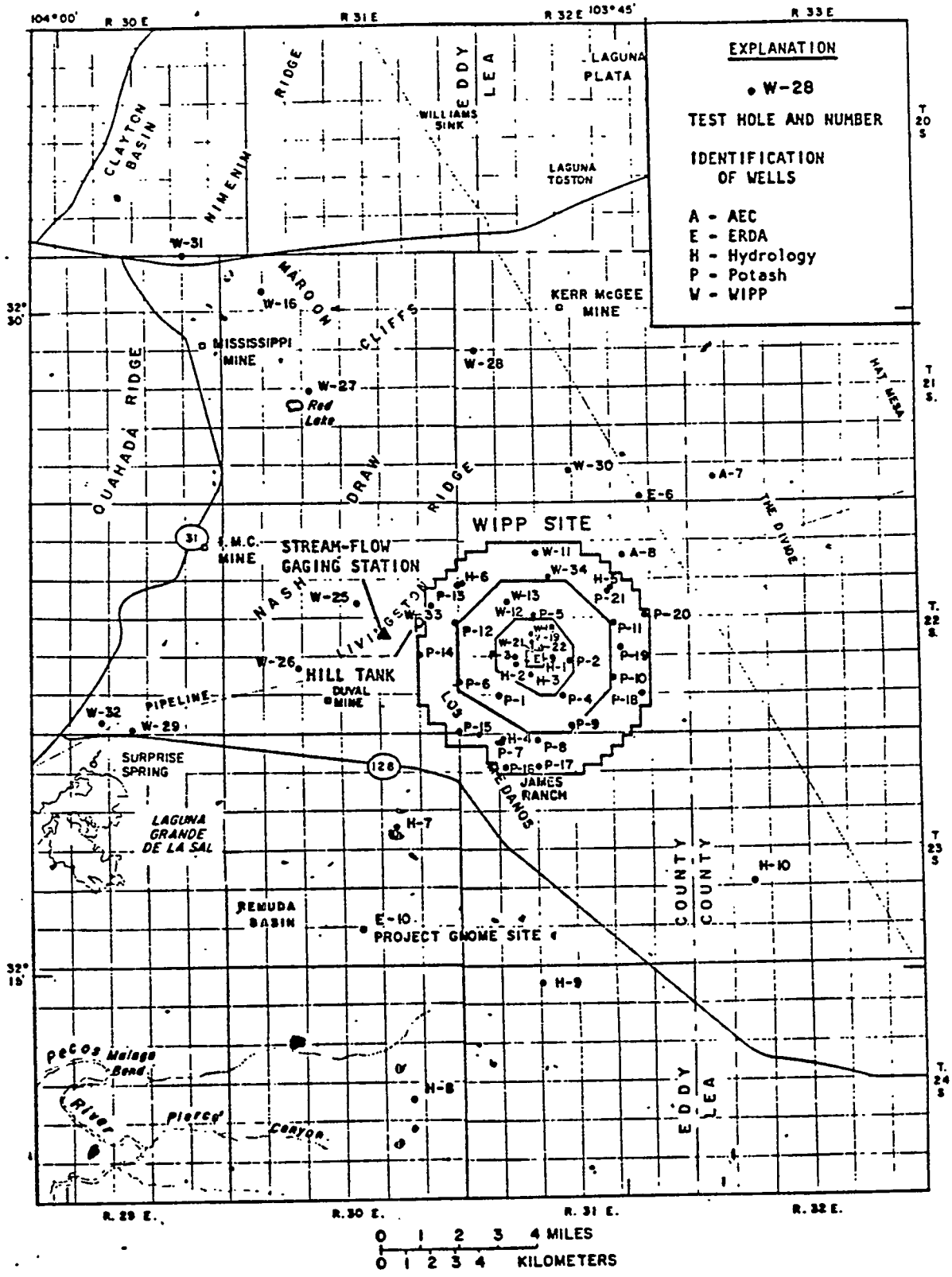


Figure 1a.--Location of test holes at and near the proposed Waste Isolation Pilot Plant (WIPP) site.

through the zone of interest, leaving an open-hole interval for testing. The three-hole complex proved to be the most commonly used and most effective design (Mercer and Gonzalez, 1981, p. 126). The casing-cementing-perforating method continued to be used in the geologic test holes, some of which later were converted to hydrologic holes.

Testing equipment designed for the WIPP geohydrologic studies used hydraulically inflated packers to isolate specific horizons and pressure transducers to measure changes in pressure head. Withdrawal, injection-slug, and pressure-pulse tests were conducted in the zones with little permeability, and standard aquifer tests were conducted in zones with greater permeability. These data were analyzed by methods discussed by Cooper, Bredehoeft and Papadopulos (1967), Lohman (1972), and Bredehoeft and Papadopulos (1980). A detailed discussion of the methods used, including data and data analyses, are not included in this report; however, this information is available in previous reports (Mercer and Orr, 1979; Mercer, Davis, Dennehy and Goetz, 1981; Mercer and Gonzalez, 1981; Dennehy and Mercer, 1982; and Dennehy, 1982).

During the investigation, water levels were measured periodically in about 40 wells. The geology of the water-bearing units was interpreted by use of formation cuttings, cores, and geophysical logs. In addition, water samples were collected from 52 selected intervals in 40 wells. Complete analyses of these samples are included in the data reports and selected analyses are included in table 2 of this report. Other hydrologic data from previous reports were used extensively in this report.

Acknowledgments

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GEOLOGIC SETTING

Sedimentary rocks of the Delaware Basin that outcrop within the WIPP site area range in age from Permian to Quaternary (table 3). The oldest rocks crop out to the west and successively younger rocks are to the east. Detailed stratigraphy primarily is based on information obtained from drill holes because the rocks generally are covered by Quaternary caliche and semi-stabilized and active dune sand. Seventy-one holes ranging in depth from 154 feet to 4,910 feet have been drilled for geologic and hydrologic investigations. Rocks penetrated in these test holes mainly consist of Permian sandstones, evaporites, and red beds, but they also include some Triassic sandstone and Tertiary and Quaternary deposits.

The oldest and deepest formations studied are included in the Guadalupian Delaware Mountain Group which forms the basin floor for the Ochoan evaporite sequence. The margins of the basin are delineated by an encircling Guadalupian reef complex consisting of the Capitan Limestone and equivalent carbonate units, which is not present under the site but nonetheless is important hydrologically. The Ochoan Series within the basin predominantly is halite and anhydrite, but also contains potash, limestone, dolomite, and fine-grained clastics. The Ochoan Series, in ascending order, includes the Castile, Salado, and Rustler Formations and the Dewey Lake Red Beds. The units above the Dewey Lake Red Beds consist of the Triassic Chinle Formation and the Santa Rosa Sandstone, small outliers of the Tertiary Ogallala Formation, and discontinuous bolson deposits of the Quaternary Gatuña Formation. A thin caliche caprock of Holocene age extends across most of the study area and locally is overlain by a shifting mantle of semi-stabilized dune sands. Holocene alluvium is present along the Pecos River.

Late Tertiary subsidence of the Delaware Basin was followed by regional uplift that caused eastward tilting of the beds in the basin. This structural deformation was later modified by local subsidence and karst development in Nash Draw, Clayton Basin and the Malaga Bend area due to near-surface salt dissolution in the Permian evaporites.

STRATIGRAPHY

Delaware Mountain Group

The Delaware Mountain Group is part of the Guadalupian Series deposited during the Permian age and mainly is composed of fine-grained clastic rocks with a few thin limestone and shale beds. The group is divided, in ascending order, into the Brushy Canyon, Cherry Canyon, and Bell Canyon Formations. The Delaware Mountain Group is underlain by the Bone Spring Formation of Leonordian age, which consists of basinal siltstone, chert, and dark limestone. The Ochoan Series overlies the Delaware Mountain Group and

principally consists of evaporites with increasing quantities of red mudstone and siltstone in the younger rocks. The following table lists the formations and their respective thicknesses from the Richardson and Bass, No. 1 Regan H. Legg well (T. 22 S., R. 30 E., sec. 27) and the Clayton W. Williams, Jr., Badger Unit Federal well (T. 22 S., R. 31 E., sec. 15) near the WIPP site.

	Legg well	Badger Unit well
Bell Canyon Formation	1,415 feet	961
Cherry Canyon Formation	1,050 feet	1,047
Brushy Canyon Formation	1,605 feet	1,936

Detailed descriptions of these formations can be found in publications by King (1948), Newell and others (1953), Hayes (1964), and Sullivan (1979). The Bell Canyon Formation is the closest water-bearing rock unit underlying the proposed WIPP facility. For this reason, the stratigraphy and hydrologic characteristics of this formation are described in detail in this report.

The Brushy Canyon Formation and Cherry Canyon Formation are composed mostly of siltstone or shales and thin fine-grained sandstone with a few thin limestone beds. Conglomerate and coarser grained sandstone are found only in the Brushy Canyon Formation (Harms, 1974). These units also interfinger with their reef-facies equivalents, the Goat Seep Limestone and San Andres Limestone (fig. 2).

Bell Canyon Formation--Stratigraphic relationships of the Bell Canyon Formation are of importance when studying the hydrology of the Delaware Mountain Group. The Bell Canyon is the fore-reef facies deposited in the Delaware Basin (Watson, 1979, p. 7). The Capitan Limestone is the reef facies equivalent to the Bell Canyon and interfingers with the Bell Canyon along the basin margin (fig. 2). The upper part of the Bell Canyon Formation was studied using cores from three test holes drilled near the WIPP site -- ERDA-10, AEC-7, and AEC-8. The stratigraphic subdivisions used in the WIPP study are shown in figure 3 and are those informal members described by Grauten (1965).

Olds and Hays sandstone members: The Olds sandstone member is separated from the underlying Hays sandstone (informal units) in most places by a shaly bed (Grauten, 1965, p. 298-299). The Olds and Hays have laminated and clean sandstones facies, and they both produce some hydrocarbons in the Delaware Basin.

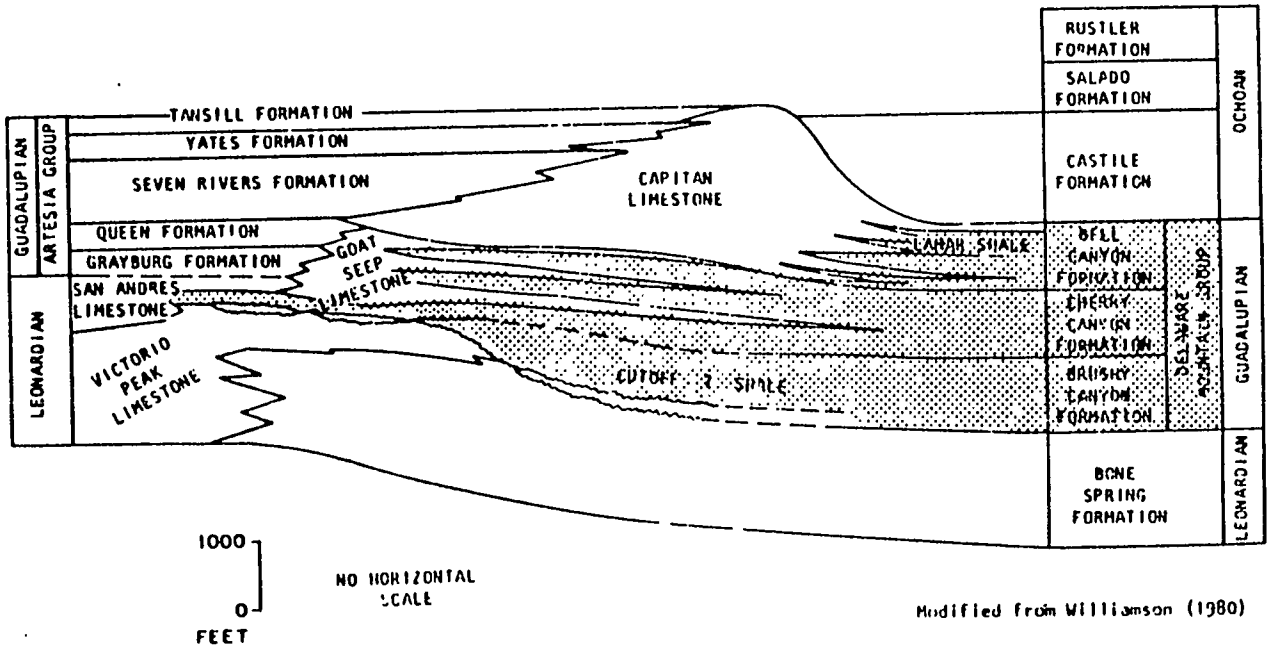


Figure 2.--Generalized stratigraphic section showing the relationships of the Guadalupian reef complex to those of the Delaware Mountain Group, southeastern New Mexico.

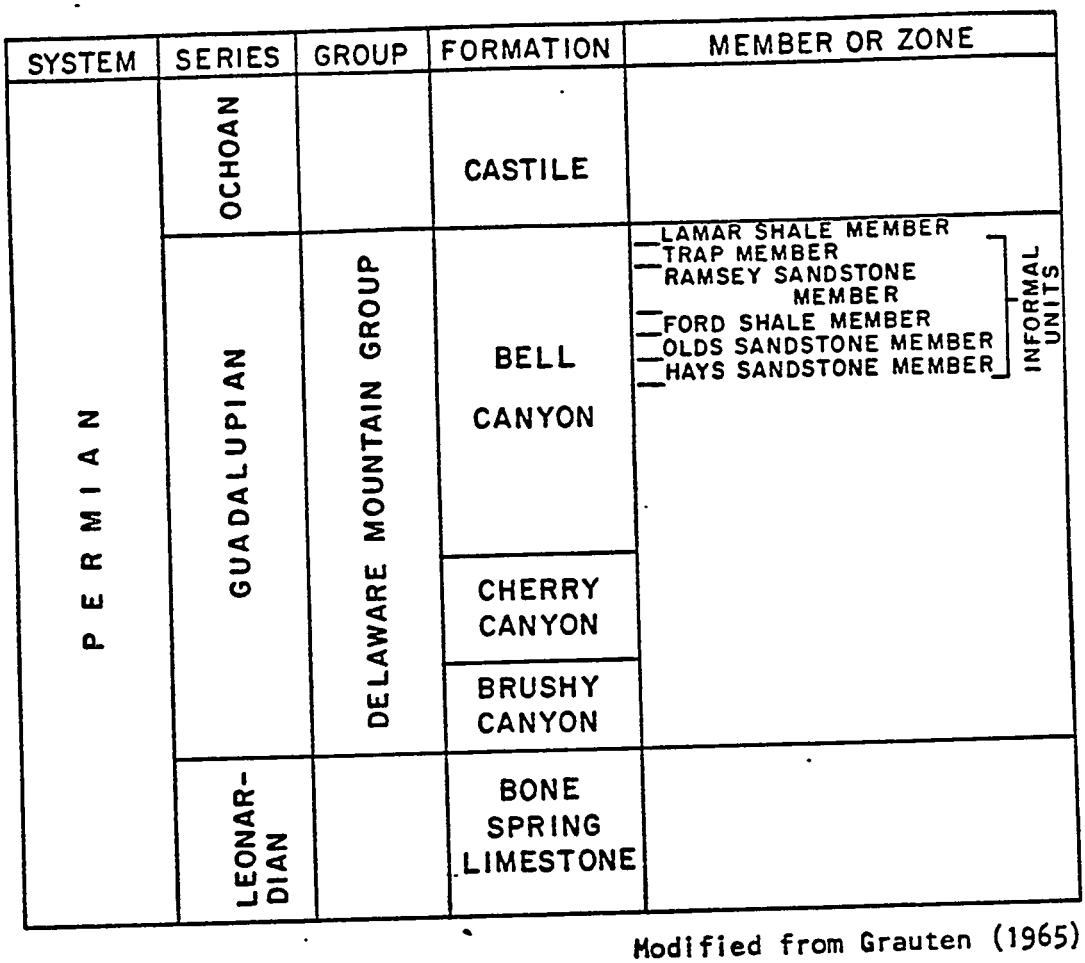


Figure 3.--Stratigraphic relationships of the Delaware Mountain Group, Texas and New Mexico.

Ford shale member: The Ford shale member overlies the Olds sandstone member (informal unit) in the Delaware Basin. It consists of two 2-foot-thick beds of black shale separated by a 6-foot-thick laminated siltstone, forming one of the most important markers used in exploration for hydrocarbons in the Bell Canyon Formation (Grauten, 1965, p. 298).

Ramsey sandstone member: The Ramsey sandstone member (informal unit) overlies the Ford member throughout the study area. As described by Grauten (1965 p. 295), the Ramsey sandstone member has two main facies: (1) A laminated, shaly siltstone, interlaminated with black shale, and (2) A clean, very fine-grained sandstone with crossbeds of laminated, limy, shaly siltstone or very fine-grained sandstone. This stratigraphic sequence is common in many of the units in the lower parts of the Delaware Mountain Group. An important characteristic of the Ramsey is that, in most instances, the clean sandstones grade laterally into laminated siltstone with negligible permeability, thus creating stratigraphic traps where hydrocarbons and other fluids may accumulate. The Ramsey is the main oil and gas producing unit of the Bell Canyon Formation.

Trap member: The Trap member (informal unit) overlies the Ramsey sandstone member and consists of an interlaminated shaly siltstone and shale sequence, the laminae of siltstone and shale being very thin (Grauten, 1965, p. 295). Some writers (Watson, 1979, p. 4) refer to this member as the upper laminated Ramsey. The Trap usually is very thin, averaging only 5 to 10 feet.

Lamar shale member: The uppermost member is the Lamar shale (informal unit), commonly referred to as the "Lamar lime". It is composed of a very dark, silty shale; in some places beds of hard, black, very shaly limestone are present. Throughout the Delaware Basin, the thickness of the Lamar is 25 to 30 feet.

Guadalupian reef complex

The Guadalupian reef complex, specifically the Capitan aquifer as defined by Hiss (1980, p. 289), is a lithosome that includes the Capitan and Goat Seep Limestone and most or all of the Carlsbad facies of Meissner (1972). It also includes shelf-margin carbonate banks or stratigraphic reefs in the upper part of the San Andres Limestone where these cannot be readily distinguished from the Goat Seep Limestone and Carlsbad facies. Generally, the units discussed are of Permian Guadalupian age and comprise a reef complex that was deposited along the margin of the Delaware Basin in a continuous, narrow, arcuate belt.

The units are composed mostly of limestones, dolomites, reef breccias (Capitan Limestone), and massive dolomites (Goat Seep Dolomite). The complex includes facies transitions composed of shelf-edge dolomites and thin interbedded sandstones (Carlsbad facies), along with chert and dolomite (San Andres Limestone). Terrigenous clastics are notably absent in this sequence of rocks (Meissner, 1972). A more detailed description of lithologic relationships in the "reef complex" described above can be found in Hiss (1976), Meissner (1972), Motts (1968), Newell and others (1953), and Silver and Todd (1969).

Ochoan Series

The Ochoan rocks studied at the WIPP site are composed of extensive evaporite deposits that filled the Delaware Basin and extended across the Guadalupian reef zone during Permian time. The Ochoan Series is represented, in ascending order, by the Castile, Salado, and Rustler Formations, and the Dewey Lake Red Beds. The Ochoan is entirely of marine origin, but it has two dissimilar parts -- a thick lower section of evaporites and a thin upper section of red beds (Jones, 1973, p. 7). The lower section, containing extensive deposits of halite and anhydrite, includes the Castile, Salado, and Rustler Formations, whereas the upper section is composed of the Dewey Lake Red Beds. The Dewey Lake is composed entirely of red sandstone, siltstone, and some shale. The sequence probably forms a protective cover that has retarded the dissolution and removal of the soluble salts in the lower evaporite units (Jones, 1954, p. 107). Among the lower evaporite units, the Castile and Rustler contain more anhydrite and carbonate than the Salado. In the area of the WIPP site, these anhydrites have formed protective barriers that have retarded the upward or downward movement of meteoric water into the salt-rich Salado Formation. The Ochoan sequence conformably overlies the Guadalupian Bell Canyon Formation and unconformably underlies the Triassic Santa Rosa Sandstone.

The WIPP geotechnical studies have generated intense interest in these rocks, not only because the halite of the Salado is to be the location for the proposed facility, but also because the evaporites could be barriers to fluid migration should the facility be breached. Numerous discussions of detailed stratigraphy by various authors can be found in documents published for the area (Vine, 1963; Hayes, 1964; Gard, 1968; Jones, 1954, 1973, 1978; Powers, Lambert, Shaffer, Hill, Weart, 1978; and Bachman, 1973, 1974, 1980, 1981); therefore, stratigraphic discussions in this paper will be limited to those deposits that may affect the hydrologic system at the WIPP site.

Castile Formation.—The Castile Formation, the basal unit in the Ochoan evaporite sequence, consists principally of anhydrite, calcite-banded anhydrite, and halite with some limestone and sandstone. As originally defined by Richardson (1904), it included all the evaporites between the Delaware Mountain Group and the Rustler Formation; however, present usage follows that of Lang (1935), who divided the Castile into two formations: the anhydrite-rich Castile below and the halite-rich Salado above.

Extensive outcrops of the Castile Formation are present in the western part of the Delaware Basin. The formation, where it is exposed, is devoid of halite and the anhydrite primarily has been altered to gypsum by weathering.

The contact between the Castile Formation and the overlying Salado Formation is conformable and gradational, but, nonetheless, generally is defined as the horizon at which dominant anyhdrite below changes to halite above (Jones, 1973, p. 10).

Salado Formation.—The Salado Formation, differentiated from the Castile by Lang (1935, p. 267), principally consists of halite in thick seams interbedded with anhydrite, polyhalite,and glauberite. The upper contact of the Salado is the distinct conformable contact between halite and the gray siltstone and sandstone of the lower part of the Rustler Formation. The Salado is the principal salt formation being investigated at WIPP because the proposed facility would be built in selected salt horizons of this unit. Additionally, the Salado Formation is important because parts of it (McNutt Potash zone) in eastern Eddy and western Lea Counties are mined for potash minerals. A discussion related to potash evaluation can be found in Jones (1978).

Jones (1975, p. 12) describes three divisions within the Salado near the WIPP site: the lower member (1,040-1,154 feet thick), the McNutt potash zone (357-375 feet thick), and the upper member (468-504 feet thick). The lower member consists largely of clayey halite interbedded with thin seams of anhydrite and polyhalite, as well as some thin-bedded siltstones and sandstones. The lithology of the McNutt potash zone, while similar to the clayey halite of the lower member, includes sylvite and langbeinite, which are both economically important potash salts. The upper member is composed of clayey halite interbedded with minor anhydrite and polyhalite. A layer of residuum which lies immediately on top of the Salado in certain areas is considered to be residue from evaporite dissolution and is considered in this report to be part of the lower part of the Rustler Formation.

Throughout the Salado Formation, the principal lithologic types are repeated in a type of rhythmic depositional cycle that consists in ascending order of a clastic, a sulfate, a halite, and a mixed halite-clastic stratum (Jones, 1954, p. 110). Jones (1973, p. 13) interprets these rock sequences to "...represent a fundamental sedimentation unit or evaporite cyclothem."

Rustler Formation.—The Rustler Formation, named by Richardson (1904), is the youngest unit in the Ochoan evaporite sequence. The Rustler is a key marker bed of the upper Permian in Texas and New Mexico. Hydrologically this unit is one of the most extensively investigated units at the WIPP site because it contains the most productive water-bearing units in the study area.

In the vicinity of the WIPP site, Vine (1963, p. B-14) has described a five-fold division of the Rustler (fig. 4). The division includes: (1) At the base, an unnamed unit of clayey siltstone and very fine-grained sandstone with thin interbeds of anhydrite and halite in its upper part; (2) the Culebra Dolomite Member, a unit of thin-bedded, solution-pitted, finely crystalline dolomite; (3) the Tamarisk Member, anhydrite with a single thin interbed of unconsolidated clayey silt (residuum from a thick seam of halite and associated polyhalite and halitic siltstone); (4) the Magenta Dolomite Member, a unit of thinly cross-laminated, fine-grained dolomite; and (5) the Forty-Niner Member, anhydrite with a single thin interbed of unconsolidated clayey silt (residuum from a much thicker seam of clayey and silty halite). The dolomite units are not only hydrologically important but are distinctive marker beds throughout the Delaware Basin (Adams, 1944, p. 1614).

The upper contact of the Rustler Formaton is represented by a distinct lithologic change, going from anhydrite to siltstone, sandstone, or shale. The discordance and hiatus between the Rustler and overlying Dewey Lake Red Beds probably are not very great.

Dewey Lake Red Beds.—The Dewey Lake Red Beds overlie the Rustler Formation in the WIPP area. This sequence was named by Page and Adams (1940) for a sequence of rocks composed of siltstone and claystone with thin lenticular beds of sandstone. As observed in many of the cores from the test holes drilled at the WIPP site, almost all of the siltstone and claystone are intruded by horizontal and crisscrossing veins of selenite. The Dewey Lake is thin bedded and contains numerous greenish-gray spots. Many of the bedding surfaces contain mud cracks and ripple marks. The Dewey Lake Red Beds range in thickness from 345 to 541 feet across the WIPP site. An erosional unconformity marks the contact between the Dewey Lake Red Beds and the overlying Santa Rosa Sandstone of Late Triassic age.

Upper Triassic rocks

Santa Rosa Sandstone.—Triassic rocks of the WIPP area, included in the Dockum Group, consist of the Santa Rosa Sandstone of Darton (1922). The Santa Rosa is only present in the eastern one-half of the WIPP site (fig. 5), having been removed by erosion in the west. At the WIPP site, the Santa Rosa consists of medium-to coarse-grained, micaceous sandstone and conglomerate with interbeds of siltstone and mudstone.

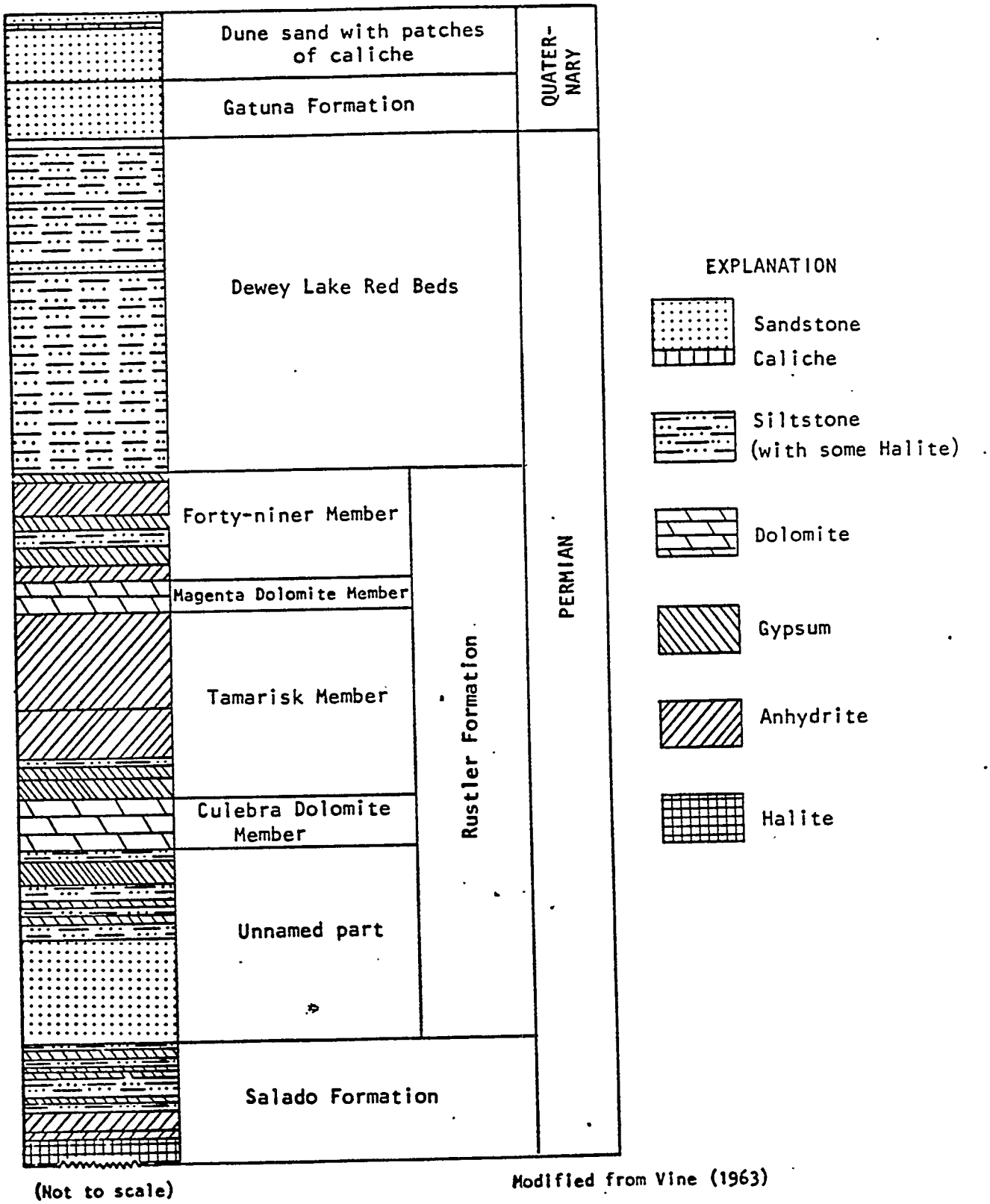


Figure 4.--The five subdivisions of the Rustler Formation in Nash Draw, Eddy County, New Mexico.

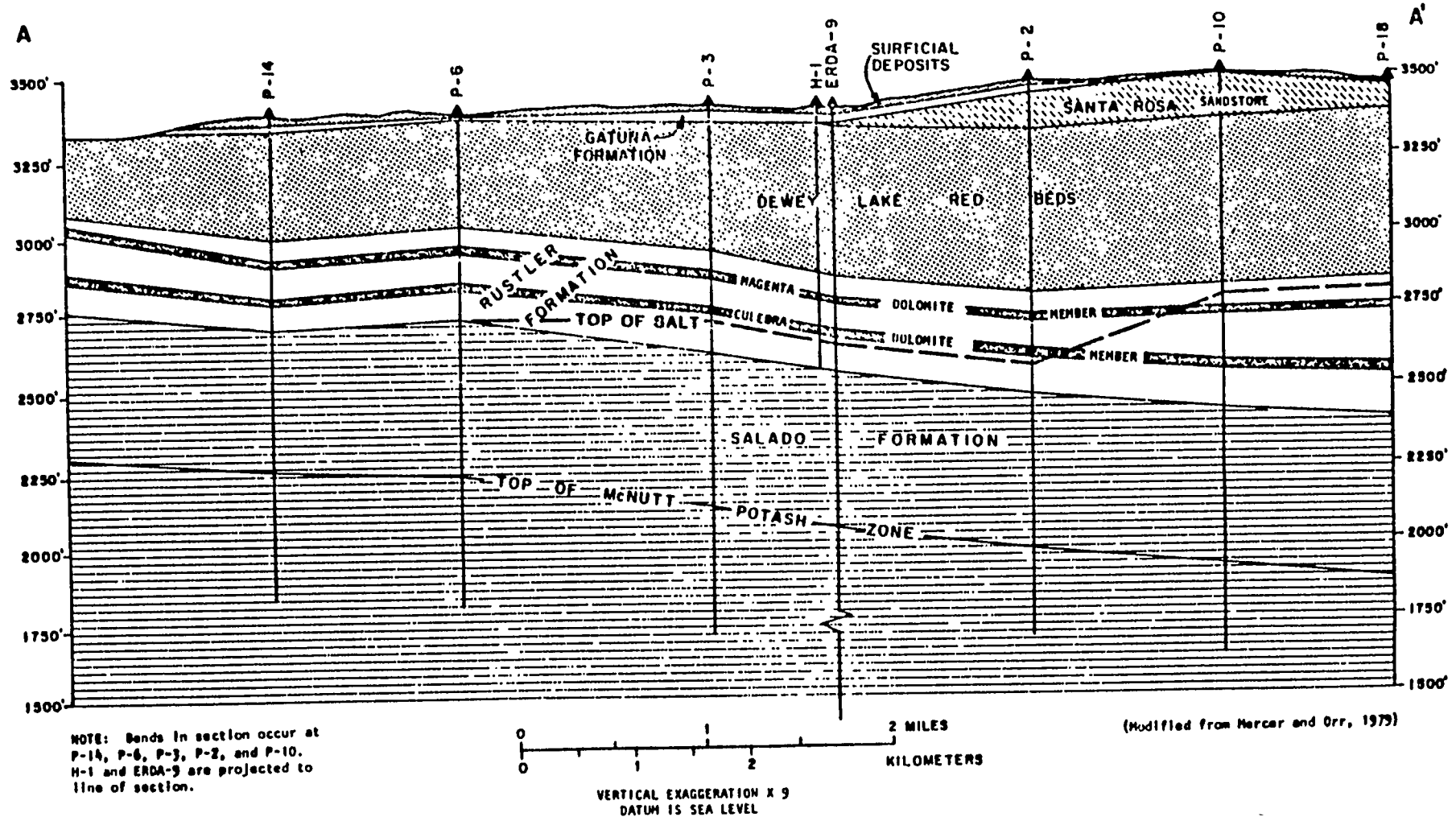


Figure 5.--Geologic section across the proposed Waste Isolation Pilot Plant (WIPP) site.

The Santa Rosa Sandstone in most of the area is truncated by a nodular to laminar limestone of middle Pleistocene age, informally called the Mescalero caliche by Bachman (1974, p. 31). In the area east of the WIPP site, the Santa Rosa may be overlain by the Triassic Chinle Formation or a Chinle equivalent.

Chinle Formation.--The uppermost unit present in the Triassic Dockum Group is the Chinle Formation or an equivalent, which, although not present at the WIPP site, was penetrated in the H-10 test hole drilled 4 miles southeast of the WIPP site (fig. 1A). The Chinle Formation at the H-10 test hole was described as a dominantly shaly mudstone interspersed with greenish-gray mudstone and lenses of sandstone and conglomerate. Anderson (1981, p. 7) discusses the presence of as much as 230 feet of Triassic Chinle Formation in test well WIPP-15 in San Simon Swale which is 10 miles east of the WIPP site. According to Nicholson and Clebsch (1961, p. 35), confusion exists due to lithologic similarities between the Chinle and Santa Rosa, which they believe cannot be separated. In fact, Bachman (1980, p. 26) believes that there is little justification to even extend these formation names into southeastern New Mexico and that the sequence should be simply referred to as Triassic or Dockum Group undivided. Although problems in nomenclature have been created concerning the Triassic Chinle Formation, this report retains the formation names and uses them, at least in the vicinity of the WIPP site.

Tertiary and Quaternary rocks

Tertiary and Quaternary deposits in the vicinity of the WIPP site include the Ogallala Formation of Miocene age, the Gatuña Formation of Pleistocene age, and sands, playa deposits, caliche, and alluvium of Holocene age. These units cover the surface of nearly the whole region and lie unconformably on older rocks.

Ogallala Formation.--The Ogallala Formation of Miocene age is the oldest record of Cenozoic depositional history and climate preserved in southeastern New Mexico (Bachman, 1980, p. 34). Although the Ogallala is well exposed along Mescalero Ridge, at Hat Mesa, Gramma Ridge, and at the Divide (fig. 1 and 1A), Bachman (1980, p. 34) indicated that the Ogallala Formation could not be recognized west of San Simon Swale towards the WIPP site except for a few thin outliers near the Divide.

In southeastern New Mexico, the Ogallala Formation generally is described as a well-sorted, windblown sand with minor poorly-sorted stream deposits and carbonate pans usually capped by a rather resistant layer of well-indurated caliche. Bachman (1980, p. 35) reports that even though the upper surface is relatively smooth, the irregular surface on which it was deposited has resulted in irregular thicknesses for the Ogallala.

Gatuña Formation.—The Gatuña Formation is the oldest known Quaternary formation in the study area and probably the thickest though the least extensive. The Gatuña was named by Robinson and Lang (1938, p. 84-85) and occurs as discontinuous bolson-type deposits in channels and depressions, possibly related to solution within the Salado and Rustler Formations. Bachman (1976, p. 140) describes a reference section of the Gatuña in the vicinity of Gatuña Canyon that consists of sandstone, siltstone, and conglomerate, with the conglomeratic beds containing pebbles of quartz and quartzite reworked from Triassic conglomerates.

Mescalero caliche.—The Mescalero caliche, an informal stratigraphic unit named for the Mescalero Plain (a broad geomorphic surface in southeastern New Mexico), occurs east of the Pecos River and west of the High Plains (Bachman, 1976, p. 141). The caliche is a well-lithified alluvial deposit of chalky, finely crystalline limestone. The caliche caps the geomorphic surface and lies with angular unconformity on the underlying Gatuña and older formations; its lower part commonly engulfs large masses of older bedrock.

Alluvium and other surficial deposits.—There are no through-flowing streams in the immediate area of the WIPP site; therefore, there are no recent stream deposits of any magnitude. Surficial deposits are composed mostly of locally-derived materials deposited by sheet wash. In some parts of the area such as Nash Draw, the surficial deposits include gypsum and dolomite fragments derived from the Rustler Formation as well as caliche fragments from the Mescalero caliche. There are small intermittent streams and collapse features that, although they may be discontinous, do contain alluvial sand and silt that is locally conglomeratic.

Hummocky surficial deposits of dune sand cover almost the entire WIPP site. The sand, locally known as the Mescalero sand (Vine, 1963, p. B-36), is fine to medium grained, with the grains predominantly angular to subrounded. Although the sand may occur as dune ridges, most of it is present on the flats and is generally stabilized by mesquite and other vegetation.

The most extensive deposits of true alluvium in the vicinity of the WIPP site are present along the west side of the Pecos River north of Malaga Bend. Isolated patches of alluvium are present to the south of Malaga Bend, but these are not very extensive.

Alluvium east of the Pecos is localized and present in depressions, as in Clayton Basin and Nash Draw. The thickest alluvial deposits, however, were found in San Simon Swale 10 miles east of the WIPP site, where drilling at WIPP-15 penetrated about 547 feet of fill (Sandia National Laboratories and the University of New Mexico, 1981, p. 7).

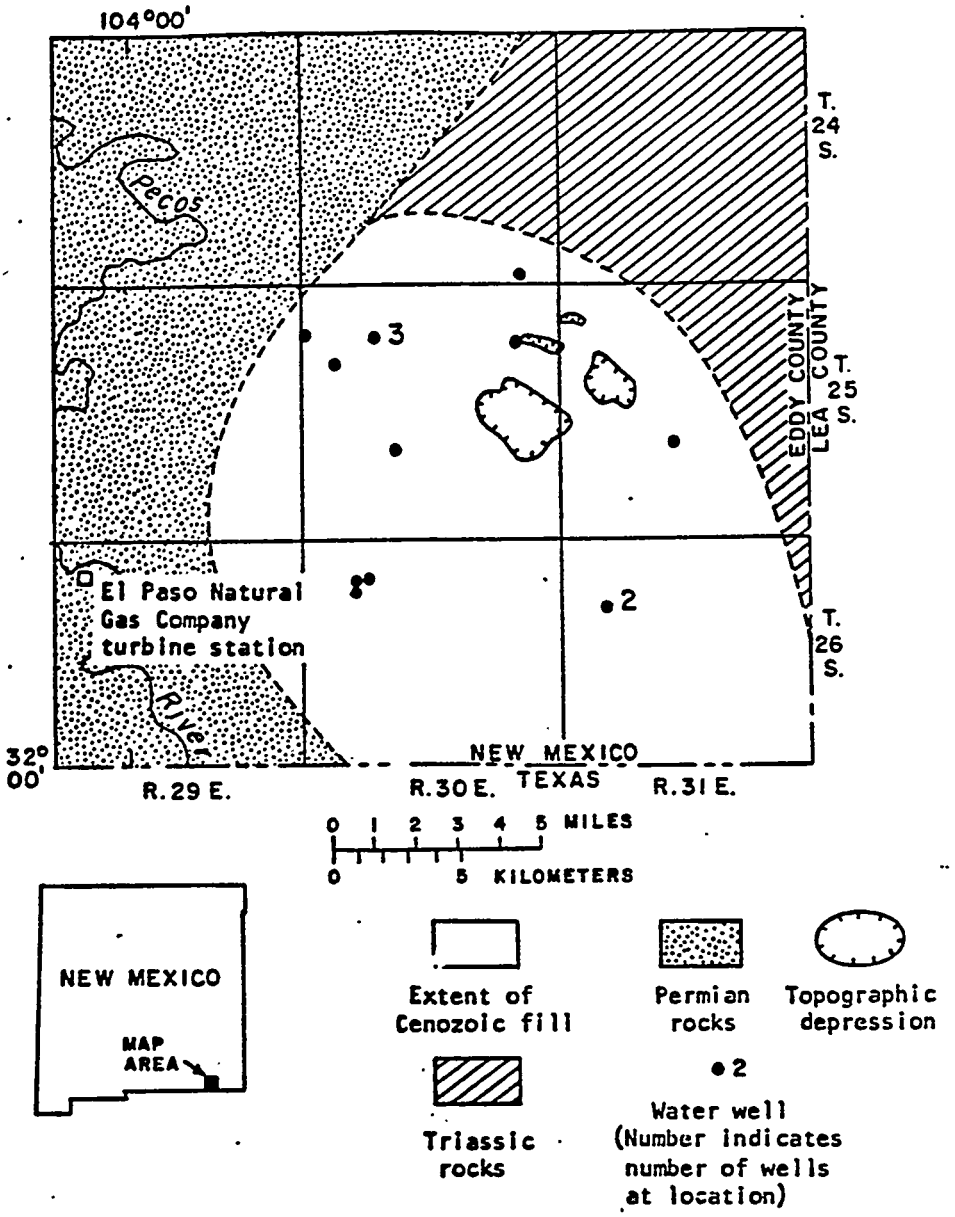
Maley and Huffington (1953) and Cooper (1962, p. E152) have described several structural features in the study area as thick accumulations of alluvium that fill deep solution depressions. Nicolson and Clebsch (1961, p. 46-47) describe similar collapse structures in southern Lea County. These studies show that alluvial deposits underlie an area of 150 square miles east of the Pecos River in Eddy County, New Mexico, and extend southward into western Texas (fig. 6). Maley and Huffington (1953, pl. 1) indicate more than 1,400 feet of fill at the center of this area near the New Mexico-Texas State line, but Cooper's investigations show that, at least in New Mexico, the thickness probably does not exceed 1,000 feet. Lithologic descriptions from logs of several holes drilled into the fill indicate the material to be sands separated by somewhat thicker interbeds of silt and clay.

Other surficial material in the WIPP site area includes the fill associated with playas. This material generally consists of alluvium and eolian sands reworked by lake waters but may also contain reworked gypsum as well as precipitated gypsum and chlorides, as is present at Laguna Grande de la Sal. Some playas may contain perennial lakes, such as Laguna Grande de la Sal; others may be dry most of the year.

GROUND-WATER HYDROLOGY

This report presents an appraisal of potential boundaries to the ground-water flow system in the vicinity of WIPP site and includes an evaluation of hydraulic flow paths from the facility to the proposed major discharge area at Malaga Bend. The hydrologic regime both above and below the facility needs to be examined in order to characterize the flow system in the WIPP site study area, particularly when the host medium for the storage facility consists of easily dissolved halite. Therefore the studies were divided into shallow hydrologic investigations (above salt), and deep hydrologic investigations (below salt). The phases of the shallow and deep hydrologic investigations included: the geology of the area, the stratigraphic location of the geohydrologic units and the occurrence of water in them, the hydraulic factors that govern ground-water movement from areas of recharge to areas of discharge, and the chemical quality of water and possible reactions with the host rocks.

The fundamental principles governing the occurrence and movement of ground water have been discussed in detail in textbooks and numerous publications, for example Meinzer (1923a and b), Tolman (1937), and Lohman (1972). The interested reader is referred to these publications and others for a more detailed discussion of this subject.



From Cooper (1962)

Figure 6.--Generalized subsurface extent of Cenozoic fill in southeastern Eddy County, New Mexico.

The terminology for hydraulic properties of ground-water systems has caused some confusion in the past. For example, the use of permeability and hydraulic conductivity interchangeably has led to much of the confusion, especially between ground-water hydrologists and petroleum engineers. In this paper hydraulic conductivity will be used when referring to the water-transmitting characteristic of the material in quantitative terms. The definition of hydraulic conductivity used here is the one described in Lohman (1972, p. 6) and is a replacement for the older term, "coefficient of permeability." "A medium has a hydraulic conductivity of unit length per unit time if it will transmit in a unit time a unit volume of ground water at the prevailing viscosity through a cross section of unit area, measured at right angles to the direction of flow, under a hydraulic gradient of unit change in head through the unit length of flow." In this report permeability will be used as a qualitative term to refer in a general way to the ability of a rock to transmit fluid. The "permeability" commonly used by petroleum engineers will be the "intrinsic permeability" described by Lohman (1972). The "intrinsic permeability" is a property only of the medium and is independent of the nature and properties of the fluid contained in it.

Transmissivity is a term used in this report that also needs definition. As defined by Lohman (1972, p. 6), transmissivity is the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It is both a property of the aquifer and of the confined liquid. The transmissivity is equal to the average hydraulic conductivity times the thickness of the aquifer. The term "aquifer" is not used in its formal sense in this report. Formal usage defines an aquifer as a geologic formation or group of formations or a part of a formation that is capable of yielding economic quantities of water to a pumped well or to springs. The use of the term aquifer in reference to most water-bearing zones at WIPP would be misleading. More appropriately these zones will be referred to as "hydrologic units" or "water-bearing zones" in this report.

Ground water exists under hydrostatic pressure and its movement generally is from places of higher potential or hydraulic head to places of lower potential or hydraulic head. The hydraulic head, at any point, is usually expressed as the elevation above a fixed datum (usually sea level) to which water will rise in a tightly cased hole. Differences in hydraulic head in feet of water within a hydrologic unit and the resulting slope of the profile is called the hydraulic gradient.

Rates of movement between any two points in a water-bearing unit depends on the difference in hydraulic head, the distance between the points, the effective porosity of the unit, and the hydraulic conductivity.

The distribution of water levels measured in wells in selected hydrologic units is illustrated by contours on maps; in confined ground-water systems, these maps are referred to as potentiometric-surface maps. The potentiometric surface is the elevation to which water will rise in tightly cased wells that penetrate confined hydrologic units; the

imaginary surface thus defined is used to picture the areal extent and movement of ground water as well as to qualitatively define any permeability changes within the unit. In some instances potentiometric-surface maps can be useful for predicting directions of ground-water flow. In general, the primary direction of water flow in porous media is at right angles to the potentiometric-surface contours. However, in cases of fracture flow, as occurs locally at the WIPP site, the direction of movement is most affected by directional differences in permeability or fracture orientation. Thus, the actual direction may have little or no relationship to the movement inferred from the regional potentiometric-surface contours. Where extensive fracturing has occurred, the flow could actually be almost parallel to the indicated gradient. Earlier maps constructed for the WIPP study area have failed to distinguish between water levels of different hydrologic units. Present potentiometric maps distinguish the three water-bearing units and show equivalent freshwater head differences in excess of 100 feet between units.

Potentiometric-surface maps for the WIPP study area need to include effects from variations in water chemistry within the individual water-bearing zones. These variations create density differences that hinder determination of representative static-pressure heads. A potentiometric-surface map constructed strictly on the existing water levels, without appropriate density correction, may lead to erroneous conclusions when efforts are made to determine flow direction from this potentiometric gradient. Various methods of correction were studied, as described in Bond (1972), Hubbert (1953), and Jorgensen and others (1982). However, it was determined for this report that the water levels would be adjusted to a common density of 1.0 (freshwater equivalent) by methods similar to those described in Hiss (1976). Because the units are almost horizontal, this method is believed to give reasonable values for general directions of flow (the Hiss method is not accurate for dipping beds). Larger errors can occur in hydraulic head calculations, adjusted for density, when thick water-bearing beds are present (not the case at the WIPP site), and especially when density varies in the vertical direction as well as in the horizontal direction. The hydrologic units at the WIPP site include thin water-bearing beds where density variations are primarily lateral, not both lateral and vertical.

As ground water moves along the flow system from recharge areas to areas of discharge, its chemical quality is altered by a variety of geochemical processes. As the ground water moves along the flow path, the concentrations of dissolved solids probably increase, especially if the water comes in contact with easily dissolved halite and other evaporite rocks.

Large concentrations of dissolved solids were found in most of the water samples collected from the hydrologic units studied at WIPP; in most instances the ground water would be classified as moderately to very saline (3,000 to 35,000 milligrams per liter of dissolved solids) to brines (more than 35,000 milligrams per liter of dissolved solids). The concentrations of

the major chemical constituents are directly related to the interaction of the host rocks with the water, which moves slowly through them because of restricted circulation. Interpretation of hydrochemical analyses from these rocks has aided in the understanding of the hydrologic mechanisms at work in the rocks below and above the proposed storage horizon. To facilitate an understanding of these mechanisms, discussions of the water chemistry in this report are included with the hydrologic discussions of the individual units. Although the geochemical complexity of the ground water in the WIPP area cannot be completely understood from the chemistry of the dissolved ions alone, it does provide a qualitative insight into the chemical history of these waters and some of the complexities associated with ground-water movement.

Hydrology of the Delaware Mountain Group

Geohydrologic characteristics.—The lithology of the Delaware Mountain Group has been described previously in detail. It is predominantly a fine-grained, silty sandstone with interbeds of black shale and black limestone. The basinal deposits are composed, in ascending order, of the Brushy Canyon, Cherry Canyon, and Bell Canyon Formations. The Delaware Mountain Group crops out in the southern Guadalupe Mountains and in the Delaware Mountains in Texas. The maximum thickness of the Delaware Mountain Group is in the central part of the Delaware Basin where its thickness exceeds 4,000 feet. The Delaware Mountain Group either pinches out or interfingers with the several stages of reef growth on the basin edge (fig. 2).

A structure-contour map (fig. 7) on top of the Lamar shale member (informal unit of the Bell Canyon Formation) of the Delaware Mountain Group shows two main types of structural provinces -- monoclinal in the west and anticlinal in the east, southeast, and the southwest (Grauten, 1965, p. 299). The Lamar shale has a general eastward dip of about 75 to 100 feet per mile.

The Cherry Canyon and Brushy Canyon Formations produce only minor quantities of oil and gas; most of the oil and gas comes from sandstone in the upper part of the Bell Canyon Formation. The oil fields developed in the upper part of the Bell Canyon do not usually occur in any pronounced structual feature that could account for the trap. Oil, gas, and water probably occur in relatively clean elongated "channel" sandstones that are porous and permeable but grade vertically and laterally into relatively impermeable siltstones and laminated shales. These rocks form permeability barriers, thus creating stratigraphic traps. The Cherry Canyon Formation contains less oil and gas, not only because of a lack of favorable structural features such as are found in the Bell Canyon, but also because of a large proportion of siltstone and increased cementation that decrease the permeability. Similarly the Brushy Canyon Formation probably contains little oil or gas because of lesser permeability from increased cementation (Berg, 1979, p. 89). Berg also concludes that the greater permeabilities found in the upper sandstones of the Bell Canyon sandstones probably result from the shallower depth and lesser cementation.

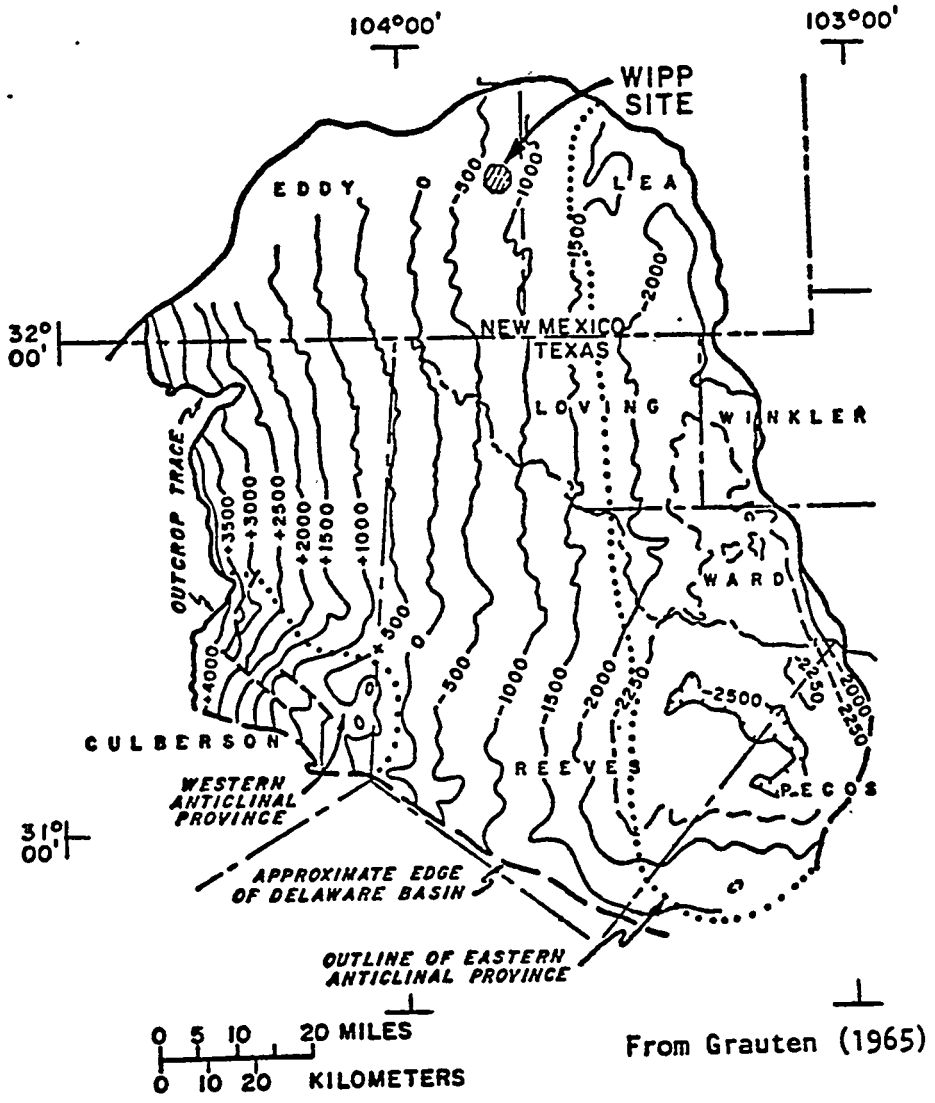


Figure 7.--Generalized structure contours on top of the Lamar shale (informal unit, Delaware Mountain Group) in the Delaware Basin, New Mexico and Texas.

Data for a regional analysis of the hydrologic characteristics of water-bearing units within the Delaware Mountain Group are sparse due to the depth, the salinity of the water, and the overall lack of permeability of these rocks. Early studies (Grauten, 1965, and Sullivan, 1979) of the Delaware Mountain Group concluded that the Lamar shale at the top of the Bell Canyon Formation plus the several thousand feet of dense anhydrite and salt of the overlying Castile Formation would probably form an effective confining bed over the Bell Canyon Formation. These confining beds, if they were not fractured, would restrict water from migrating upward from the Bell Canyon Formation to dissolve the salt of the Salado Formation and would also restrict movement of fluids downward from the proposed facility horizon to the Bell Canyon Formation. Since these studies, interpretations of the potential for upward movement of fluids from the Bell Canyon into the overlying evaporites (Anderson, 1978, 1981) has created a need for a re-evaluation of the hydrologic system of the Delaware Mountain Group.

This study is restricted to the upper part of the Bell Canyon Formation because it is the closest water-bearing zone below the evaporites and contains the most porous sandstones of the Delaware Mountain Group. The hydrologic system of the Delaware Mountain Group, as defined by the available data, probably is confined to the upper 600 feet of the Bell Canyon Formation; individual sandstone units in any one area probably are no thicker than 45 to 60 feet.

Based on drill-stem tests conducted on the Bell Canyon Formation and from data from previous studies, it became apparent that earlier studies (Mercer and Orr, 1977; Hiss, 1976) that indicated that the Delaware Mountain Group is a uniform hydrologic unit were in error. Numerous studies of oil reservoirs indicate that the sandstones of the upper part of the Bell Canyon are present as narrow, sinuous channels that grade laterally into less permeable shales and siltstones. These channel sandstones may be covered with siltstone and locally are poorly connected hydrologic units. Though studies of geophysical logs may indicate that it is continuous, each major sandstone body is composed of many individual sandstone beds that are either separated by siltstone or have different degrees of cementation (Williamson, 1979, p. 71). Grauten (1965) describes the apparently continuous sands of the Ramsey Sandstone actually to be composed of three or more separate sublenses of porous sandstone separated by relatively impermeable siltstone beds, each sublens to be virtually separated hydraulically from the others. The entire system is confined by overlying beds with negligible permeability; in the case of the sandstones of the Ramsey member, the overlying Trap and Lamar shale members form a very effective seal (Grauten, 1965, p. 302). As a result, vertical permeability within these sandstone units is very small. This very small vertical permeability is indicated by data from a drill-stem test in test well AEC-8 where two sandstone units, separated by a siltstone unit 16 feet thick, were individually tested (Mercer and Orr, 1979, p. 133). The water levels for the upper and lower sandstones stabilized at 553 and 568

feet below ground level. Extensive evaluation of drill-stem tests in other wells throughout the basin found that differences of this magnitude are common. These differences indicate that confining beds between the sandstones are so poorly connected that they cause hydraulic head differences of 15 feet in sandstone lenses only 16 feet apart.

The hydraulic properties of the upper part of the Bell Canyon have been compiled from several sources including drill-stem tests at the WIPP site (table 4) and selected oil-field production data. The following discussion also includes the average values for hydraulic properties published in the Delaware Mountain Group Symposium (Sullivan, 1979) for reservoirs at which oil, gas, and water are present and includes the values for the hydraulic properties for the permeability barriers of siltstone and shale.

The primary porosity of the upper Bell Canyon sandstones (generally the Ramsey) is intergranular and generally ranges from 20-28 percent. The permeabilities of these sandstones in the Ramsey range from 14 to 90 millidarcy (Berg, 1975) although permeability may be greater locally. The siltstones and shaly siltstones forming the permeability barriers generally have porosities ranging from 10 to 20 percent with a permeability usually less than 0.1 millidarcy. A good example of this type of stratigraphy is shown in the cross section across the El Mar oil field in Loving County, Texas (fig. 8).

The unknown factor in this analysis is the degree to which the sandstones are interconnected on a regional scale. If the siltstone barriers also are present on a regional scale, the permeability values given for the sandstones are probably too large, and calculated rates of movement are also too large. The permeability barriers; however, are present locally.

Three test holes (AEC-7, AEC-8, and ERDA-10) were drilled into the upper part of the Bell Canyon Formation and were hydraulically tested to evaluate the deep water-bearing units in the Bell Canyon Formation in the vicinity of the WIPP site. Several sand stringers that were identified from the geophysical logs and cores were permeable enough to test and contained brine. These zones included an upper and lower sand in test hole AEC-8 (probably pre-Ramsey), a series of sandstones in test hole ERDA-10 (Ramsey and pre-Ramsey), and sandstone in test hole AEC-7 (Ramsey). Although test holes AEC-8 and ERDA-10 are only about 14 miles apart and the sandstones tested are about the same depth below the top of the Bell Canyon, they may not be in good hydraulic connection because they appear to be channel sandstones. Test hole AEC-7 penetrated similar sandstones at a shallower depth.

The tests were conducted using standard and modified drill-stem-test procedures (Mercer and Orr, 1979) which test primarily the horizontal hydraulic conductivity. From analyses of the hydraulic data (table 4), the hydraulic conductivities of the sandstones were 4.0×10^{-2} foot per day for the zone tested in test hole AEC-7, 2.0×10^{-2} and 7.0×10^{-3} foot per day for the two zones tested in test hole AEC-8; and 5×10^{-2} foot per day for

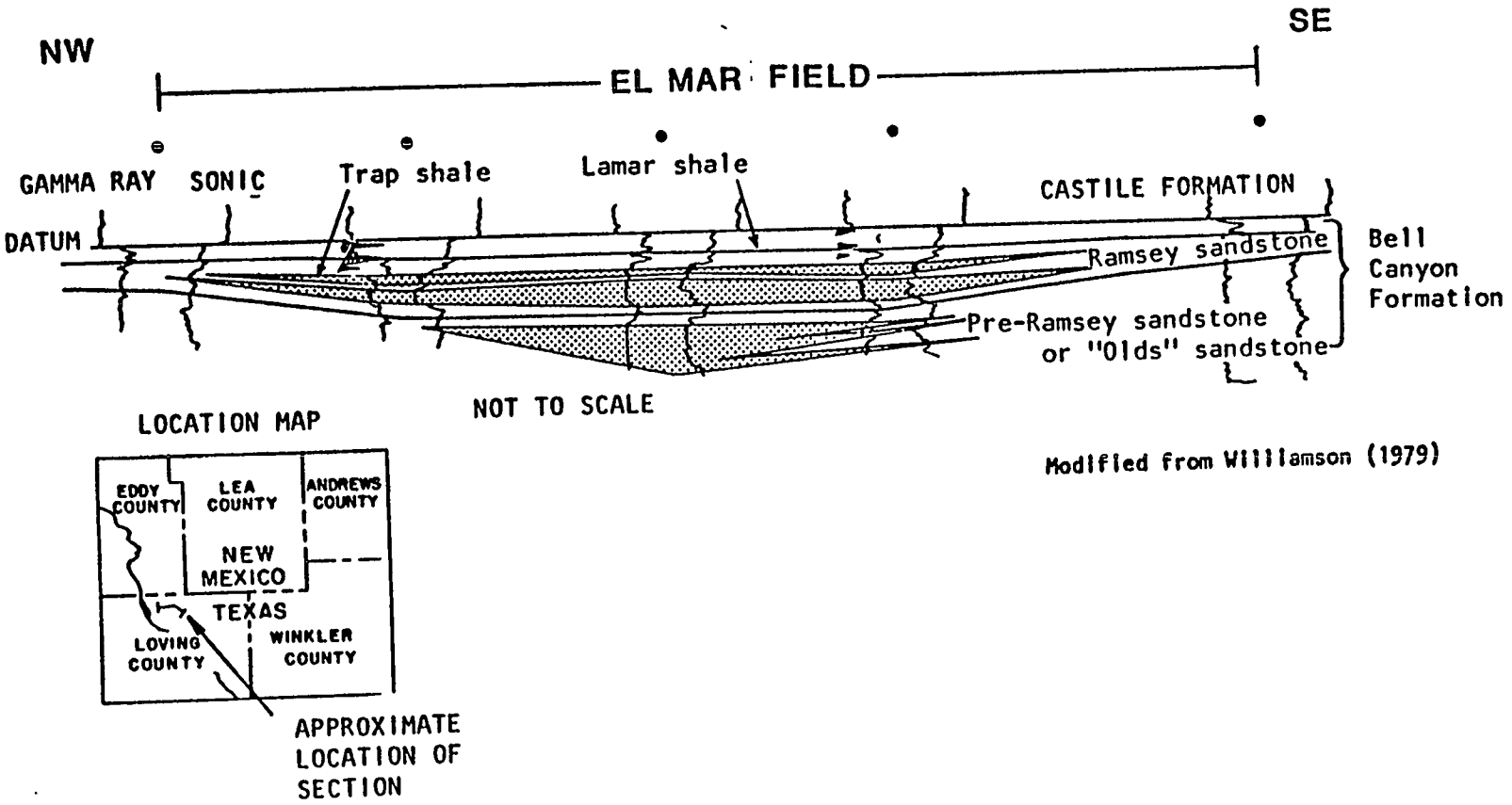


Figure 8.--Generalized geologic section across the El Mar Field, Loving County, Texas.

the zone tested in ERDA-10. The Lamar shale also was tested in the three holes to evaluate the effectiveness of the zone as a confining bed which would restrict upward movement of fluids, assuming the unit is not fractured. The tests of the Lamar shale yielded values of hydraulic conductivity of 2.0×10^{-6} foot per day in test hole AEC-8 and 4.0×10^{-4} foot per day in test hole ERDA-10. In AEC-7, the Lamar shale was evaluated to determine its effectiveness as a confining bed, but it had such negligible permeability it could not be tested. These permeability values for the upper sandstone of the Bell Canyon were within the range of permeability values reported by various oil companies for the sandstones and shales of the Delaware Mountain Group throughout the basin. These tests also indicated that the head in the upper part of the Bell Canyon Formation, although it extends above the lower part of the Rustler Formation, is still less than the heads in Rustler Formation. Therefore, the potential is for downward movement if these zones were interconnected. The head was also lower when converted to freshwater-equivalent.

Ground-water movement.--Several studies have produced potentiometric-surface maps for the Delaware Mountain Group; however, because most of the pressure-head information comes from the upper part of the Bell Canyon, these maps probably are most representative of that zone. The common procedure during oil exploration is to run a drill-stem test on a zone that (from geophysical logs) appears to have the greatest porosity along with some associated permeability. Because of the lack of lateral continuity in many of the sandstones tested in the upper part of the Bell Canyon, less reliable data are available than would be expected from the number of wells shown on an oil and gas map.

Hiss (1976) and McNeal (1965) have constructed potentiometric-surface maps for the upper part of the Bell Canyon Formation, and the maps generally are similar even though Hiss's map only covers the northern part of the Delaware Basin. Both of these maps were constructed after adjusting hydraulic head data to a freshwater datum to account for variations in brine density. In the WIPP characterization study, available oil-field drill-stem tests, production tests, and water analyses were coupled with data collected from the deep test holes AEC-7, AEC-8, and ERDA-10 near the WIPP site to construct a potentiometric-surface map. The base map developed by Hiss (1976) was used and new information was corrected for density as described by Hiss and incorporated in a new map. The new contour map duplicated Hiss's map with very little modification (fig. 9).

The potentiometric gradient of the upper part of the Bell Canyon is nearly parallel with the regional structural trend. Water apparently enters the unit in the western part of the basin, perhaps in the Delaware and Guadalupe Mountains, and moves northeastward across the basin at a hydraulic gradient ranging from 25 to 40 feet per mile. The rate of water movement in the sandstone is probably very slow because it is assumed to be restricted by negligible hydraulic conductivity of the intervening siltstones. Although

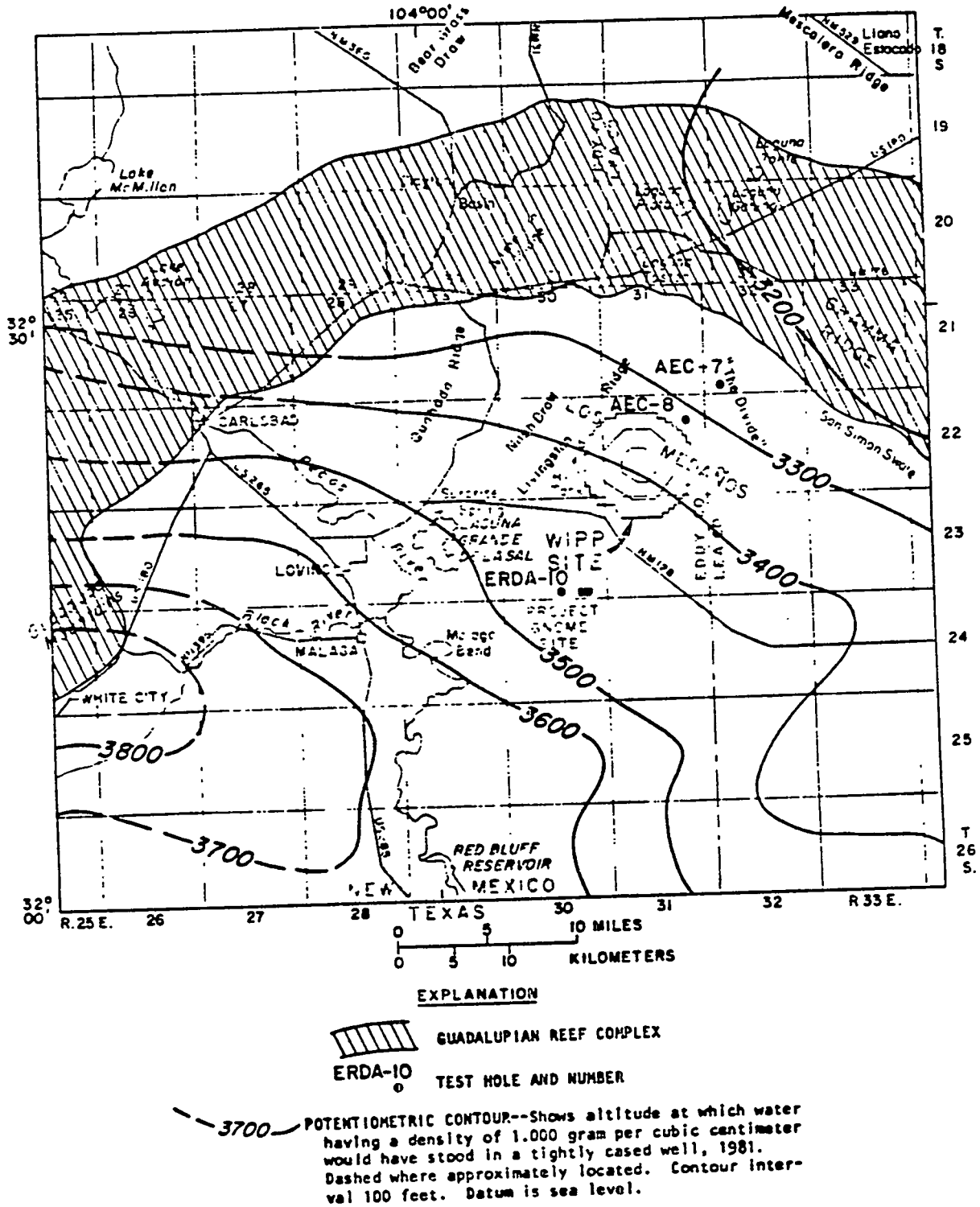


Figure 9.--Potentiometric surface of the hydrologic unit in the upper part of the Bell Canyon Formation (Delaware Mountain Group) at and near the proposed Waste Isolation Pilot Plant (WIPP) site.

the Capitan aquifer of Hiss (1976) abuts and overlies the Delaware Mountain Group along the basin margins, the lithologic and hydrologic characteristics of the Capitan aquifer and Delaware Mountain Group (in particular the upper part of the Bell Canyon Formation) are quite different (Hiss, 1980, p. 289). The hydraulic conductivity of the Delaware Mountain Group is several orders of magnitude less than that of the Capitan aquifer; this fact, coupled with differences in quality of water, would indicate that only a relatively small quantity of water in the Delaware Mountain Group, if any, would move into the Capitan aquifer. Data from tests of the upper part of the Bell Canyon Formation in test holes AEC-7, AEC-8, and ERDA-10 fit with the regional trend. Fluid density and permeability variations and discontinuity of the upper sandstone units in the Bell Canyon preclude detailed site-specific analyses by means of the potentiometric-surface map.

Hydrochemistry.—Generally, the waters in the upper part of the Bell Canyon Formation are brines in which sodium and chloride are the predominant ions (table 5). The "clean" sandstones near the outcrop of the Ramsey sandstone of the Bell Canyon appear to be saturated with relatively freshwater (Grauten, 1965, p. 303). As the water moves across the Delaware basin, however, the salinity of the water increases; locally dissolved-solids concentrations of more than 300,000 milligrams per liter occur in the structural trough of the basin (McNeal, 1965, p. 317). Concentrations of dissolved solids in brines sampled during the testing of the upper part of the Bell Canyon at the WIPP site ranged from 180,000 milligrams per liter in test hole AEC-8 to 270,000 milligrams per liter in test hole ERDA-10 (table 2). The abundance of calcium, magnesium, sodium, and potassium cations, the presence of chloride and sulfate as the major anions, and the measured low hydraulic conductivity support the concept of extensive brine-rock interaction as the water moves slowly northeastward across the basin. Detailed information on the composition of the water from the Bell Canyon in test holes AEC-7, AEC-8, and ERDA-10 is included in table 2.

Hydrology of the Guadalupian reef complex

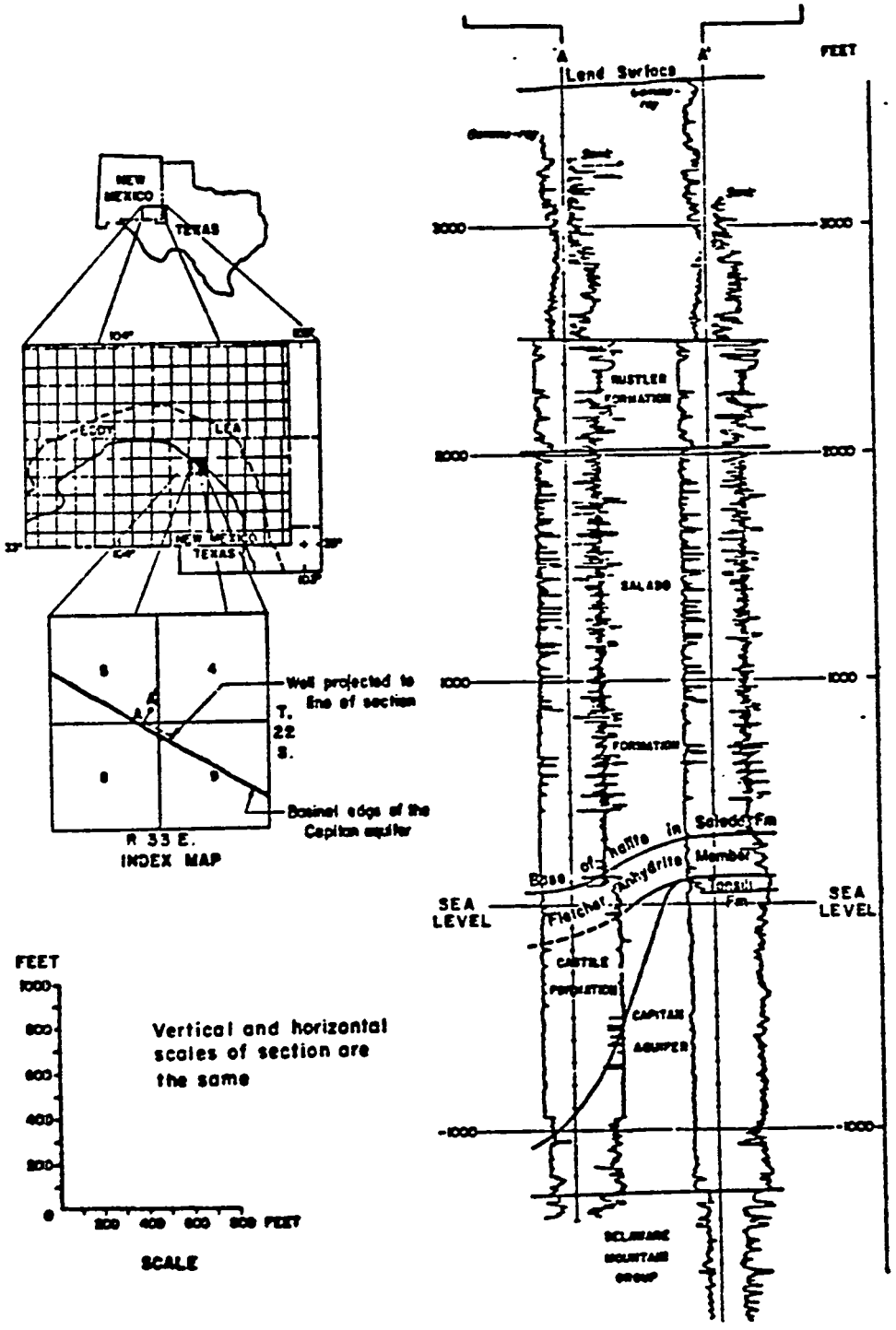
Geohydrologic characteristics.—In general, the position and dimensions of the Guadalupian reef complex which contains the Capitan aquifer, as defined by Hiss (1976, 1980) and as used in this report, closely agree with the location of the Capitan and Goat Seep Limestones and carbonate banks of the Carlsbad facies of Meissner (1972). It also includes shelf-margin carbonates and the upper part of the San Andres Limestone. Although the Capitan aquifer is one of the most productive aquifers in southeastern New Mexico, it is present in the subsurface, at the closest, some 10 miles north of the proposed WIPP facility. Here the Capitan aquifer is generally composed of a relatively "clean" carbonate with low insoluable residue, especially near the forereef edge.

This report is concerned with the section of the Capitan aquifer that parallels the northern and eastern margins of the Delaware Basin in an arcuate strip that extends from the Guadalupe Mountains southwest of Carlsbad to the Glass Mountains near Fort Stockton, Texas. The width of the Capitan aquifer in this strip ranges from 10 to more than 14 miles (Hiss, 1976, p. 141). In the subsurface, the forereef edge is relatively abrupt and abuts against the sediments of the basin (fig. 10). Approximately 1,200 feet of vertical relief along the forereef edge was detected in two oil test holes drilled a few hundred feet apart (horizontal distance) in sections 5 and 9, T. 22 S. R. 33 E. in Lea County (Hiss, 1976, fig. 18). The backreef edge of the Capitan aquifer is much more irregular. The thickness of the unit is quite variable. A maximum thickness of nearly 2,400 feet is present about 13 miles northeast of Carlsbad.

Hiss (1976, p. 90) reported that thickness of more than 1,500 feet has been observed in 49 percent of the wells that penetrate the Capitan aquifer in New Mexico. He also discussed the presence of submarine canyons that eroded into the reef in Eddy and Lea Counties, New Mexico, which decrease the overall thickness of the aquifer by one-half or more. These features all have a bearing on the occurrence and movement of water in the reef complex.

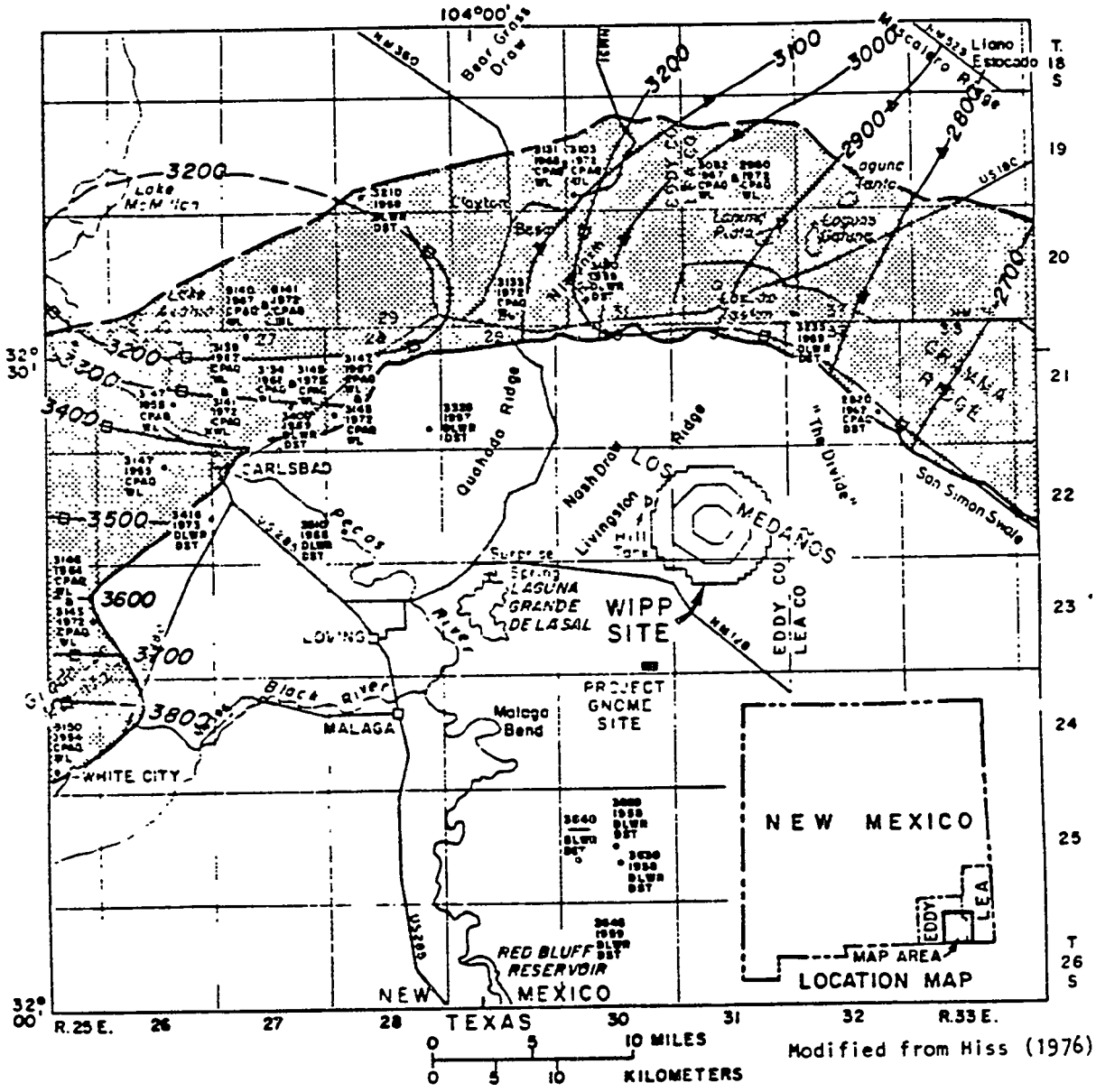
Hiss (1976, p. 198) calculated the hydraulic conductivity of the Capitan aquifer along the eastern margin of the Delaware Basin in Texas and New Mexico to range from 1 to 25 feet per day; average values for the aquifer in southern Lea County and east of the Pecos River valley at Carlsbad are about 5 feet per day. Although no values of hydraulic conductivity are available for the Capitan aquifer west of Carlsbad, Motts (1968, p. 295) indicates that yields of developed wells are from 1,000 to 4,000 gallons per minute. He also indicates from his studies that the occurrence and movement of water in the Capitan aquifer is controlled primarily by lithofacies changes. Permeabilities are greatest in coarser grained rather than finer grained detrital carbonates and in calcareous rather than dolomitic rocks. This association also is borne out by the work of Hiss.

Ground-water movement.--Water in the Capitan aquifer is under water-table conditions southwest of the Pecos River at Carlsbad, but to the north and east where the aquifer is entirely in the subsurface, artesian conditions prevail. Hiss (1976, p. 296) indicates that water entering the Capitan aquifer system in the Guadalupe Mountains moves eastward toward Carlsbad where most of the water discharges into the Pecos at Carlsbad Springs. He concludes that a deep, incised submarine canyon near the Eddy-Lea County line forms a hydraulic restriction that constrains the eastward movement of water from the vicinity of the Pecos River. Apparently there is little movement of water between the Pecos River and this restriction (fig. 11). However, east of this restriction the regional potentiometric surface, represented by the hydraulic head in the aquifer, has been changed significantly in response to withdrawal of both ground water and petroleum, especially during the last 50 years (Hiss, 1980, p. 294).



Modified from Hiss (1976)

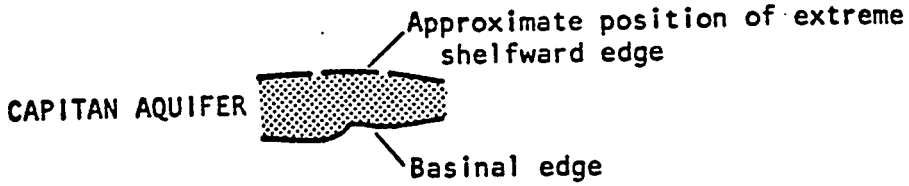
Figure 10.--Steepness of the basinal edge of Capitan aquifer, Lea County, New Mexico.



Modified from Hiss (1976)

Figure 11.--Potentiometric surface of the Capitan aquifer in the vicinity of the proposed Waste Isolation Pilot Plant (WIPP) site.

EXPLANATION



2800 —△——△— HEAD MEASURED IN THE CAPITAN AQUIFER AND SHELF AQUIFER SYSTEM WHERE HYDRAULIC CONNECTION BETWEEN THE TWO AQUIFERS IS RELATIVELY GOOD.

3200 —□——□— HEAD MEASURED IN DELAWARE MOUNTAIN GROUP WHERE THE HYDRAULIC CONNECTION WITH THE CAPITAN AQUIFER IS RELATIVELY POOR.

Contours are dashed wherever data are sparse or of doubtful reliability. Contour interval 100 feet. Datum is sea level.

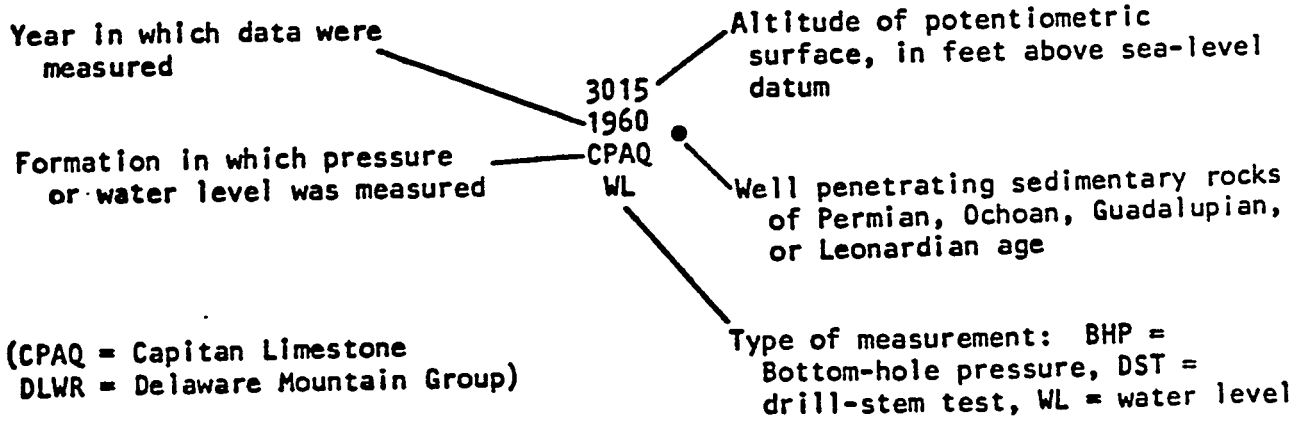
The contours express a generalized regional head considered to be representative for the Delaware Mountain Group during 1960 to 1970. Similarly, contours in the Capitan aquifer are an interpretation of the head representative for the latter part of 1972.

Considerable subjective judgment was used in contouring the data points. In general, two factors were weighed in considering each data point;

(1) The year in which the head was measured. This is important because prior fluid withdrawal from the oil and water fields causes a decline in head in nearby areas.

(2) The reliability of the data. In general, the data were ranked according to reliability in the following order: Fluid level in water wells, initial oil field bottom-hole pressures, and analysis of pressures from drill-strem tests.

DATA POINT



(Values of head are expressed as water with a density of 1.000 gram per cubic centimeter).

In summary, the Capitan aquifer system is unique hydrologically in that it forms a long narrow arcuate belt composed of very permeable rocks. Rocks with little permeability adjoining and underlying the Capitan aquifer control the movement of water. Lateral movement into the basin is prevented by the nearly impermeable anhydrites of the Castile Formation, while downward movement is controlled by the higher hydraulic head in the relatively impermeable Delaware Mountain Group. The shelf-aquifer system (Hiss, 1976) to the west and east of the Pecos River is interconnected with the Capitan aquifer, but the relatively lesser permeability of the shelf-aquifers (one to two orders of magniture less than that of the Capitan) restricts hydraulic connection.

Hydrochemistry.—There is an extensive discussion of the chemical composition of ground water associated with the Capitan aquifer in Hiss (1976, p. 208). In general, the water with relatively small chloride-ion concentrations is present in the Capitan aquifer throughout the region where the rocks have the greatest permeability; conversely, the water with the largest concentrations is present in rocks with the least permeability. The slightly saline water found in the Capitan aquifer and backreef rocks in southeastern New Mexico and western Texas probably is a result of selective displacement of the original brines by freshwater moving from the Glass and Guadalupe Mountains into formations with the regionally greatest transmissivity (Hiss, 1976, p. 210). Moderately saline waters are found in the Capitan aquifer in eastern Eddy County, especially in the area of the apparent hydraulic restriction near the Eddy-Lea County line.

Hydrology of the Castile Formation

Geohydrologic characteristics.—The Castile Formation, consisting of thick anhydrite beds with thin interbeds of salt, lies between the Delaware Mountain Group and the overlying Salado Formation. It is almost completely confined within the Delaware Basin (Oriel, Myers, and Crosby, 1967), the only evaporite unit so restricted. Generally, the Castile averages between 1,500 and 1,850 feet in thickness except in west-central Ward County, Texas, southeast of the WIPP site where it reaches a maximum thickness of more than 2,100 feet (Adams, 1944, p. 1,604). Based on data from test holes drilled during site-characterization investigations at the WIPP site, the Castile is 1,518 feet thick in test hole AEC-7, 1,377 feet thick in test hole AEC-8, and 1,492 feet thick in test hole ERDA-10.

Extensive outcrops of the Castile are present in the western part of the Delaware Basin, in south-central Eddy County, New Mexico, and southward into Texas. The upper anhydrite beds have been altered to gypsum in the area of outcrop and contain solution features.

Very little hydraulic data are available from the Castile Formation. In the salt zones, the presence of water is restricted because the salt does not readily maintain primary porosity, solution channels, or open fractures. The same characteristics are inherent in the anhydrite, with the exception that if developed, fractures may remain open temporarily. Anhydrite hydrates to gypsum in the presence of slightly saline water. Hydration usually is accompanied by a 64-percent expansion in volume, which possibly could seal the fractures and prevent further water migration.

Drill-stem tests were conducted in the Castile Formation during drilling of test holes AEC-7, AEC-8, and ERDA-10 (Lambert and Mercer, 1977). The permeabilities of the anhydrites and salt interbeds were neglibible and in most tests could not be determined with conventional testing methods. However, based on the sensitivity of the test equipment, a conservative estimate for a hydraulic conductivity of the sections tested would be equal to or less than 1×10^{-8} foot squared per day.

In most of the basin, the Castile evaporites act as a barrier or confining layer for water moving in the upper part of the Bell Canyon Formation of the Delaware Mountain Group. It has been suggested that movement of fluids upward from the Bell Canyon Formation through the Castile evaporites could develop a flow path for deep dissolution of the overlying Salado salts and subsequently develop dissolution features referred to as "breccia pipes" (Anderson, 1978, 1981). Anderson also suggested that the upward moving water would, as the concentration of dissolved salts increased, begin to move back downward due to a density differential. This concentrated brine, it is postulated, would move back down through the fracture system in the Castile to discharge into the Bell Canyon Formation. Anderson is concerned that these features could develop at or near the WIPP site.

For this density flow mechanism to work, an extensive fracture system would have to develop through the anhydrites of the Castile. Detailed studies of logs and cores from drill holes in the vicinity of the WIPP site have failed to identify such a fracture system or any other evidence that would indicate water has moved vertically through the evaporite sequence. In fact, to date (1983), no dissolution feature that has been identified within the basin has extended down as deep as the Castile Formation.

The hypothesis also requires that the upper part of the Bell Canyon Formation would be capable of transmitting these saturated brines away from the density-flow systems. The minimal permeability of sands in the Bell Canyon Formation probably would preclude removal of the volume of salt-bearing brines suggested by the hypothesis, even in the time intervals suggested.

Appreciable quantities of water have been reported in the Castile Formation along the western side of the Delaware Basin, but only in weathered zones near the outcrop. Anhydrites in these areas have been altered to

gypsum, forming solution channels and cavities. These cavities are filled with silt and broken blocks of gypsum and act as reservoirs for ground water. Water is used locally for stock watering, but usually has large concentrations of dissolved solids.

Isolated pockets of brine and associated hydrogen sulfide have been penetrated by test holes of various oil companies and during site-characterization investigations at the WIPP site. These occurrences have been discussed in several reports resulting from these investigations (Griswold, 1980; Register, 1981). In general, these pressurized brines are present in a fractured anhydrite bed in the Castile. The brines, in all known instances, are associated with structual features as determined by seismic methods and appear isolated and not part of an interconnected hydrologic system as determined by testing. Geochemical studies by Lambert (1978) show the Castile brine present in ERDA-6 test hole to be chemically and isotopically distinct from indigenous fluids in rocks above and below the Castile. Presently (1982), the Department of Energy is conducting a program that will test the brines extensively, so any further speculation here on the genesis of these brine pockets probably would be premature. The testing is being conducted on test holes ERDA-6 and WIPP-12 and includes standard drill-stem tests and constant head-variable discharge flow tests.

Another dissolution feature that would require the extensive development of a hydrologic system in the Castile is the regional breccias that Anderson (1978) has described in the Castile Formation. These breccias, he postulated, are present in the subsurface at stratigraphic horizons corresponding to major halite beds; the proposed source of the water is the Capitan reef system. As discussed by Bachman (1980), a well-developed flow system would be required over an extended period of time for such extensive lateral dissolution to take place. During careful examination of geophysical logs Bachman could not find a hydraulic system that was in the Castile Formation; in fact, he indicates that the halite beds have never been in close proximity with the Capitan reef system. Bachman proposes instead that the halites were deposited in individual and discrete sub-basins within the large Delaware Basin. The dissolution breccia zones described by Anderson would correspond to areas outside these sub-basins where halite was not deposited. To complete the circulation system, Anderson's (1981, p. 143) theory relies on fracture communication through the evaporites into the Bell Canyon Formation to drain off the brine: as discussed earlier, evidence for this flow mechanism is lacking.

Ground-water movement.—No regional flow system is present within the Castile Formation; the brine appears to occur in isolated pockets. Within the outcrop areas, some localized flow systems have developed in places where anhydrites have been hydrated to gypsum and localized recharge can occur through solution channels and cavities.

Hydrology of the Salado Formation

The Salado Formation consists predominantly of halite with minor beds of anhydrite, polyhalite, clastic rocks, (sandstones and siltstones), and potash minerals. The massive halite beds within the Salado are intended to be the host geologic medium for the WIPP facility.

The Salado is from 1,700 to 2,000 feet thick in most of the area underlying the WIPP site; it is 1,976 feet thick at test hole ERDA-9. Thicknesses may range from as little as 1,200 feet in the northeast to as much as 2,310 feet in deformationally thickened masses in the central part of the area (Jones, 1973, p. 11-18). Jones reports that in the western part of the study area variations in thickness of the Salado are complex and may be quite large. Their complexity and size are believed to reflect a combination of geologic factors involving: (1) Gradual thinning northward in response to changes in deposition patterns during the Ochoan; and (2) rapid thinning westward in response to increased dissolution.

West of the study area, where the Salado is near the surface, most of the halite has been removed by dissolution; in the northwest, where it at one time extended over the buried Guadalupian reef complex, it is absent. Dissolution in the Salado and overlying evaporites has been responsible for development of many shallow and surficial solution related features. Within Nash Draw and possibly in Clayton Basin, solution has been removing halite from the uppermost part of the Salado Formation.

In the WIPP site area, a clay bed with broken gypsum and some fine-grained sandstone is present at the contact of the upper part of the Salado Formation with the overlying Rustler Formation. Jones (1973, p. 20) describes this clay as a subsurface saprolite (a residue concentrated through dissolution of clayey halite and other clay-bearing evaporites by percolating ground water). The residue thins to the east and grades into and intertongues with halite; to the west, it thickens and crops out along the Pecos River. Jones (1973, p. 20) indicates that the practice of assigning this unit to the Rustler Formation by many geologists should be discontinued because the residue is clearly part of the Salado Formation. From a geological standpoint, this unit may be more properly placed with the Salado Formation; however, as a hydrologic unit it is more easily included with the Rustler Formation. For a more detailed discussion of dissolution and time of dissolution, reference is made to reports by Jones (1973) and Bachman (1973; 1980).

The occurrence of water in the Salado Formation is restricted because the halite does not readily maintain primary porosity, solution channels, or open fractures. During drilling of test holes at the WIPP site and during investigations for potash mining operations, no evidence of circulating water was observed in the Salado.

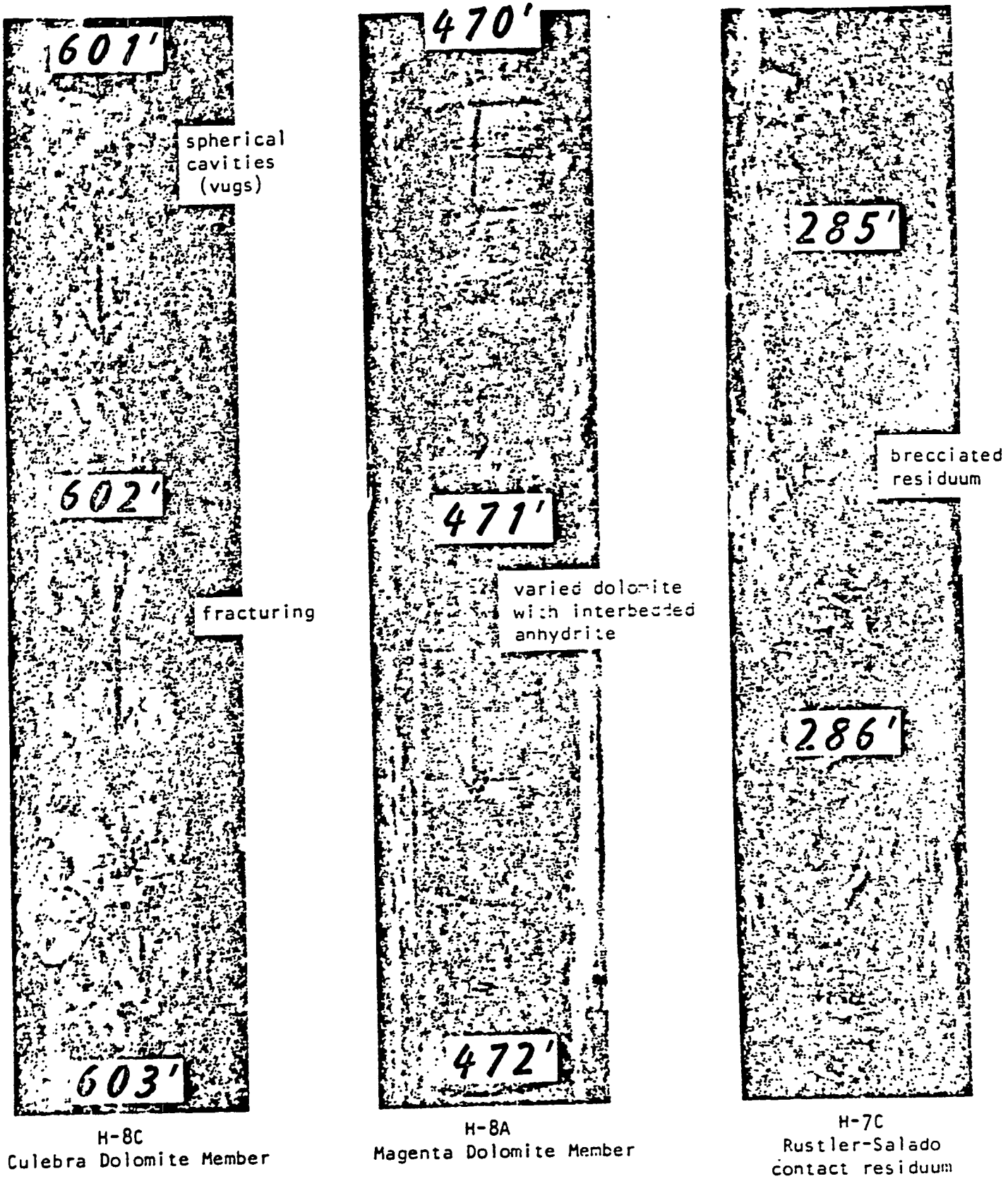
The hydraulic conductivity of the halite in the Salado Formation has been measured in test hole AEC-7 (Peterson, Lagus, Broce, and Lie, 1981); and these tests indicate that the halite has some measurable permeability. The tests were conducted using compressed-air injection into a zone of halite that was isolated by inflatable packers. The flow of air into the formation was measured, and the flow rates were interpreted in terms of formation permeabilities (intrinsic permeability as defined by Lohman, 1972) and porosities. The formation property values were determined based on the assumption that the halite bed could be modeled as an ideal unsaturated porous medium with a porosity of 0.001. Stressing the assumptions they used and cautioning the indiscriminant use of the values obtained to model fluid particle velocity and fluid penetration distances, Peterson, Lagus, Broce, and Lie (1981, p. 52) reported values of permeability (assuming a porosity of 0.001 and a measured well depth of 2,269 feet) of 12 and 21 microdarcies. This depth corresponds to the proposed depth for the WIPP facility. They conclude that the measured in-situ permeability of the halite may be greater than the true value because of formation discontinuities such as microfractures of the borehole wall created by drilling.

As previously discussed, the Salado Formation does not have active circulation of water; however, small pockets of brine have been penetrated during mining and drilling operations. Pockets of gas (nonflammable) and "air" have been penetrated at various depths during drilling of several stratigraphic test holes at the WIPP site. The air or gas was under sufficient pressure to cause unloading (blowouts) of the drilling fluid from the borehole.

Hydrology of the Rustler Formation

The Rustler Formation in the WIPP site area has been divided into five members that are in ascending order: an unnamed lower member, the Culebra Dolomite Member, an anhydrite called the Tamarisk member (Vine, 1963) that is partly altered to gypsum, the Magenta Dolomite Member, and an upper anhydrite called the Forty-niner member (Vine, 1963) (fig. 4). The Tamarisk and Forty-niner members also contain halite in areas where dissolution has not been active. The Magenta and Culebra Dolomite Members at the WIPP site are the most significant units from a hydrologic standpoint and consequently were the most extensively studied.

The Culebra Dolomite Member consists of 25 to 30 feet of microcrystalline dolomite. It characteristically contains many small spherical cavities that range from 2 to 20 millimeters in diameter (fig. 12) and may be partly filled with secondary gypsum and calcite. Although many cavities are open, they do not appear to be interconnected except along fractures. Vine (1963, p. B-14) considers these cavities to be either a primary or a diagenetic phenomenon and not related to weathering in outcrops or secondary solution in the subsurface. In the subsurface, the Culebra is bounded above by anhydrites, which may contain gypsum as thick rinds along



NOTE: Numbers on columns indicate feet below land surface.

Figure 12.--Core sections from hydrologic units of the Rustler and Salado Formations

the contact with the dolomite. These gypsum rinds probably are formed by the movement of water through the dolomite. Underlying the Culebra there is either a clayey halite or a clayey residue, depending on whether the halite has undergone dissolution. Dissolution and removal of this halite bed is directly associated with subsidence, fracturing and the occurrence of permeable zones in the Culebra. In the outcrops, the dolomite may be also locally brecciated or deformed by dissolution collapse.

The Magenta Dolomite Member (fig. 12) ranges in thickness from 20 to 30 feet and is characterized by alternating wavy laminae of silty dolomite and anhydrite (altered in places to gypsum). The dolomite is detrital in origin and is bounded above and below by anhydrite, which may be altered to gypsum along the contact with the dolomite.

A layer of residuum underlies the Rustler Formation in Nash Draw and geologically probably is part of the Salado Formation, but for hydrologic purposes it is considered part of the Rustler Formation. It is a unit composed of clay with crudely interlayered seams of broken gypsum and fine-grained sandstone (Jones, 1973, p. 20) (fig. 12). The clay is considered to be the result of dissolution of clayey halite and other evaporites in the upper part of the Salado. The clay, gypsum, and sandstone comprise a distinctive sequence referred to as the Rustler-Salado residuum. Because it is formed by dissolution, the residuum is quite variable in thickness, especially in Nash Draw. The unit thins eastward, grading into and intertonguing with the halite from which it originated. The residuum thickens westward and crops out at places along the Pecos River.

Exposures of the Rustler along the Pecos River and in Nash Draw are locally deformed, creating an irregular outcrop pattern. This deformation is caused by collapse of the harder, less soluble beds resulting from differential dissolution within the anhydrite, gypsum, and halite of the Rustler and the upper part of the Salado. Generally, the dolomite members are not as susceptible to dissolution as the evaporites; consequently the dolomites are present throughout most of the area. The dolomites commonly are slumped and form draped features in outcrops along Nash Draw, while in other areas they may be broken into discontinuous blocks.

In some areas of Nash Draw, dissolution and erosion has been so extensive that the Magenta and Culebra Dolomite Members are virtually in contact, whereas in a normal stratigraphic sequence they would be separated by as much as 150 feet of red beds and anhydrite. Other evidence of dissolution in the Rustler can be found throughout Nash Draw as indicated by the development of sinkholes and other types of karst topography. Bachman (1981) presents a detailed discussion of these types of near-surface dissolution features. Nash Draw is separated by a low topographic divide from Clayton Basin to the north (fig. 1). A similar type of genesis, that of dissolution collapse accompanied by erosion, also is postulated for this feature.

There has been extensive dissolution of the Rustler Formation in the Malaga Bend area, causing the development of karst mounds (Bachman, 1980, p. 74). As described by Bachman, these mounds and other similar features appear to be controlled more by surficial dissolution in the Rustler Formation than deep-seated geologic processes.

Eastward from the Pecos River, especially east of Nash Draw where the Rustler Formation is covered and protected by the Dewey Lake Red Beds and younger rocks, structures are less chaotic and the Rustler attains a more regular character. In fact, detailed stratigraphy, lithology, and estimates of thickness are obtainable only from drill holes. The geologic section (fig. 5) eastward from Nash Draw identifies the lateral extent of the dissolution front in the Rustler. The structure of the rocks indicates a relatively simple homoclinal dip to the east.

The Rustler Formation ranges in thickness from 300 feet in test hole P-14 at the western edge of the WIPP site to more than 460 feet in P-18 near the southeastern edge of the site. The increase of 160 feet in thickness between P-14 and P-18 may provide an approximate measure of the minimum thickness of halite that is, by dissolution, missing at test hole P-14. The thickness of the Rustler Formation is 330 feet in the northeast part of the study area near test hole AEC-7. Jones (1973, p. 23) believes the difference in formation thickness between the southeast and northeast corners of the area may be depositional in origin because the formation is more thickly bedded in the southeast near test hole P-18. The theory for depositional variation in thickness is enhanced because evaluation of cores from test holes in these areas show no evidence of the dissolution residues common in other areas where the Rustler is thinner. The varying thicknesses shown by a thickness map of the Rustler (fig. 13) represent both changes resulting from dissolution as well as those resulting from the depositional history. This becomes important when describing the hydrologic system because the areas of dissolution have an important bearing on the hydraulic properties of the Rustler Formation and associated rocks.

The hydrologic units of the Rustler Formation have been among the most extensively studied rocks at the WIPP site for two reasons: (1) They are the most productive;and (2) They directly overlie the Salado Formation and could provide a potential avenue for halite dissolution and consequently a means for transporting radionuclides from the proposed repository. Based on a previous study (Mercer and Orr, 1979), the most areally extensive water-bearing units have been identified as the the Culebra Dolomite Member, the Magenta Dolomite Member, and the Rustler-Salado contact residuum. Locally, water also may be found in some of the altered anhydrite units and at places in residue zones where halite has been leached. These occurrences usually are limited to Nash Draw and appear to be discontinous.

A discussion of the hydraulic characteristics logically leads to the division of the study area into two parts: (1) the Nash Draw area southward to Malaga Bend on the Pecos River; and (2) the WIPP site area proper, east of Nash Draw.

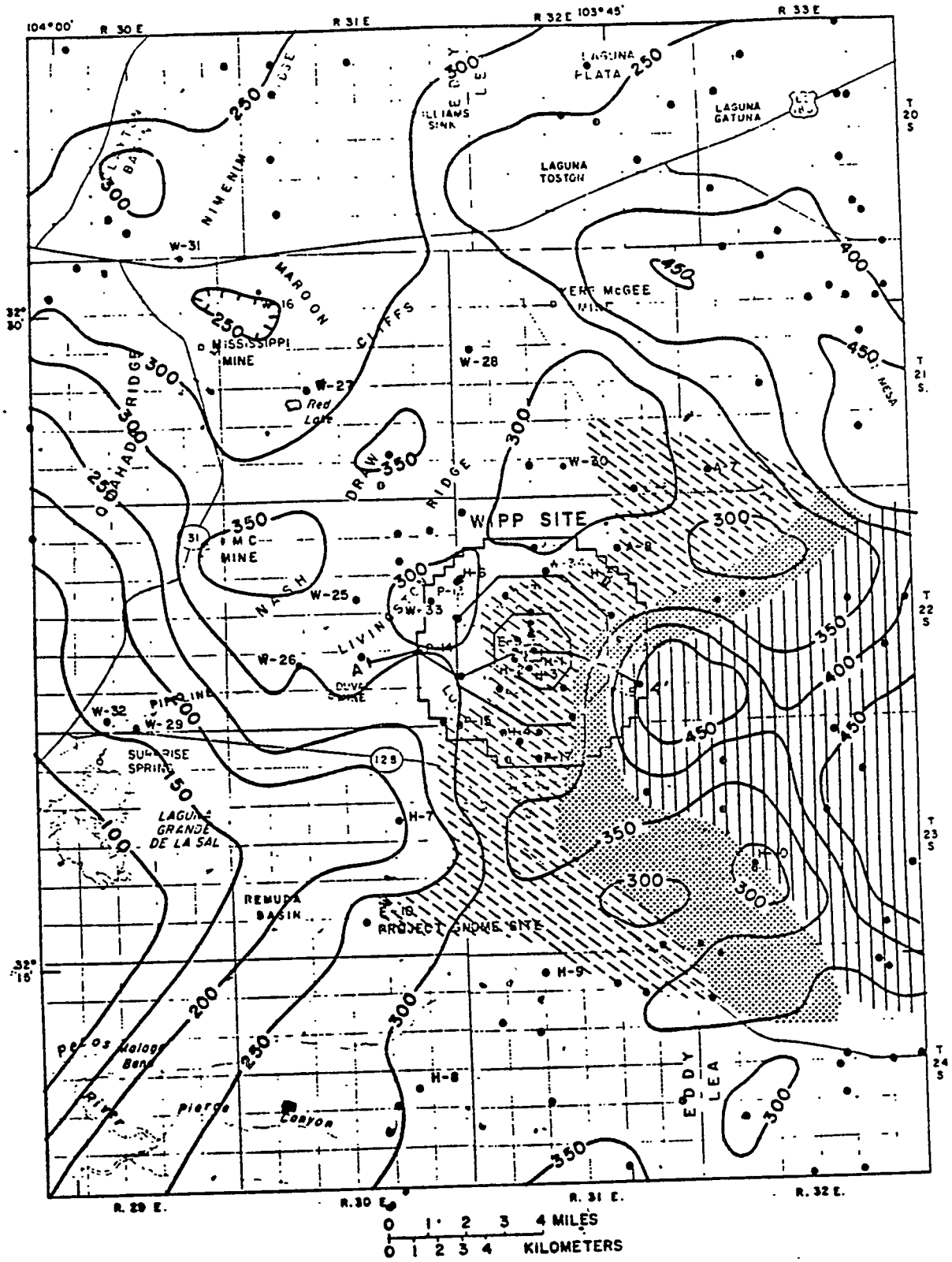


Figure 13.--Presence of halite beds and thickness of the Rustler Formation at and near the proposed Waste Isolation Pilot Plant (WIPP) site.

EXPLANATION

(FOR FIGURE 13)

PRESENCE OF HALITE BEDS IN THE RUSTLER FORMATION

- Above and below both Magenta and Culebra Dolomite Members
- Above and below Culebra Dolomite Member
- Below Culebra Dolomite Member
- None

A ——— A'

LINE OF GEOLOGIC SECTION

—400—

LINE OF EQUAL THICKNESS OF RUSTLER FORMATION--Dashed where approximately located. Interval 50 feet.

DRILL HOLE

NOTE: See figure 5 for section showing top of halite in Rustler Formation.

The hydrologic flow system in Nash Draw is very complex and probably is controlled by geologic factors that caused development of the feature itself. Bachman (1980, p. 52) proposes the process of "solution-and-fill," which was discussed by Lee (1925) as the process responsible for the development of Nash Draw. Bachman describes the process whereby near-surface dissolution occurs as surface and ground water penetrates soluble rocks through joint systems and related fractures. The fractures are widened, developing cavities that either collapse (forming sinks) or subside (causing disruption of the more resistant beds). Collapse and subsidence commonly have been observed in Nash Draw. Arroyos actually disappear along fractures into caves in the gypsum.

Hydrology of the Rustler-Salado contact residuum--Brine in the Rustler-Salado contact residuum, immediately above the top of the salt in the vicinity of Nash Draw, was first described by Robinson and Lang (1938) and referred to as the "brine aquifer." Robinson and Lang (1938, p. 86) suggested that the structural conditions that caused the development of Nash Draw also might control the occurrence of the brine; thus, the "brine aquifer" boundary may coincide with the topographic surface expression of Nash Draw. Their studies show the brine to be concentrated along a strip 2 to 8 miles wide and about 20 miles long (figure 14). Data from the test holes they drilled indicates that the residuum (containing the brine) ranges in thickness from 10 to 60 feet and averages about 24 feet. Hydraulic properties determined by Hale, Hughes, and Cox (1954, p. 22) were computed primarily for the area between Malaga Bend on the Pecos River and Laguna Grande del la Sal. They calculated a value of transmissivity of 8,000 feet squared per day and estimated the potentiometric gradient to be 1.4 feet per mile. In this area, the "brine aquifer" apparently is part of a continuous hydrologic system as evidenced by the coincident fluctuation of water levels in the test holes (as far as Laguna Grande de la Sal) with irrigation pumping rates along the Pecos River (Hale, Hughes, and Cox, 1954, p. 22).

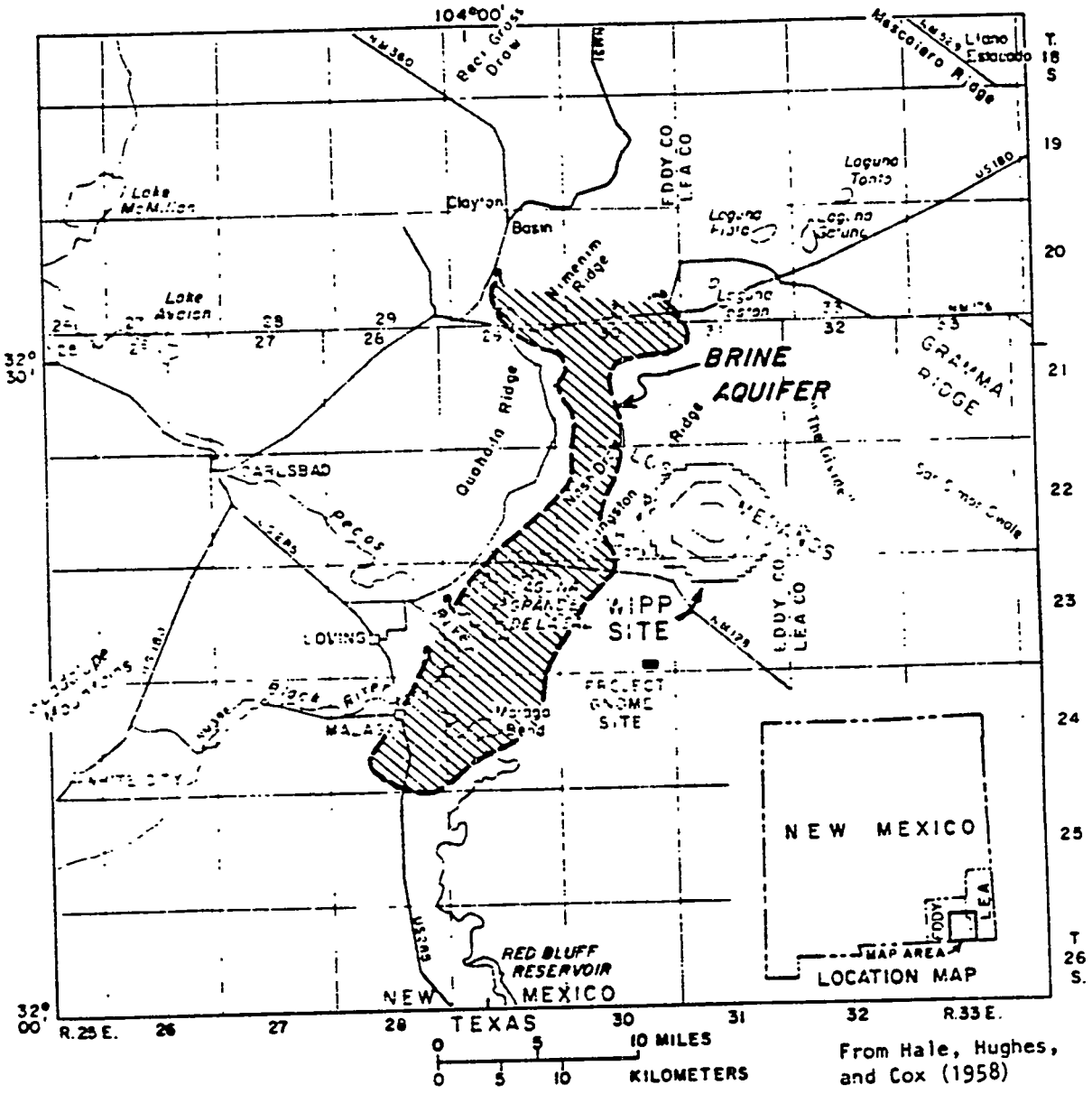


Figure 14.--Approximate areal extent of the "brine aquifer" near the proposed Waste Isolation Pilot Plant (WIPP) site.

In conjunction with the "brine aquifer" study, Robinson and Lang (1938) also made a study of Laguna Grande de la Sal and the area between it and Malaga Bend to determine if brine in the lake was a source of recharge to the system. They determined, at the time of their study, that the sources of the water in the lake were precipitation and surface drainage, ground water inflow from upper units above the "brine aquifer", and effluent from the U.S. Borax and Chemical Company operation. Since that time, the U.S. Borax and Chemical Company plant has been closed; however, there still may be some inflow from mining activities that take place further north in Nash Draw. Robinson and Lang identified several factors that led to their conclusion that the lake and underlying "brine aquifer" were not connected, these factors were: (1) Test holes drilled into the hydrologic units under the lake contained water with a different chemical composition and a much lesser chloride concentration; and (2) Water levels in the fill indicated movement toward the lake and not away from it (in fact, the hydraulic heads were above the lake level in most test holes). Theis and Sayre (1942, p. 71) supported their conclusion because they found water levels in the lake to be high in winter and low in summer, whereas the hydraulic head in the "brine aquifer" is high in the irrigation season and low between seasons.

Discharge of ground water into Laguna Grande de la Sal and probably into the fill is by the flow of springs and seeps, particularly along the northern end. The largest of these springs was indentified by Robinson and Lang (1938 p. 95) and called Surprise Spring (SW¼ NE¼ SW¼ sec. 4, T. 23 S., R. 29 E.), which was reported to discharge 115 to 125 gallons per minute. More recent WIPP studies indicate that the spring and accompanying seeps now discharge over such a broad area that accurate measurements of flow could not be made. This increase in the areal extent of the discharge area indicates an increase in discharge probably resulting from the effects of effluent added by mining activities since Robinson and Lang's (1938) studies. The discharge of the spring probably comes from the cavernous gypsum of the Tamarisk Member of the Rustler Formation even though alternative sources, the Culebra Dolomite Member or the Rustler-Salado contact residuum, have been proposed. Data from more recent WIPP investigations would indicate that the water chemistry and hydraulic-head information identify the source of the water to be something other than the Culebra or the residuum. Analyses of water samples from the Culebra Dolomite Member and Rustler-Salado contact residuum in test hole WIPP-29 (fig. 1A) near Surprise Spring indicate a considerable difference in both sodium and chloride concentrations when compared to Surprise Spring. There is 2.5 times more calcium in the water discharging from Surprise Spring. Additionally, hydraulic-head data from a potash test hole drilled by Amoco in Laguna Grande de la Sal (T. 23 S., R. 29 E., sec. 4) shows the Culebra to have a hydraulic head about 21 feet above lake level, indicating a confined system although there maybe some minor upward leakage. The Culebra was confined under about 40 feet of gypsum mud and flowed at a rate of approximately 20 gallons per minute when first penetrated during drilling activities. This evidence indicates that neither the water present in the Culebra Dolomite Member nor in the Rustler-Salado residuum is in good hydraulic connection with the brine from the Spring flowing into Laguna Grande de la Sal and that the most likely source is from the Tamarisk Member.

In the northern one-half of Nash Draw, the approximate outline of the "brine aquifer" (Rustler-Salado contact residuum) as described by Robinson and Lang (1938) (fig. 14) has been supported by drilling associated with the WIPP geotechnical studies. These studies also indicate that the main differences in areal extent occur along the eastern side where the boundary is very irregular and in places (test holes P-14 and H-7) extends further east than previously indicated by Robinson and Lang.

Other differences from the earlier studies include the variability in thickness (table 1) of residuum as seen in test holes W-25 to W-29. These holes indicate thicknesses ranging from 11 feet in test hole W-26 to 108 feet in test hole W-29 in Nash Draw compared to 8 feet in test hole P-14 east of Nash Draw. The specific geohydrologic mechanism that has caused dissolution to be greater in one area than in another is not apparent although a general increase in chloride concentration in water from the north end to the south may indicate the effects of movement down the natural hydraulic gradient (table 2).

The historical data concerning hydraulic properties collected from the Rustler-Salado contact residuum are concentrated in the area from north of Laguna Grande de la Sal south to Malaga Bend. The data discussed in this report and collected for the WIPP regional hydrologic studies are from the Nash Draw area generally north of Laguna Grande de la Sal to the Maroon Cliffs, west to Quahada Ridge and east of Nash Draw (including the WIPP site) to The Divide (fig. 1).

A potentiometric-surface map for the hydrologic unit of the Rustler-Salado contact residuum is based on data from both the Rustler-Salado contact residuum of Nash Draw and the residual brine at the contact of the Rustler and Salado Formations east of Nash Draw in the WIPP site area. The map data are adjusted for the effects of variations in water chemistry, which create density differences. As discussed under the methods of investigation, the static heads represented by water levels in the wells were adjusted to a common density of 1.00 (freshwater equivalent, table 6). The potentiometric-surface map, representing freshwater equivalent heads, is shown in figure 15. The contours on this map represent the approximate values of static head and show the variance in gradients between Nash Draw and the area of the WIPP site. The average hydraulic gradient in Nash Draw is about 10 feet per mile; in contrast, at the WIPP site the average gradient is 39 feet per mile. This difference reflects the changes in transmissivity which are as much as five orders of magnitude greater in Nash Draw. The transmissivity determined from aquifer tests in test holes completed in the Rustler-Salado contact residuum of Nash Draw, including test holes P-14 and H-7C (table 7), ranges from 2×10^{-4} foot squared per day at test hole W-27 to 8 feet squared per day at test W-29. This is in contrast to the WIPP site proper where transmissivities range from 3×10^{-5} feet squared per day at test hole P-18 and H-5C to 5×10^{-2} feet squared per day at test hole P-14.

The potentiometric-surface map of the hydrologic unit of the Rustler-Salado contact residuum gives evidence that there are two areas of considerably different permeability. The zone of greater permeability is associated with the residuum (brine aquifer) of Nash Draw, where flow is primarily through associated fractures and the intergranular spaces of the clay and gypsum. In contrast, brine underlying the WIPP site east of Nash Draw occurs in a zone of minute permeability along the contact between the Salado Formation and the overlying Rustler Formation (bedding-plane flow).

As stated earlier, potentiometric-surface maps can be useful in showing the areal variations in hydraulic gradient from which a general trend in movement can be inferred. Inspection of the potentiometric-surface map for the hydrologic unit of the Rustler-Salado contact residuum indicates that the apparent ground-water flow is southwest across the WIPP site towards Nash Draw and then south-southwest down Nash Draw toward Malaga Bend (fig. 15).

Although caution should be used in making interpretations of the hydraulic-head distribution in the WIPP site for the hydrologic unit of the Rustler-Salado contact residuum, the inferred flow direction probably is valid. Static-head interpretations of the Rustler-Salado contact residuum within the area of the WIPP site are complicated by variations in water chemistry and its effects on density and by the great length of time required during testing to establish static conditions in test holes because of the minute permeabilities.

The calculations of the rate of movement of water in the Rustler-Salado contact residuum are complicated by the variations in permeabilities as well as in the hydraulic gradient. The rate of movement of 0.2 foot per day was calculated by Hale and Clebsch (1958, p. 11) for the residuum (brine aquifer) south of Laguna Grande de la Sal. Assuming, as they did, an average effective porosity of 0.2, an average hydraulic conductivity of 0.15 foot per day, and a hydraulic gradient of 10 feet per mile, the flow rate for the section from Maroon Cliffs to Laguna Grande de la Sal would be 0.002 foot per day, assuming that the residuum behaves as a uniform porous medium. Although the hydraulic characteristics of the Rustler-Salado contact residuum are variable, this rate probably is a conservative value. The rate of movement in the Rustler-Salado contact residuum at the WIPP site has not been determined because the hydraulic properties are extremely variable and because of the lack of a valid value for the effective porosity. Water-quality data, in particular the large concentrations of magnesium and potassium, indicate an extremely slow rate of movement with long periods of rock-water contact.

The area of recharge suggested by Lang (Robinson and Lang, 1938, p. 86) is in the area of Bear Grass Draw (T. 18 S., R. 30 E.), some 30 miles north of Malaga Bend. He suggests that water percolating into the ground may pass into the truncated lower part of the Rustler Formation and then migrate south and east into Nash Draw, gradually dissolving salt in the Salado Formation. Data from WIPP regional studies indicate a hydraulic gradient from the north

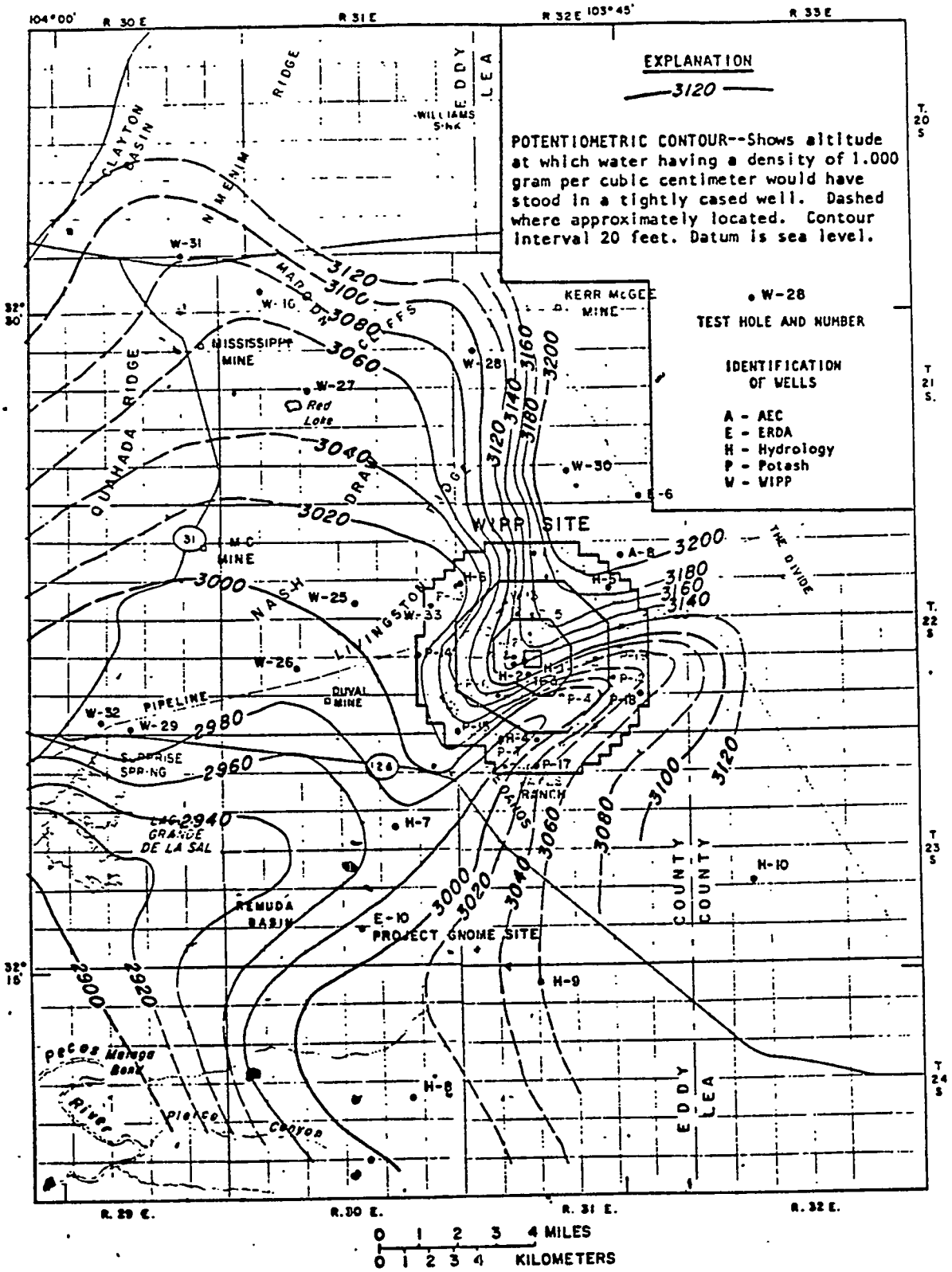


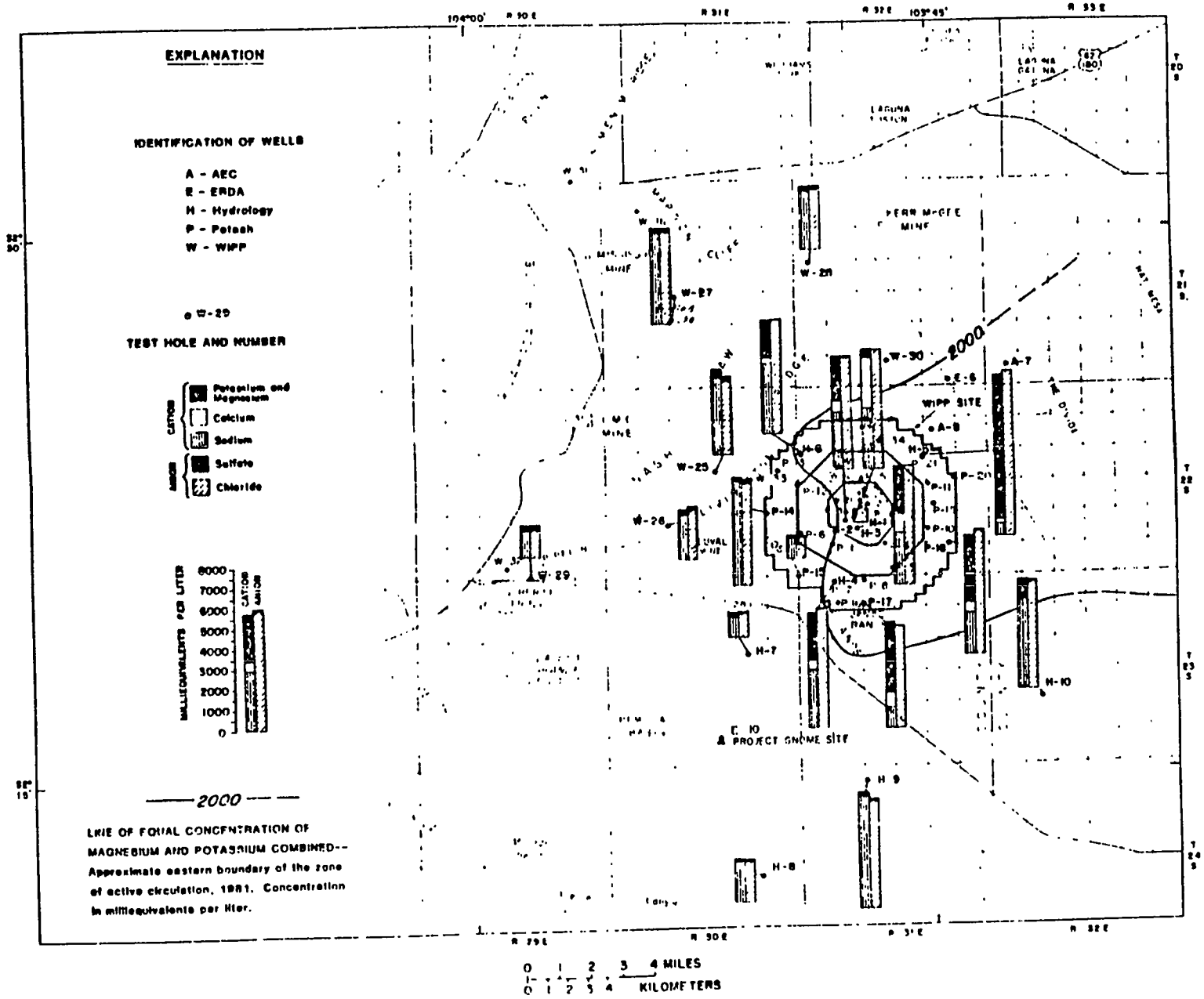
Figure 15.--Adjusted potentiometric surface of the Rustler-Salado contact residuum (1982 at and near the proposed Waste Isolation Pilot Plant (WIPP) site.

and that the Bear Grass Draw area may be a possible area of recharge. There also is a possibility of some recharge occurring in Clayton Basin and Nash Draw.

Hale, Hughes, and Cox (1958, p. 23) believed the Rustler-Salado contact residuum discharges to the alluvium near Malaga Bend on the Pecos River. Because the confining beds in this area probably are fractured due to dissolution and collapse of the evaporites, the brine (under artesian head) moves up through these fractures into the overlying alluvium and then discharges into the Pecos River. Theis and Sayre (1942, p. 69) estimated that the discharge rate was about 200 gallons per minute and that in the Malaga Bend area about 342 tons of sodium chloride per day were discharged to the river, presumably all coming from the "brine aquifer".

Although the potentiometric-surface map (fig. 15) indicates a potentiometric high to the east of the WIPP site, there is not sufficient data to determine its origin. Suggestions have been made that there could be leakage from the overlying Culebra in this area; however, to accomplish this leakage the water would have to move through 80 feet of clay and silt and a 25-foot-thick anhydrite bed. Drilling at the WIPP site has not revealed any fractured anhydrite that could increase the vertical permeability, allowing water to move into the Rustler-Salado contact residuum, nor is there any indication that the water has altered the anhydrite to gypsum. Additionally, the hydraulic-head difference between the two hydrologic units (tables 6 and 9), as much as 400 feet in test hole H-1, coupled with the water-quality difference (table 2), would tend to indicate the zones are isolated and confined systems. The apparent high at test hole H-5 could be due to the conversion of the dense brine to equivalent freshwater head.

Evidence for very slow ground-water movement is found in the water quality, especially in the magnesium concentrations. Large magnesium concentrations appear to be indicative of an environment in which ground-water flow is extremely slow and there has been extensive interaction between the water and its host rock. Large concentrations of magnesium, ranging from 21,000 milligrams per liter in water from test hole H-6 to 82,000 milligrams per liter in water from test hole H-5, were present in most of the test wells in the eastern part of the WIPP site (table 2). Aquifer tests at these test holes were characterized by minute transmissivities (table 7). To the west, approaching the more developed part of the flow system of the Rustler-Salado contact residuum in Nash Draw, the magnesium concentrations decreased by 1 to 2 orders of magnitude (fig. 16). Magnesium concentrations of 1,200 milligrams per liter in water from test hole P-14 and 350 milligrams per liter in water from test hole P-15 may indicate the eastern boundary of the more developed Rustler-Salado flow system. Magnesium concentrations are as little as 430 milligrams per liter in water from test hole H-8; other values range from 910 milligrams per liter in water from test hole H-7 to 3,200 milligrams per liter in water from test hole W-25. Based on the chemical analyses, the magnesium concentration in the brine could be used to outline the zone of active circulation (fig. 16) (see hydrochemistry section on the Rustler Formation).


EXPLANATION
IDENTIFICATION OF WELLS
A - AEC
E - ERDA
H - Hydrology
P - Potash
W - WIPP
TEST HOLE AND NUMBER
Potassium and Magnesium
Calcium
Sodium
Sulfate
Chloride
CATIONS
ANIONS
MILLIEQUIVALENTS PER LITER
2000
LINE OF EQUAL CONCENTRATION OF MAGNESIUM AND POTASSIUM COMBINED--Approximate eastern boundary of the zone of active circulation, 1981. Concentration in milliequivalents per liter.
WIPP SITE
H-10
H-8
H-9
H-7
H-3
W-30
W-29
W-27
W-26
W-25
P-17
P-14
P-15
P-18
P-20
A-7
A-8
E-6
H-6
H-5
H-4
H-2
H-1
P-1
P-2
P-3
P-6
P-11
P-12
P-13
H-11
H-12
H-13
H-14
H-15
H-16
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H-29
H-30
H-31
H-32
H-33
H-34
H-35
H-36
H-37
H-38
H-39
H-40
H-41
H-42
H-43
H-44
H-45
H-46
H-47
H-48
H-49
H-50

Water at the Rustler-Salado contact, or in the residuum, contains the largest concentrations of dissolved solids in the WIPP area, ranging from 41,500 milligrams per liter in test hole H-1 to 412,000 milligrams per liter in test hole H-5C. These waters are classified as brines. The areal distribution of major chemical constituents in water is shown in figure 16. The general chemical composition of the brine collected from the Rustler-Salado contact residuum also is listed in table 2; the major dissolved cations and anions are listed in table 8 and expressed in milligrams per liter, milliequivalents per liter, and percentage composition.

The dissolved mineral constituents in the brine largely consist of sulfates and chlorides of calcium, magnesium, sodium, and potassium; the major constituent is sodium chloride. Concentrations of the other major ions vary according to the spatial location of the sample and probably are directly related to the interaction of the brine and the host rocks and reflect as a residence time within the rocks. Residence time of the brine depends upon the transmissivity of the rock. For example, the presence of large concentrations of potassium and magnesium in water is correlated with minimal permeability and a relatively undeveloped flow system.

The dissolved-solids, magnesium, and potassium concentrations of the ground water increase from west to east in the WIPP area. An arbitrarily chosen line of equal concentration representing 2,000 milligrams per liter of potassium and magnesium combined (fig. 16) approximates a dividing line between zones of generally small concentrations to the west and rapidly increasing concentrations to the east. This same line, when viewed in terms of values of transmissivity, represents a division between areas of minute transmissivity (less than 1×10^{-3} foot squared per day) and areas of greater transmissivity (more than 1×10^{-1} foot squared per day). This line indicates a division between the more developed flow system with accompanying evaporite dissolution and the minimally developed flow system in which ground-water movement, if any, is restricted to openings along bedding planes. A general lack of residuum to the east of this line, which indicates dissolution of the underlying Salado halite has not occurred, is further evidence that this area is not part of the more developed flow system.

Hydrology of Culebra Dolomite Member of the Rustler Formation--The Culebra Dolomite Member of the Rustler Formation ranges from 25 to 30 feet in thickness and is the most persistent and productive hydrologic unit in the area. In the WIPP site, the Culebra is a vuggy, finely crystalline dolomite that is present below the thick anhydrite of the Tamarisk Member, which in Nash Draw is mostly altered to gypsum. Water in the dolomite usually is present in fractures and is confined by the overlying gypsum or anhydrite and the underlying clay and anhydrite beds. The water may be under water-table conditions in the area south of Laguna Grande del la Sal where the Culebra has been subjected to solutional activity that has caused the confining beds to be extremely fractured and altered.

The structural character of the Culebra is related directly to the degree of dissolution. In Nash Draw, the Rustler Formation has undergone considerable deformation due to dissolution of parts of the evaporites and removal of halite from the underlying halite beds of the Salado. The effects of dissolution can be seen in some areas where large discontinuous blocks of Culebra are near the surface and have steep, erratic dips. In other areas, the Culebra is continuous and forms draped features. The Culebra crops out along the Pecos River in the Malaga Bend area. In those parts of the area east of Nash Draw where the Rustler is overlain by the Dewey Lake Red Beds and younger deposits, the dissolution effects have not been nearly as great and the structure of the Culebra is relatively regular.

In the WIPP site area there is a structural high clearly shown by contours drawn on the top of the Culebra Dolomite Member (Jones, Cooley and Bachman, 1973, p. 50). These contours outline an anticline in the northeastern part of T. 22 S., R. 32 E.; the anticline plunges to the southeast across the central part of the township. Excluding other minor structural irregularities, the overall gentle dip of the Culebra is to the east.

Hydraulic properties of the Culebra Dolomite Member, as determined by testing, vary considerably from place to place and appear to be related to the size and number of fractures and the size of the fracture openings. As previously mentioned, these fractures and openings are related to the degree of evaporite dissolution occurring either in the Rustler or the upper part of the underlying Salado Formation. The potentiometric-surface map, representing equivalent freshwater heads (table 9), is shown in figure 17.

The contours on the map indicate a variability in gradient as well as flow direction for different parts of the region. The gradient variability may reflect lateral variations in permeability within the Culebra Dolomite Member caused by local differences in the number and spacing of fractures. The flow direction may be variable. This variability may be caused by differences in fracture orientation in areas of greater permeability. The gradient in Nash Draw northeast of test hole W-29 is about 16 feet per mile, whereas, southwest of test hole W-29 it is 5 feet per mile. The gradients in the WIPP site area vary considerably, generally being about 7 feet per mile in the central part and 20 feet per mile in the northern and southern parts. The contours also indicate a potentiometric high near test hole H-5, which may reflect the effects of the conversion of brine density to freshwater head. The broad area south of WIPP, where gradients appear to be extremely flat, may represent the transition from an area of fractured dolomite to that of a fractured and disrupted unit created by the extensive dissolution in the Nash Draw area.

Calculated values of transmissivity for the Culebra are based on the assumption of flow in porous media; because flow probably takes place along fractures, these values need to be used with care. It is believed, however, that the porous-media assumption should approximate flow conditions in the

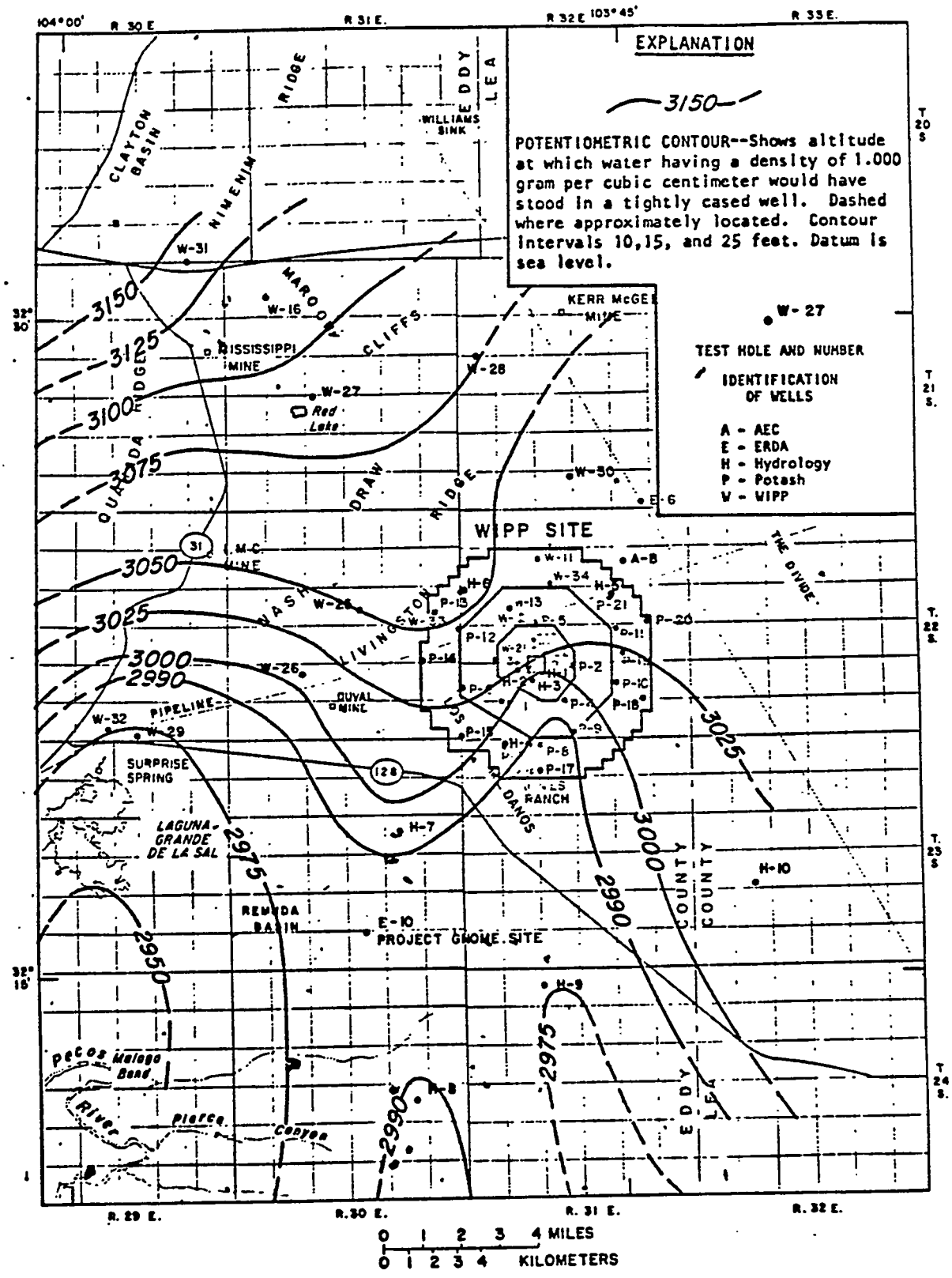


Figure 17.--Adjusted potentiometric surface of the Culebra Dolomite Member of the Rustler Formation (1982) at and near the proposed Waste Isolation Pilot Plant (WIPP) site.

Culebra because the dolomite is thin and the fractures probably are closely spaced (fig. 18). Although the fracturing shown in figure 18 is associated with halite removal on the outcrop, areas of halite dissolution in the subsurface probably have similar fractures. Values of transmissivity for tests from 20 of the test holes drilled during WIPP investigations are included in table 7.

Transmissivities calculated for the Culebra in Nash Draw range from 18 feet squared per day (Gonzalez, 1983) on the north end at test hole W-28 to 1,250 feet squared per day at test hole W-26 west of the WIPP site. These compare with a value of 535 feet squared per day calculated for the Culebra at the Project Gnome site (fig. 1A) (Cooper, 1962a, p. 37).

Hydraulic properties also were determined by laboratory tests of samples of the Culebra Dolomite Member taken from the Project Gnome shaft. One sample from a depth of 505 feet had a total porosity of 14.4 percent and an effective porosity of 7.8 percent, while a sample from 515 feet had a total porosity of 13.7 percent and effective porosity of 11.1 percent. The average effective porosity of 10 percent compares with the 12 percent value obtained by Grove and Beetem (1971) for a tracer test conducted on the Culebra in the same area.

Transmissivities calculated for the Culebra Dolomite Member in the WIPP site area range from 1×10^{-3} foot squared per day at test hole P-18 to 140 feet squared per day at test hole P-14 and generally are less than 1 foot squared per day (table 7). Most of these values are several orders of magnitude less than those in Nash Draw. Smaller transmissivities probably signify that less dissolution has occurred in the halite beds below the Culebra and upper part of the Salado Formation. Greater permeability has been noted where a silty residue is present immediately below the Culebra. This residue results from dissolution of a clayey halite bed below the Culebra, which caused subsidence and fracturing in the dolomite.

Transmissivity values calculated from tests in two test holes in the WIPP site area are much larger than the average; these test holes are H-6B, with a transmissivity of 73 feet squared per day, and P-14, with a transmissivity 140 feet squared per day. Both of these test holes are on the western side of the WIPP site along Nash Draw. Geologic data from cores from these test holes indicate that the large transmissivity values may be related to localized dissolution in the Rustler Formation or upper part of the Salado Formation. Although not expressed topographically at the surface, these large values may indicate an eastward subsurface extension of the geologic processes that formed Nash Draw. Approximately 8 feet of residuum was penetrated at the base of the Rustler in test hole P-14 and about 2 feet of residuum was penetrated in test hole H-6B. The transmissivity of the Rustler-Salado contact residuum in these test holes also is the largest in the WIPP site area. A similar occurrence was found south of the WIPP site in test hole H-8B where the transmissivity was calculated to be 16 feet squared



Figure 18.--Outcrop of Culebra Dolomite Member of Rustler Formation where removal of underlying halite has caused fracturing.

per day and in test hole H-9B where the value was 231 feet squared per day (table 7). Because of these large values of transmissivity it also is possible, as in the case of test holes H-6B and P-14, that the geologic processes active in Nash Draw also may be occurring here.

When the distribution of halite beds in the Rustler Formation (fig. 13) is compared to the distribution of transmissivity across the WIPP site, it appears that dissolution of the halite in the lower part of the Rustler Formation is related to the permeability changes in the Culebra Dolomite Member. As these halite beds below the Culebra are dissolved, subsidence occurs, creating fractures in the dolomite which open up and allow movement of water. No fractures were noted in the overlying anhydrite in cores from most of the WIPP site test holes; thus, the Culebra is assumed to be effectively isolated from overlying water-producing zones east of the site, however, west of the site fracturing may create some interconnection. It is generally accepted that the extensive dissolution in the Rustler Formation in Nash Draw is responsible for the permeability increases in the Culebra in this area.

The direction of ground-water movement in fractured rock, such as the Culebra Dolomite Member, is affected by directional differences in hydraulic conductivity (anisotropy); consequently, the regional direction of flow may have little or no relationship to the localized direction of flow indicated by the contours on the potentiometric-surface map. In Nash Draw the Culebra hydrologic unit is so extensively fractured that there may not be directional differences in hydraulic conductivity. Based on this premise and an inspection of the potentiometric-surface map, the flow trend in Nash Draw generally is southward toward Malaga Bend. Local flow paths in the area of the WIPP site, however, may not be as easy to determine. Because it was concluded that the ground-water flow in the Culebra at the WIPP site was in fractures, it became evident that further studies of the ground-water system were needed. Therefore, several hydrologic test holes penetrating the Culebra at the WIPP site were selected by project personnel for site-specific tracer and aquifer tests. These tests will determine the degree of anisotropy, effective porosity (for rate calculations), dispersivity, and transmissivity. The study is being conducted by Sandia National Laboratories and is in progress at the time of this report (1983); thus, any further evaluation of the flow system would be premature.

Based on water-quality data (table 2), hydraulic head differences (tables 7, 9, and 10), and analyses of cores taken from the hydrologic test holes in the WIPP site area, probably no effective vertical connection exists between the Culebra Dolomite Member and the underlying and overlying hydrologic units. In test hole H-3 near the site center, the stabilized hydraulic head in the Culebra is 155 feet lower than that in the overlying Magenta Dolomite Member and is 480 feet higher than the hydraulic head in the underlying hydrologic unit of the Rustler-Salado contact residuum. In the northwest part of the WIPP site at test hole H-6, the hydraulic head difference between the Culebra and Magenta is only 2 feet, however,

differences in the sodium and chloride concentrations in the water from the two units at test holes H-6A and H-6B indicate that vertical flow probably is very small. The dissolved sodium concentration in water from the Culebra was 18,000 milligrams per liter compared to 1,100 milligrams per liter in the Magenta; the chloride concentration was 28,000 milligrams per liter in the Culebra and 1,200 milligrams per liter in the Magenta.

In test hole W-25 in the north part of Nash Draw, the static-head difference between the Culebra and Magenta is 4 feet; the sodium concentration in the Culebra was 5,100 milligrams per liter and in the Magenta it was 3,100 milligrams per liter, whereas the chloride concentration in the Culebra was 8,300 milligrams per liter and in the Magenta it was 5600 milligrams per liter. These minimal hydraulic head differences and similar sodium and chloride concentrations, along with similar values of transmissivity (Culebra, 270 feet squared per day; and Magenta, 375 feet squared per day), suggest localized vertical interconnection in the north end of Nash Draw.

From test hole W-29 south to Malaga Bend, places probably exist where the Rustler-Salado contact residuum and Culebra may be interconnected (the Magenta has been stripped by erosion); however, data are insufficient in this area to verify this possibility. A geochemical study to quantify the degree of interconnection currently (1983) is being conducted by Sandia National Laboratories.

The Culebra was unsaturated in the ERDA-6 and AEC-7 test holes to the northeast of the site. Similar information has been reported for the area along Quahada Ridge west of Nash Draw. These data may identify permeability boundaries in the Culebra Dolomite to the west and northeast.

The potentiometric-surface contours shown in figure 17 indicate a recharge area for the Culebra Dolomite to the north and northwest of Nash Draw. Like the hydrologic unit of the Rustler-Salado contact residuum, one potential area of recharge would be in the vicinity of Bear Grass Draw (T. 18 S., R. 30 E.), where the beds of the Rustler are truncated and downward percolating water could enter the Culebra. Although conclusive data are lacking, some recharge may be occurring in the area of Clayton Basin, where dissolution and collapse have disrupted beds in the Rustler Formation.

The discharge from the Culebra Dolomite Member probably is in the area south of Laguna Grande de la Sal near Malaga Bend, where the Culebra and overlying beds are significantly fractured. The ground water in this area probably is under water table or slightly confined conditions with flow eventually discharging to the Pecos River. Some potential discharge to the Cenozoic deposits has been suggested to the east of Nash Draw (Tps. 25 and 26 S., RS. 30 and 31 E.) (Cooper, 1962b, p. E152); however, if the discharge does occur, it is probably minimal. The currently (1983) available data are not sufficient in this area to draw any positive conclusions; therefore future studies may be warranted.

Use of water from the Culebra Dolomite is quite limited because of the variability of yields and the marginal water quality. Where the water quality is acceptable, water from the Culebra is used for stock watering, but rarely for domestic purposes.

The dissolved solids in waters associated with the Culebra Dolomite Member range in concentration from 2,950 milligrams per liter at test hole H-8B to 239,000 milligrams per liter at test hole W-29; the water quality from test hole W-29 may be affected by effluent from the mining activities in Nash Draw. The water is classified as being slightly saline to brine.

The areal distribution of major chemical constituents in water from the Culebra is represented by bar graphs in figure 19. The general chemical composition of the water collected from the Culebra is listed in table 2. Major dissolved cations and anions, expressed in milligrams per liter, milliequivalents per liter, and percentage composition are presented in table 8.

The dissolved mineral constituents in the water from the Culebra consist largely of sulfates and chlorides of calcium, magnesium, sodium and potassium; the major constituents are sodium and chloride. The other predominant ions depend on the areal location of the water within the Culebra. The hydraulic characteristics of the Culebra have a bearing on the residence time of the water in the rocks; the residence time affects the concentration and type of dissolved constituents in the water. The potassium and magnesium concentrations are related to the transmissive characteristics of the rocks and the rate of circulation.

The mineralization of water in the Culebra increases from west to east across the WIPP area; the combination of potassium and magnesium also increases (fig. 19). An arbitrarily chosen line of equal concentration representing 100 milligrams per liter of potassium and magnesium combined (fig. 19) approximates not only a dividing line between active and restricted circulation systems, but also approximately coincides with a line to the east of which halite is present in the Rustler Formation below the Culebra and to the west of which the halite beds have been removed by dissolution. As previously mentioned, the removal of these halite beds has caused an increase in the transmissivity of the dolomite. Although not as obvious in the Culebra as at the Rustler-Salado contact residuum, this line divides the area into zones where transmissivities generally are greater than 1 foot squared per day to the west and are generally less than 1 foot squared per day to the east. Even though this division is arbitrary, it does relate the water chemistry to the existing ground-water flow system.

Hydrology of Magenta Dolomite Member of the Rustler Formation--The Magenta Dolomite Member of the Rustler Formation is a persistent and distinctive clastic carbonate bed with thin laminae of anhydrite. The Magenta ranges in thickness from 20 to 30 feet and is present throughout most of the study area. The Magenta is the uppermost water-producing horizon in the Rustler

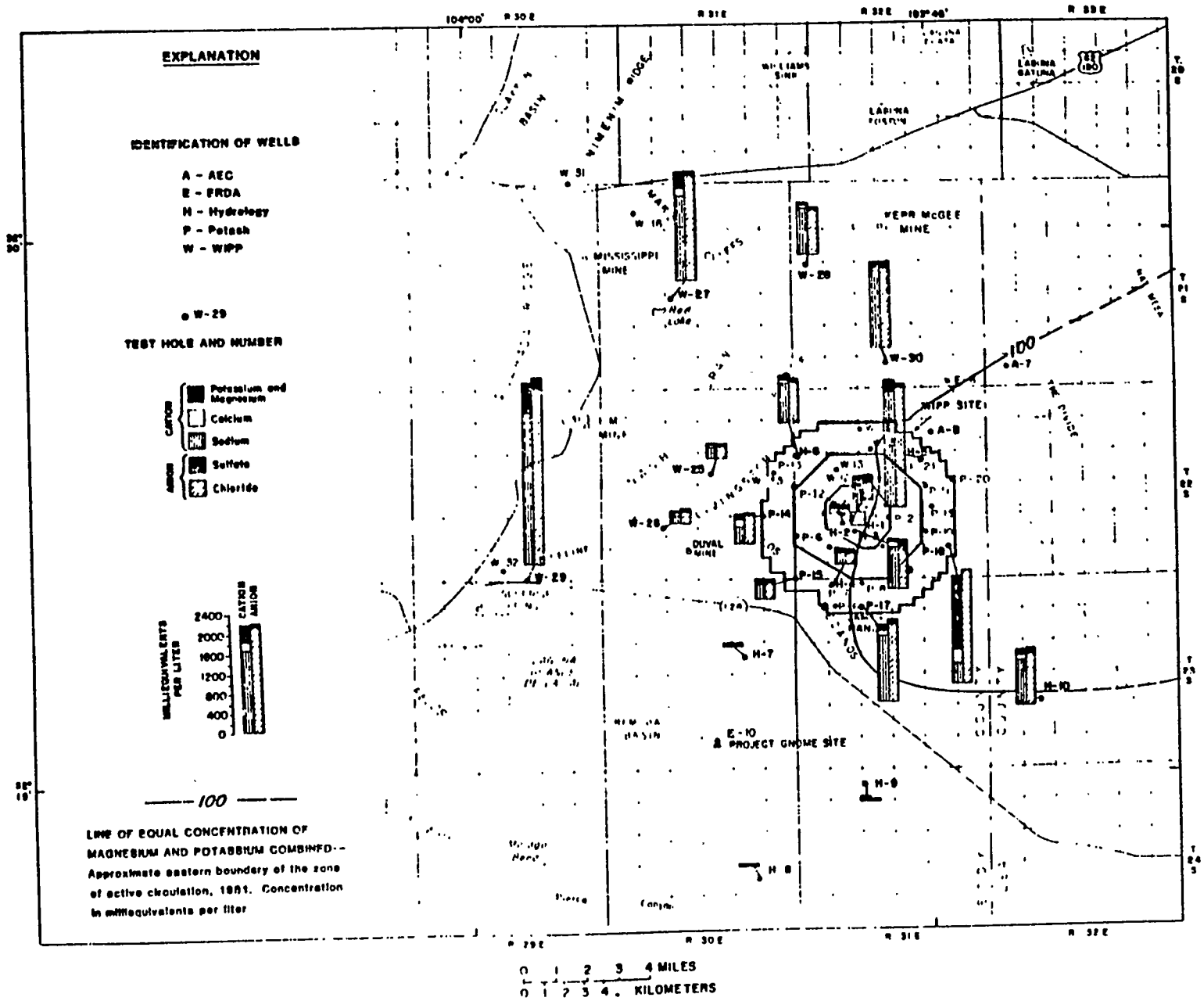


Figure 19.--Concentrations of major chemical constituents in water from the Culebra Dolomite Member of the Rustler Formation at and near the proposed Waste Isolation Pilot Plant (WIPP) site.

Formation. Stratigraphically, it occurs between the thick anhydrite beds of the Tamarisk and Forty Niner Members (fig. 4). Water, when present, usually occurs in the thin silt beds or silty dolomite but also has been found along bedding planes between rock units and in fractures. The Magenta, where it was tested, was always under confined conditions except where it was extensively fractured and altered. In test holes H-7A, W-26, and W-28 the dolomite was virtually unsaturated and was extensively fractured; the underlying anhydrite was fractured and in places altered to gypsum. The water formerly present in the Magenta in this area probably drained through the fractures into the underlying units.

The structure of the Magenta Dolomite, particularly in Nash Draw, is related to the presence or absence of evaporite dissolution. The Magenta in the northern and central parts of Nash Draw and along the eastern boundary is present in the subsurface as a relatively continuous bed; however, in the vicinity of test hole W-29 and south to Malaga Bend, most of the Magenta has been stripped by erosion. There are isolated blocks scattered throughout this area; the Magenta is present along the sides of karst sinks and in other collapsed features as breccia. The breccia mounds shown on Bachman's (1980) maps, particularly in T. 22 S., R. 29 E., sections 33 and 34, are excellent examples of this type of occurrence. These same features were described by Vine (1963, p. B-41) as domal structures.

Outcrops of the Magenta are present along the western side of Nash Draw below Quahada Ridge. Although relatively continuous, they do show effects of weathering and are quite fractured and are not saturated. A reasonable conclusion is that the dissolution responsible for the formation of Nash Draw fractured the Magenta and brecciated the underlying anhydrite, subsequently draining the water into lower units. These fractures later were filled with secondary minerals. Evidence for this type of occurrence can be found in the cores taken from test holes in the area. An isolated occurrence of spring remnants was found along Livingston Ridge (Bachman, 1981, p. 5). These spring deposits are represented by a northeast-trending alignment of gypsite mounds (east 1/2 of sec. 15, T. 22 S., R. 30 E.). The spring deposits are believed by Bachman to have resulted from the evaporation of sulfate-bearing water that had drained from the surface through fractures in the Rustler Formation, particularly in the vicinity of test hole W-33. An additional source for the water could be from subsurface drainage from the fractured Magenta.

To the east of Nash Draw, in the vicinity of and including the WIPP site, the Magenta generally dips gently to the east.

Although some flow along Livingston Ridge may be in fractures, the core samples and hydraulic tests at the WIPP site indicate the flow in the Magenta probably is within the silt beds and the silty dolomite, with some minor flow along bedding planes. Fracture flow probably is predominant in Nash Draw.

The potentiometric map (fig. 20), representing freshwater equivalent heads (table 10), indicates a flow system with some variability in permeability across the WIPP site. The contours show the gradient across this area to be about 16 feet per mile on the eastern side and steepening to about 32 feet per mile along the western side near the boundary of Nash Draw. This steepening of gradient may reflect the drainage of ground water from the Magenta into lower units through the fractures associated with Nash Draw dissolution activity or may only reflect a decrease in permeability. The gradient in Nash Draw of 13 feet per mile indicates a more uniform permeability than at the WIPP site. The Magenta, as an identifiable continuous bed, is not present below the central part of Nash Draw because erosion has removed it and the beds overlying the Rustler Formation down to the Tamarisk Member.

Values of transmissivity for the Magenta Dolomite Member are included in table 7. In Nash Draw, these values range from 53 feet squared per day in test hole W-27 to 375 feet squared per day in test hole W-25; the large values probably are the result of increased permeability in fractured rock. The transmissivity calculated for test hole W-25 is the largest value recorded in the region for the Magenta; this test probably was affected by vertical leakage along fractures that connect with the underlying Culebra. The Magenta is unsaturated in test hole W-26 as a consequence of fracturing caused by dissolution in lower beds. These fractures drained water from the unit; however, core analyses have indicated that these fractures were later filled with gypsum. Evaluation of the core from test hole W-28 indicated that bedding-plane partings and fractures were filled with gypsum, which would significantly decrease the permeability; vertical fracturing was not as evident as in test hole W-26. The Magenta also was unsaturated in test hole H-7A at the margin of Nash Draw south of the WIPP site. The ground water at test hole H-7A also probably drained into lower units; the subsequent alteration of the rocks considerably decreasing the vertical permeability. The core showed that this dolomite has been altered extensively to a partly cemented dolomite mud with the thin anhydrite beds having been altered to gypsum. Like the other cores, secondary filling of gypsum sealed the fractures.

Hydraulic tests for the Magenta in the WIPP site area were conducted in seven test holes; transmissivity values from these tests ranged from 4×10^{-3} foot squared per day in test hole W-30 to 3×10^{-1} feet squared per day in test hole H-6A (table 7). Hydraulic tests from the regional test holes south of the site showed that the transmissivity ranged from 6×10^{-3} foot squared per day in test hole H-8A to 1.0 foot squared per day in test hole H-9A (table 7).

The contours on the potentiometric-surface map for the Magenta Dolomite Member (fig. 20) indicate that water moves westward across the WIPP site towards Nash Draw, where it probably flows through fractures into lower units. In the northeast end of Nash Draw, the water flow generally is to the southwest, probably moving down through fractures into lower units in the central part of the draw.

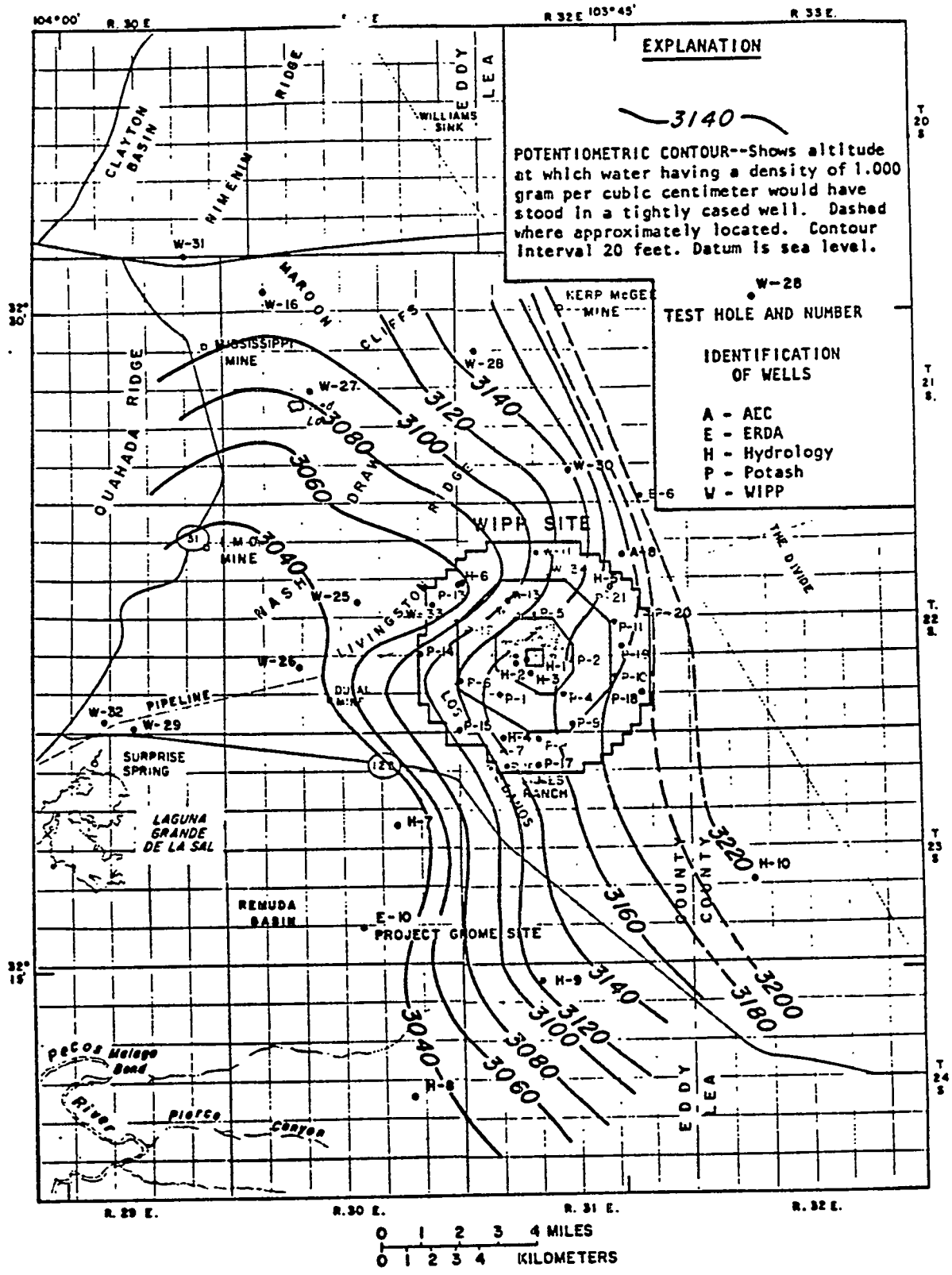


Figure 20.--Adjusted potentiometric surface of the Magenta Dolomite Member of the Rustler Formation (1982), at and near the proposed Waste Isolation Pilot Plant (WIPP) site.

The static heads and water-quality analyses indicate isolation of the Magenta from other units in the area east of Nash Draw and east and south of test hole H-6. The hydraulic head differences between units in this area range from 115 feet in test hole H-2 to 155 feet in test hole H-3 (tables 6, 9, and 10). Static-head variations in Nash Draw vary from 8 feet in test hole W-27 and 4 feet in test hole W-25 to 72 feet in test hole W-28; W-28 probably is anomalous for Nash Draw. It is expected that some hydraulic connection does exist between zones in all the other Nash Draw test holes. The water quality in the Culebra and Magenta hydrologic units in test holes W-25 and W-27 (table 2) is very similar, indicating the possibility of hydraulic connection between these units.

Recharge for the Magenta probably takes place outside of the WIPP area, as it does for the other hydrologic units in the Rustler Formation. The most likely area is to the north in the vicinity of Bear Grass Draw and possibly in Clayton Basin. An inspection of the contours on the potentiometric-surface map indicates the possiblity of recharge to the east of the WIPP site. This apparent recharge is believed to be the effect of either the corrections made for variable water quality (and its density effect on the static-head calculations) or the locally steep gradients that result from decreased permeability to the east.

Discharge of water from the Magenta Dolomite in Nash Draw probably takes place in one of two ways, either by moving into lower units such as the Culebra or into cavernous zones in the Forty-niner Member, which has been altered by dissolution. The ultimate area of discharge would be into the brecciated area in the Rustler near Malaga Bend and then into the Pecos River.

The dissolved solids in water associated with the Magenta Dolomite Member of the Rustler Formation range in concentration from 5,030 milligrams per liter in test hole H-9A to 261,000 milligrams per liter in test hole H-10A. The water is classified as being saline to briny (table 2). The areal distribution of major chemical constituents is represented by bar graphs in figure 21. The major dissolved cations and anions in water collected from the Magenta Dolomite are expressed in table 8 in milligrams per liter, milliequivalents per liter, and percentage composition.

As is characteristic of the other hydrologic units in the Rustler Formation, the dissolved mineral constituents in the Magenta consist largely of sulfates and chlorides of calcium, potassium, magnesium, and sodium; the major constituents by percentage are sodium and chloride.

The relationship between the magnesium and potassium concentrations and the hydraulic properties of the hydrologic unit of the Magenta Dolomite Member is not as well defined as in other units, but does exist. The mineralization of the water and the combined concentrations of magnesium and potassium in the Magenta increase from the northwest to the southeast. The unusually large degree of mineralization in the water at test hole W-27 may

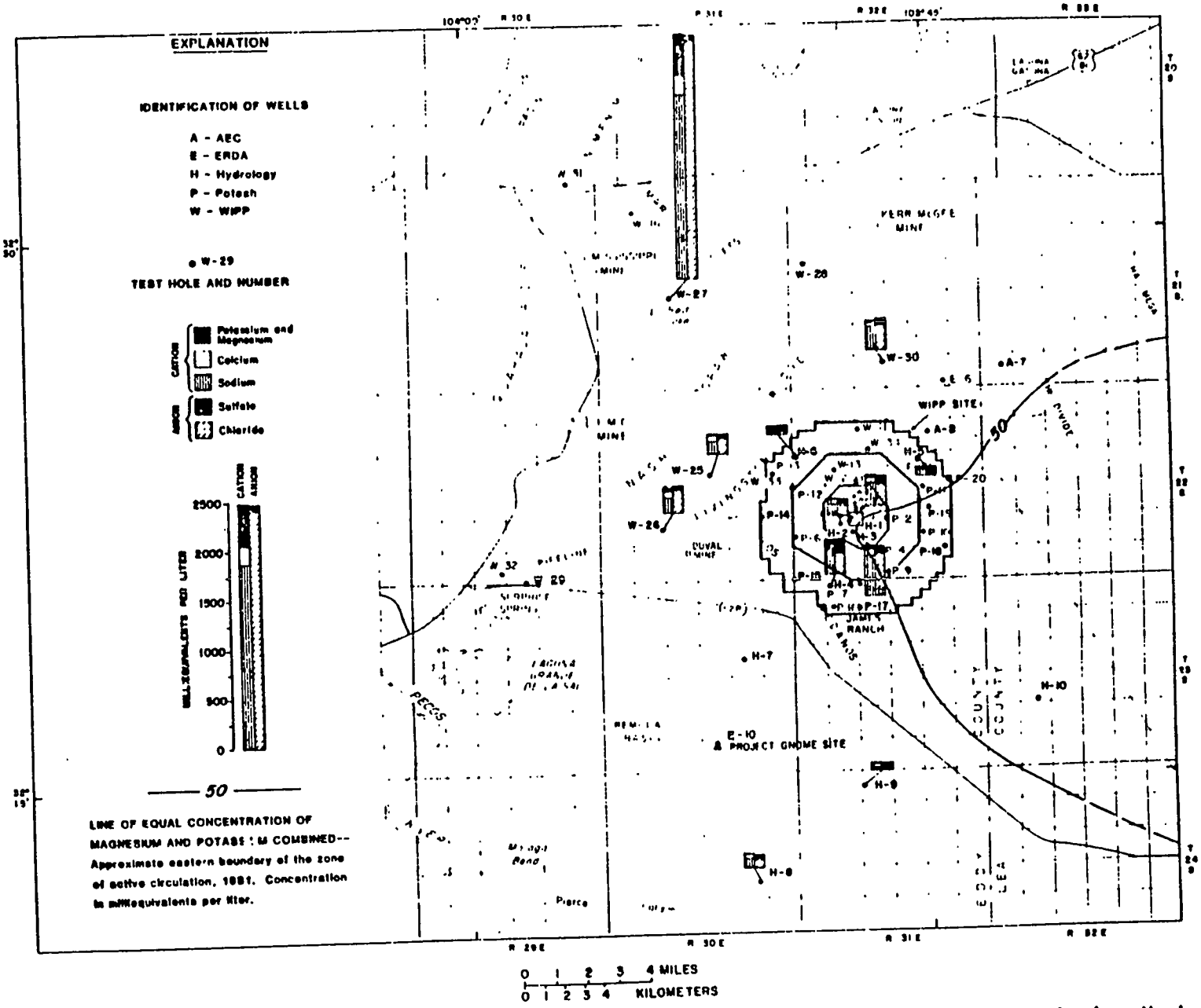


Figure 21.--Concentrations of major chemical constituents in water from the Magenta Dolomite Member of the Rustler Formation at and near the proposed Waste Isolation Pilot Plant (WIPP) site.

be caused by a relatively well developed hydraulic connection between the Magenta and other rock units that contain highly mineralized water.

The arbibrarily chosen line of equal concentration representing 50 milligrams per liter of potassium and magnesium combined (fig. 21) indicates a division between a relatively well developed flow system and one in which circulation is restricted. Although not as well defined as in the case of the Culebra, the line does indicate the area in which halite has been removed from below the Magenta (halite removed to the northwest, halite present to the southeast). The effects of the fracturing resulting from the halite removal on the hydraulic properties of the Magenta are not as pronounced as in the Culebra.

Hydrology of the Dewey Lake Red Beds

Geohydrologic characteristics--The Dewey Lake Red Beds comprise the youngest rocks in the Ochoan sequence at the WIPP site and mark an abrupt change in the depositional environment. This change was from predominantly evaporitic deposits in the Rustler to a deltaic sequence of alternating thin, even beds of siltstone and mudstone with lenticular interbeds of fine-grained sandstone. Nearly all the siltstone and mudstone are veined with selenite gypsum in the cores. The Dewey Lake dips gently eastward, increasing in thickness from 350 feet in test hole P-14 to 546 feet in test hole P-18 (fig. 5). The Dewey Lake Red Beds are separated from the overlying Triassic Santa Rosa Sandstone by an erosional unconformity east of test hole ERDA-9; west to Livingstone Ridge (along Nash Draw), the Dewey Lake is overlain by the Gatuna Formation and other Cenozoic deposits. The thickness of the formation decreases to the west where it was thinned by post-Permian erosion. The Dewey Lake in Nash Draw has been almost completely removed, in places being present only in sinks and other features fractures. The Dewey Lake crops out in low bluffs along the north and east sides of Nash Draw. Because of its characteristically minimal permeability, it does not contain significant quantities of ground water.

Drilling during areal geohydrologic evaluation did not identify a continuous zone of saturation within the Dewey Lake Red Beds; however, localized zones of permeability were detected. In the geologic test holes, the presence of these zones was indicated by minor losses of circulation during drilling. Detailed data collected during air-drilling of the hydrologic test holes (Mercer and Orr, 1979) did identify minor zones of saturation, particularly in several of the thin lenticular sands in the upper part of the Dewey Lake at test holes H-1, H-2, and H-3.

In most instances, the only indication of ground water was the presence of moist cuttings. In test hole H-2C an attempt was made to test the moist sands present at a depth of 185 feet. After monitoring the zone for 5 hours, very little water had entered the hole and the test was stopped (Mercer and

Orr, 1979, p. 58). Geologic data from the wells at the WIPP site indicate the sands to be lenticular, pinching out laterally. Where water is present, it probably is perched or semiperched, and its occurrence is very localized, probably depending to a great extent on locally favorable conditions for recharge.

The Dewey Lake has not normally been found to yield water to wells; however, several wells used for domestic and stock purposes at the James Ranch could possibly be completed in one of these lenticular sands. These wells in T. 23 S., R. 31 E., sections 6 and 7, range in depth from 94 to 212 feet (Cooper and Glanzman 1971, p. A-16). These wells either have saline water or small yields; geologic data indicate they are completed in the upper part of the Dewey Lake. Just east of this area there is an extensive, thick, active area of sand dunes, which could be a recharge area for these water-bearing sand units. No other wells in the area are known to produce water from the Dewey Lake.

Ground-water movement--Recharge of sand units in the Dewey Lake could result from localized conditions, as in the James Ranch area, or could occur by downward percolation of water through fractures or along bedding planes in the mudstone and siltstone. Discharge towards deeper zones through existing fractures or through dissolution of the gypsum veinlets is minor. The Dewey Lake is a protective cover that retards dissolution of evaporites in the Rustler Formation. If the groundwater penetrated to the top of the Rustler Formation in the WIPP site, then the upper anhydrite should be altered to gypsum. Cores and geophysical logs do not indicate that this alteration is present except where the Dewey Lake is thin or absent. Ground-water movement within the Dewey Lake is restricted owing to the perched character of the water in these lenticular sands.

Upper Triassic - Santa Rosa Sandstone

Geohydrologic characteristics--The Santa Rosa Sandstone, present only in the eastern one-half of the WIPP site, overlies the Dewey Lake Red Beds (fig. 5). The Santa Rosa crops out at the north end and along the east side of Nash Draw. The Santa Rosa consists of a fine- to coarse-grained sandstone with interbeds of siltstone and mudstone; it ranges in thickness from a featheredge west of test hole ERDA-9 to 176 feet in test hole H-10. To the west of test hole ERDA-9, the Santa Rosa has been removed by erosion. Throughout most of the area, the Santa Rosa is covered by surficial Cenozoic deposits; however, in test hole H-10, the sandstone is overlain by 392 feet of unsaturated Triassic Chinle Formation.

In the WIPP site area, the Santa Rosa Sandstone was tested in two test holes, H-5 and H-10. Although the Santa Rosa Sandstone is reported to be a principal aquifer in southwestern Lea County (Nicholson and Clebsch, 1961, p. 57), water was only present in the lower part of the formation in test hole H-5. Air drilling was used to identify the presence of water. Although an attempt was made to test the zone, the only reliable data collected were from a water sample from which the chemical composition of the water was determined (table 2). The water was under water-table conditions and was present in a sandstone immediately overlying the Dewey Lake Red Beds. In test hole H-10, the Santa Rosa was monitored during air drilling and no indication of water was found. Several wells east of the WIPP site have been reported to be obtaining water from the Santa Rosa, but yields are reported to be small. According to geophysical logs, a well in T. 22 S., R. 31 E., sec. 15, just west of test hole H-5, was completed in the lower part of the Santa Rosa; however, well yields were reported to be very small.

Ground-water movement--The Santa Rosa probably is recharged by precipitation in the area where it is overlain by permeable Cenozoic deposits, especially in the eastern part of the WIPP site. The water moves downward until it is impeded by the relatively impermeable Dewey Lake Red Beds and then probably moves down the structual dip to the east. Where it lies beneath the Chinle Formation, the water that is found in the Santa Rosa probably is under confined conditions. Small quantities of water probably discharge locally into the Dewey Lake through fractures and along bedding planes. Nicholson and Clebsch (1961, p. 57) believe that further to the east ground-water movement in the Santa Rosa is controlled by the collapse features of San Simon Swale. Nicholson and Clebsch show the pressure gradients to be toward the Swale.

Tertiary and Quaternary rocks

Of the Tertiary and Quaternary rocks in the vicinity of the WIPP site, the Gatuña Formation of Pleistocene age and the playa deposits and alluvium of Holocene age are the only units that contain water. The volume of water in these sediments is quite small.

The Ogallala Formation of Miocene age is an aquifer north and east of the area; however, along The Divide near the WIPP site, it occurs in isolated outliers no more than 60 feet thick. These outliers generally are unsaturated.

The Mescalaro caliche of Holocene age is a well lithified calcium carbonate and functions more as a barrier to downward movement of water than as a ground-water reservoir. The Mescalero caliche covers most of the WIPP site area although it is not present in Nash Draw.

Gatuña Formation—The Gatuña Formation is present as discontinuous bolson-type deposits. In the WIPP site area, the Gatuña is represented by several tens of feet of poorly sorted silt, clay, and sandstone that may grade downward into conglomeratic sandstone containing clasts of siltstone and sandstone (Jones, 1978, p, 10). Of the post-Tertiary rocks in the study area, the Gatuña Formation is the thickest and least extensive; characteristic of its erratic distribution, the Gatuña is absent in some test holes and is more than 100 feet thick in others (143 feet in test hole H-8, for example). Where it does occur at the WIPP site, it is generally no thicker than 46 feet (table 1). In most areas, the Gatuña is overlain by the Mescalero caliche.

Because of its erratic distribution, there is no known continuous saturated zone within the Gatuña Formation. Although Cooper and Glanzman (1971, p. A-10) have reported that there were some limited occurrences of water in the Gatuña in the Project Gnome area, no water was found during the drilling at the WIPP site. If water is present in places, it probably would be perched in sandstone lenses overlying the less permeable Dewey Lake Red Beds.

During foundation tests in the central part of the WIPP site, 30 exploration holes were drilled to test the hydraulic conductivity of the Gatuña. Packer permeability tests in these holes were conducted using injected water; these tests indicated that the hydraulic conductivity generally ranged from less than 3×10^{-3} to 1.9 feet per day; one value of 5.1 feet per day was noted (Register, 1981, p. 8). No indication of water was found in any of these holes.

Water movement in the Gatuña apparently is restricted by the discontinuous "perched" zones and the sporadic occurrence of the unit. Recharge to the Gatuña probably is by local downward percolation of precipitation, especially in areas where rain water is ponded on the surface. This recharge probably is hindered by the caliche cover in the WIPP site area. Discharge probably is locally to phreatophytes although some water may percolate downward into lower zones, particularly in the eastern part of the study area where the Gatuña overlies the Triassic Santa Rosa Sandstone.

Surficial deposits and alluvium—In the main part of the study area there are no through-flowing streams; the "alluvium," here referred to as surficial deposits, is composed of locally derived material deposited by sheet wash or from discontinuous arroyos. These surficial deposits are present almost everywhere in the region and usually are only a veneer over the underlying bedrock. Exceptions exist where deposits are concentrated in depressions created by dissolution of underlying rocks.

The only stream-deposited alluvium in areas near the WIPP site is along the Pecos River, mostly along the west side of the river north of Malaga Bend. This alluvium is composed of sand, gravel, silt, and clay and is as much as 200 feet thick. One of the most notable features of the alluvium is its large variation in thickness, which probably is caused by the alluvium

filling the depressions created by dissolution of underlying rocks (Hale, Hughes, and Cox, 1954, p. 20). South of Malaga Bend, the alluvium is present in isolated patches, which may be as much as 150 feet thick but generally average about 50 to 75 feet.

Playas within the study area are reported to contain alluvium and eolian sands that have been reworked by shallow lake waters (Vine, 1963, p. B-35). Playa deposits consist of silt, sand, and gypsum sand; the thickest deposits exceed 55 feet at Laguna Grande de la Sal (Robinson and Lang, 1938, p. 85). The gypsum and other materials deposited in the other playas in Nash Draw are similar to those at Laguna Grande de la Sal, but the deposits are not as thick.

Windblown sands are common throughout most of the area east of Nash Draw. The sands are only a few feet thick except where they have been concentrated by wind into dunes. The greatest concentration of dunes is located east of James Ranch, where they may have a localized effect on the hydrology.

No wells in the WIPP site area are known to produce water from the surficial deposits or from the windblown sands; however, where these deposits are thickest, they may contain localized perched zones of ground water. The sand dunes east of James Ranch are very permeable; however, evapotranspiration probably removes most of the downward percolating water.

The playa deposits are known to contain water, but the water generally has such large salt concentrations that it is unusable. Robinson and Lang (1938, p. 95) reported the water associated with the Laguna Grande de la Sal playa was under a slight artesian head.

The alluvium associated with the Pecos River, especially north of Malaga Bend, is a productive aquifer. Transmissivities in the alluvium vary considerably, but calculations made by Bjorklund and Motts (1959, p. 191) average 13,600 feet squared per day; the hydraulic conductivity probably averages 116 feet per day. The average hydraulic conductivity, however, could be misleading; lime-cemented conglomerates in the alluvium may greatly increase the value because of solution channels. Detailed data for the alluvium can be found in studies by Hale, Hughes, and Cox (1954) and Bjorklund and Motts (1959). South of Malaga Bend, the alluvium is less extensive and more variable in thickness, so average hydraulic properties are more difficult to determine.

Water associated with the surficial deposits and windblown sand probably is perched or semiperched; consequently, the occurrence of water is spotty and greatly dependent on local conditions. Recharge takes place in areas of surface ponding, and discharge moves downward through fractures and joints into more permeable zones. In several trenches dug through sand dunes at the WIPP site, the sand was found to be unsaturated and no perched water was found. The significant evapotranspiration rate in the area and the relatively impermeable underlying beds (caliche and siltstone) probably preclude large volumes of water moving downward.

The water in the playa deposits usually is localized, and water movement is restricted. The water table in the area around the playas slopes inward toward the playas, indicating water in the fill is moving into the playa and being discharged by evaporation. The source of the water is partly from recharge from precipitation and partly from ground-water inflow from springs (Robinson and Lang, 1938, p. 94).

Recharge to the alluvium is from several sources. Near Carlsbad water moves from the Guadalupian Reef complex to the alluvium. In the south near Malaga Bend, adjacent Permian geologic units, such as the Rustler, recharge the alluvium. Infiltration from precipitation and from streams, canals, and applied irrigation water also are sources of recharge to the alluvium. The alluvium near Malaga Bend is the most likely discharge area for water flow from hydrologic units associated with the WIPP site. The alluvium in this area probably would be the zone of contact with the biosphere if there should be a breach of the facility and a release of radionuclides. Water moving through the alluvium generally flows toward the Pecos River and then southwestward toward the Red Bluff Reservoir. Because the thick accumulations of sediment have been derived, to a great extent, from evaporites and fine-grained clastic rocks, the permeability of the alluvium is probably minimal, resulting in fairly low flow velocities (Hale and Clebsch, 1958, p. 15). However, localized zones of greater permeability may be present, especially where semiconsolidated alluvium is fractured. North of Malaga Bend, wells drilled into the alluvium vary in yield, but the yields are large enough to be used for irrigation.

The occurrence of water in the Tertiary and Quaternary rocks in the WIPP area generally is quite variable and is restricted to the area south of the WIPP site. The quality of ground water characteristically ranges from fresh to saline, although in isolated areas near playas it may be quite briny.

The only hydrologic unit that contains large volumes of water is the alluvium along the Pecos River. Although not specifically investigated during this study, it has been discussed in some detail in previous reports about the area (Hendickson and Jones, 1952; Hale, Hughes and Cox, 1954; and Bjorklund and Motts, 1959). The discussion in this report will be restricted to the hydrochemistry of ground water in the alluvium in the area around Malaga Bend.

Generally, the chemical composition of the water in the alluvium near Malaga Bend is affected by brine inflow from the Permian rocks to the east, downward percolation of relatively fresh water from irrigation, and local dissolution of evaporites. This mixing has caused changes in the overall quality of the water, with dissolved constituents dominated by sodium and chloride. Hale, Hughes, and Cox (1954, p. 40) reported that the chloride concentration in the water in the alluvium increases with depth and a saturated brine is present in the lower part of the fill. The overall ionic composition of the water is similar to the ground water from the other hydrologic units, predominantly consisting of chlorides and sulfates of calcium, magnesium, sodium and potassium.

SURFACE-WATER HYDROLOGY

There are no permanent streams or bodies of surface water present within the WIPP site; therefore, the potential for surface-water transport of waste is only treated briefly in this report. The purpose of these investigations was to relate surface water as a source or discharge point of flow from the ground-water system and as a potential part of the pathway for radionuclides if the WIPP facility were breached.

The Pecos River is a perennial stream and is the major drainage for the region around WIPP. The Pecos River is located west-southwest of the WIPP site and, at its closest point, is 10 miles from the outer exclusion boundary of the WIPP site. Most local tributaries originate in the Guadalupe Mountains, to the west of the Pecos. East of the Pecos, including Los Medaños and the WIPP site, the surface drainage is almost undeveloped. The closest major drainage to the WIPP site is Nash Draw; however, it is a closed drainage area with no surface outlet to the Pecos River. The land surface of the WIPP site is very hummocky and contains numerous small topographic depressions, which generally contain what little surface runoff takes place. A surface-water gaging station was established near Hill Tank (fig. 1A) on an unnamed arroyo draining from the WIPP site to Nash Draw (in sec. 24, T. 22 .S., R. 30 E.). During 4 years, only one flow occurred and it was of such short duration that it could not be measured. Apparently surface runoff from the WIPP site is minimal; most surface water is lost to evapotranspiration.

The most significant effect of surface water on the hydrology of the WIPP site takes place at Malaga Bend on the Pecos River where water from the Rustler Formation discharges to the river. Additional data on the Pecos River and the regional surface-water conditions are included in the report by Powers, Lambert, Shaffer, Hill, and Weart (1978).

SUMMARY AND CONCLUSIONS

The WIPP site is proposed as a mined repository for defense associated radioactive waste at depth of approximately 2,150 feet in bedded salts of the Permian Salado Formation. The characteristics of the geohydrologic systems at the WIPP site need to defined because of the potential for transport of radionuclides to the biosphere by ground water in the unlikely event the storage facility is breached.

The sedimentary formations in the WIPP site area that contain water are present both below and above the halite of the Salado Formation. The formations of concern range in age from Permian to Quaternary. About 70 test holes have been drilled as part of the geologic and hydrologic site characterization.

The major water-bearing zones below the Salado Formation that have been identified during hydrologic investigations, are the fine-grained sandstones of the Bell Canyon Formation of the Delaware Mountain Group. In addition, isolated pockets of pressurized brine have been found in fractures in the anhydrite of the Castile Formation. Investigations to date (1983) indicate that these zones are isolated from units either above or below the Castile. The water-bearing zones of concern above the Salado Formation include a zone composed of the residue from evaporite dissolution at the contact between the Rustler and Salado Formations, and the Magenta and Culebra Dolomite Members of the Rustler Formation. Water in Tertiary and Quaternary sediments is perched in isolated sands.

The Guadalupian reef complex is a major hydrologic unit in the area and forms a long arcuate belt around the margins of the Delaware Basin in which the WIPP site is located. Lateral movement of water away from the reef is restricted by the minimally permeable anhydrites of the Castile Formation.

In the upper part of the Bell Canyon Formation, the brines usually are present in relatively isolated permeable channel sandstones, which have hydraulic conductivities ranging from 7×10^{-3} to 5×10^{-2} foot per day. These channel sandstones grade vertically and laterally into siltstones and shales that have negligible permeability; hydraulic conductivities usually are less than 2×10^{-6} foot per day. Siltstones and shales overlying these channel sandstones restrict upward movement of water to the minimally permeable anhydrites of the Castile Formation. Potentiometric-surface maps indicate water movement across the basin to the northeast; however, the rate of movement is extremely slow. Also, when compared to the hydraulic heads in the units overlying the evaporites, the general movement would be down; that is heads decrease with depth.

Water-bearing units in the Delaware Mountain Group probably are restricted to the upper 600 feet of the Bell Canyon Formation; the individual permeable sandstone beds are no thicker than 45-60 feet. The dissolved ions in the brines of the Bell Canyon in the WIPP site area are predominantly sodium and chloride; dissolved-solids concentrations range from 180,000 to 270,000 milligrams per liter.

The hydrologic units of the Rustler Formation are the principal water-bearing units above the Salado Formation in the WIPP site vicinity and thus have been the most extensively studied. Water-bearing units in the Rustler Formation include the residues (residuum) from evaporite dissolution at the contact between the Rustler and Salado Formations and the Culebra Dolomite and Magenta Dolomite Members.

Brine at the Rustler-Salado contact "brine aquifer of Robinson and Lang (1938) is present either in a clay residuum bed or along the bedding planes between these units. The residuum is common along Nash Draw and is most extensive between Laguna Grande de la Sal and Malaga Bend, where transmissivities are as large as 8,000 feet squared per day. In the northern

end of Nash Draw, transmissivities range from 2 x 10^{-4} foot squared per day in test hole W-27 to 8 feet squared per day in test hole W-29; in the WIPP site proper, transmissivities range from 3 x 10^{-5} foot squared per day at test holes H-5C and P-18 to 5 x 10^{-2} foot squared per day at test hole P-14. The ground-water flow in the eastern part of the site primarily is along bedding planes. Density-corrected potentiometric-surface maps indicate flow is southwest across the WIPP site towards Nash Draw at a gradient of 39 feet per mile and then south-southwest down Nash Draw to Malaga Bend on the Pecos River at a gradient of about 10 feet per mile. The dissolved ions in the brines of the Rustler-Salado contact residuum are predominantly sodium and chloride; dissolved-solids concentrations range from 41,500 milligrams per liter at test hole H-1 to 412,000 milligrams per liter at test hole H-5C. Large concentrations of dissolved potassium and magnesium in ground water in the eastern part of the study area indicate restricted flow and extensive interaction between the ground water and its host rock.

The Culebra Dolomite Member of the Rustler Formation is the most persistent and productive hydrologic unit in the WIPP vicinity. Its hydraulic properties vary considerably from place to place primarily as a result of the size and number of fractures and openings. These fractures are related to the degree of evaporite dissolution within the Rustler that causes subsidence and collapse of the overlying dolomite. The most extensive evaporite dissolution and fracturing are present in Nash Draw. Transmissivities calculated for the Culebra in Nash Draw range from 18 feet squared per day at test hole W-28 to 1,250 feet squared per day at test hole W-26. At the WIPP site east of Nash Draw, transmissivities range from 1.0 x 10^{-3} foot squared per day at test hole P-18 to 140 feet squared per day at test hole P-14. Density-corrected potentiometric-surface maps indicate that flow at the WIPP site is to the south at a hydraulic gradient that ranges from 7 to 20 feet per mile; the flow is then to the southwest to Nash Draw where gradients range from 16 feet per mile in the north end to less than 5 feet per mile near Malaga Bend. Flow directions may be affected significantly by directional differences in permeability in the dolomite. In Nash Draw, the Culebra Dolomite is extensively fractured and flow is virtually south to a discharge area at the Pecos River near Malaga Bend.

Water in the Culebra is slightly saline to briny; dissolved-solids concentrations range from 2,950 milligrams per liter at test hole H-8B to 239,000 milligrams per liter at test hole W-29. Dominant dissolved ions are sodium and chloride; other ions include sulfate, potassium, calcium, and magnesium. Not only does the mineralization of the water generally increase from west to east across the site, but so do the concentrations of potassium and magnesium. This change indicates a decrease in circulation along the eastern side of the WIPP site. This restricted circulation is caused by a decrease in permeability within the Culebra Dolomite Member.

The Magenta Dolomite Member is the uppermost hydrologic unit in the Rustler Formation. Water is present in the area of the WIPP site, usually in thin siltstone beds or silty dolomite and less commonly in fractures. In Nash Draw, the occurrence of water in the Magenta Dolomite Member is variable

because of localized drainage from the unit that results from the chaotic structure created by extensive evaporite dissolution. In the southern end of Nash Draw, the Magenta has been completely removed by erosion. Transmissivities calculated for the Magenta Dolomite in the northern end of Nash Draw range from 53 feet squared per day at test hole W-27 to 375 feet squared per day at test hole W-25; these relatively large values result from the increased permeability in the fractured rock. The transmissivity in the vicinity of the WIPP site ranges from 4×10^{-3} foot squared per day at test hole W-30 to 3×10^{-1} foot squared per day at test hole H-6A. The movement of ground water in the site area, as estimated from density-corrected potentiometric-surface maps, is west toward Nash Draw at a gradient of as much as 32 feet per mile and then southwest in Nash Draw at a gradient of 13 feet per mile.

The flow in the Magenta Dolomite Member eventually moves downward through fractures into lower units. The water in the Magenta is saline to briny; concentrations of dissolved solids range from 5,030 milligrams per liter at test hole H-9a to 261,000 milligrams per liter at test hole H-10A. Dissolved mineral constituents of the water include sulfates and chlorides of magnesium, potassium, and calcium, the major percentages being sodium and chloride. Larger magnesium and potassium concentrations in the eastern part of the site may indicate restricted circulation in the Magenta.

The relative static heads or formation pressures of the hydrologic units in the Rustler Formation decrease with depth; that is, hydraulic heads are highest in the Magenta and lowest at the Rustler-Salado contact. There appear to be two regional flow systems; one in the area around the proposed WIPP site and one in Nash Draw. In the WIPP site area, the presence of impermeable interbeds of halite and anhydrite and the differences in static head and water quality probably indicate restricted vertical hydraulic connection between units; however, in Nash Draw, where dissolution and subsidence are more common, hydraulic connection between units probably exists. Recharge for the Rustler units probably is to the north of Nash Draw near Bear Grass Draw; the major discharge takes place at Malaga Bend on the Pecos River.

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Table 1. Geologic and hydrologic data from test holes drilled at and near the proposed Waste Isolation Pilot Plant site

[FNL, from north line; FEL, from east line; FSL, from south line; FWL, from west line; Sec., Section; T, Township; R, Range; units, in feet below land surface]

Test hole	Altitude, in feet above sea level	Location			Depth of rock			
		Sec. T. R.	Distance, in feet, from section lines		Surficial deposits	Gatuna Formation	Santa Rosa Formation	Dewey Lake Red Beds
H-1	3397.71	29 22S 31E	623.31FNL	1082.75FEL	0-15	15-35	N.P.,(Not Present)	35-502
H-2A	3377.85	29 22S 31E	726.17FNL	1698.43FWL	0-14	14-38	N.P.	38-457
H-2B	3377.68	do	695.57FNL	1660.57FWL	do	do	N.P.	do
H-2C	3377.75	do	637.15FNL	1708.62FWL	do	do	N.P.	do
H-3	3389 48	29 22S 31E	2085.30FSL	138.1FEL	0-4	4-22	N.P.	22-502
H-4A	3332.91	5 23S 31E	545.89FNL	720.00FWL	0-13	13-29	N.P.	29-315
H-4B	3332.76	do	498.47FNL	632.54FWL	do	do	N.P.	do
H-4C	3333.54	do	446.36FNL	717.89FWL	do	do	N.P.	do
H-5A	3506.15	15 22S 31E	1093.12FNL	184.33FEL	0-8	N.P.(Not Present)	8-225	225-732
H-5B	3505.97	do	1006.80FNL	234.21FEL	do	N.P.	do	do
H-5C	3506.37	do	1006.47FNL	134.20FEL	do	N.P.	do	do
H-6A	3347.26	18 22S 31E	283.80FNL	274.93FWL	0-12	12-38	N.P.	38-427
H-6B	3347.57	do	195.61FNL	322.15FWL	do	do	N.P.	do
H-6C	3347.93	do	280.61FNL	374.81FWL	do	do	N.P.	do
H-7A	3163.55	14 23S 30E	2495.04FNL	2492.35FWL	0-5		N.P.	57-87
H-7B	3163.63	do	2565.8FNL	2563.45FWL	do	do	N.P.	do
H-7C	3163.48	do	2591.93FNL	2467.51FWL	do	do		do
H-8A	3433.0	23 24S 30E	1962.61FNL	1486.59FEL	0-4 4-10 Mescalero Caliche	10-153	N.P.	153-399
H-8B	3433.8	do	1994.76FNL	1405.39FEL	do	do	N.P.	do
H-8C	3433.0	do	2059.39FNL	1470.14FEL	do	do	N.P.	do
H-9A	3405.4	4 24S 31E	2392.14FNL	138.92FWL	0-5	5-25	N.P.	24-455
H-9B	3405.6	do	2391.04FNL	283.63FWL	do	do	N.P.	do
H-9C	3405.9	do	2479.06FNL	188.02FWL	do	do	N.P.	do
H-10A	3686.52	20 23S 32E	433.04FSL	2068.91FEL	0-9	9-90	90-482 Chinle 482-658	658-1204
H-10B	3687.01	do	484.54FSL	1984.84FEL	do	do	do	do
H-10C	3686.88	do	384.54FSL	1981.84FEL	do	do	do	do

Depth of rock							
Rustler Formation	Magenta Dolomite Member of Rustler Formation	Culebra Dolomite Member of Rustler Formation	Top of Salado Formation	Top of salt in Salado Formation	Top of McNutt potash zone	Top of Castile Formation	Test hole depth in feet
502-824	563-589	676-699	824	731(R)			856
457-	515-543						563
457	515-543	623-645	M.P.				661
457-764	515-543	623-645	764	676(R)			795
502-821	559-584	672-694	821	823(S)			894
315-	375-400						415
315-	377-402	498-522					529
315-626	377-403	490-516	626	?			661
732-	783-810	897-920					824
732-	785-805	897-920					925
732-1041	788-812	899-924	1041				1076
427-	492-511						525
427-	492-511	604-627					640
427-721	490-514	604-627	721	723.4(S)			741
87-283	117-140						154
87-283	117-140	237-283					286
87-283	117-140	237-273.5	283	405(S)			420
399-	466-488						505
399-	466-488	588-614					624
399-733	466-488	588-614	733	798(S)			808
455-	523-554						559
455-	523-554	647-677					708
455-791	523-554	647-677	791	791(S)			816
1204-	1256-1280						1318
1204-	1256-1280	1360-1391					1398
1204-1501	1256-1280	1360-1391	1501	1501(S)			1535

Table 1. Geologic and hydrologic data from test holes drilled at and near the proposed Waste Isolation Pilot Plant site — Continued

Test hole	Altitude, in feet above sea level	Location		Depth of rock			
		Sec. T. R.	Distance, in feet, from section lines	Surficial deposits	Gatuna Formation	Santa Rosa Formation	Dewey Lake Red Beds
P-1	3345.1	29 22S 31E	328FSL 552FWL	0-10	10-40	N.P.	40-358
P-2	3479.4	28 22S 31E	121FNL 171FEL	0-18	18-38	38-164	164-690
P-3	3382.7	20 22S 31E	104FSL 2154FWL	0-10	10-41	N.P.	41-468
P-4	3443.8	28 22S 31E	149FSL 1485FEL	0-8	N.P.	8-93	99-609
P-5	3470.9	17 22S 31E	186FSL 160FEL	0-13	N.P.	13-146	146-623
P-6	3354.1	30 22S 31E	2509FNL 195FWL	0-8	8-18	N.P.	18-357
P-7	3332.0	5 23S 31E	514FNL 393FWL	0-11	11-45	N.P.	45-312
P-8	3338.6	4 23S 31E	640FNL 92FWL	0-11	9-39	N.P.	39-391
P-9	3411.5	33 22S 31E	1493FSL 126FEL	0-11	N.P.	11-66	66-562
P-10	3509.3	26 22S 31E	2341FNL 323FWL	0-8	N.P.	8-151	151-686
P-11	3503.9	23 22S 31E	156FNL 183FWL	0-9	N.P.	9-224	224-745
P-12	3373.6	24 22S 30E	165FNL 198FEL	0-8	N.P.	N.P.	8-461
P-13	3345.2	18 22S 31E	110FNL 147FWL	0-12	12-38	N.P.	38-427
P-14	3359.6	24 22S 30E	309FSL 613FWL	0-10	10-42	N.P.	42-387
P-15	3309.5	31-22S 31E	411FSL 190FWL	0-11	11-32	N.P.	32-231
P-16	3317.9	5 23S 31E	939FSL 1647FWL	0-14	14-32	N.P.	32-316
P-17	3335.9	4 23S 31E	1356FSL 398FWL	0-14	14-46	N.P.	46-382
P-18	3477.2	26 22S 31E	139FSL 733FEL	0-9	N.P.	9-87	87-628
P-19	3545.1	23 22S 31E	1652FSL 2335FWL	0-8	N.P.	8-232	232-758
P-20	3552.7	14 22S 31E	801FSL 79FEL	0-6	N.P.	6-261	261-780
P-21	3509	15 22S 31E	859FN. 130FEL	0-8	N.P.	8-225	225-734
ERDA-6	3540.2	35 21S 31E	2152FSL 910FEL	0-17	17-42	42-71	71-536
ERDA-9	3418.86	20 22S 31E	267.23FSL 176.74FEL	0-15	15-42	42-51	51-538
ERDA-10	3371.2	34 23S 30E	200FNL 2327FEL	0-5	5-151	N.P.	151-366
AEC-7	3654.00	31 21S 32E	2040FNL 2040FEL	0-12	N.P.	12-112	112-662
AEC-8	3531.5	11 22S 31E	935FNL 1979FWL		?	31-165	165-660

Depth of rock							
Rustler Formation	Magenta Dolomite Member of Rustler Formation	Culebra Dolomite Member of Rustler Formation	Top of Salado Formation	Top of salt in Salado Formation	Top of McNutt potash zone	Top of Castile Formation	Test hole depth in feet
358-677	423-448	538-565	677	597(R)	1191-1583		1591.0
690-1008	748-773	857-883	1008	906(R)	1506-1883		1895.0
466-786	529-553	642-665	786	688(R)	1287-1668		1676.0
609-930	662-686	775-802	930	826(R)	1446-1853		1857.0
623-947	686-711	804-827	947	350(R)	1428-1785		1830.6
357-659	417-443	537-560	659	661(S)	1162-1560		1573.0
312-630	373-398	496-522	630	562(R)	1155-1556		1575.0
391-715	450-474	563-588	715	606(R)	1237-1652		1660.0
562-881	617-644	734-757	881	778(R)	1401-1796		1796.0
686-1086	757-781	931-957	1086	712(R,	1594-1983		2010.8
745-1058	796-823	912-938	1058	958(R)	1550-1917		1943.1
461-749	519-543	633-656	749	752(S)	1226-1597		1598.4
427-721	490-514	604-627	721	725(S)	1201-1547		1577.3
387-687	453-477	573-595	687	695(S)	1158-1519		1545.0
231-542	294-321	413-435	542	460(R)	1057-1453		1465.0
316-646	376-401	500-523	646	552(R)	1174-1585		1585.0
382-715	438-463	558-583	715	602(R)	1234-1648		1660.7
628-1088	704-730	909-938	1088	654(R)	1604-2087		2000.5
758-1117	814-839	967-997	1117	890(R)	1621-2011 projected		2000.0
780-1103	839-866	953-979	1103	1002(R)	1604-1977		1994.5
734-1043	788-812	899-924	1043	944(R)	1526-1887		1916.5
536-815	595-621	710-735	815	815(S)		2401	2775
538-848	596-620	704-727	848	750(S)	1350-1730	2824	2876.6
366-628	366-385	476-504	628	678(S)		2337 3829(D)	4418
662-991	733-759	870-896	991	930(R) 1000(S)		3004 4522(D)	4721
660-985	715-738	833-859	985	985(S)		2966 4343(D)	4910

Table 1. Geologic and hydrologic data from test holes drilled at and near the proposed Waste Isolation Pilot Plant site — Concluded

Test hole	Altitude, in feet above sea level	Location					Depth of rock			
		Sec.	T.	R.	Distance, in feet, from section lines		Surficial deposits	Gatuna Formation	Santa Rosa Formation	Dewey Lake Red Beds
WIPP-11	3426.07	9	22S	31E	711.70FNL	394.08FWL	0-13	13-29	29-161	161-663
WIPP-12	3471.53	17	22S	31E	147.9FSL	83.91FEL	0-9	N.P.	9-155	155-628
WIPP-13	3405.43	17	22S	31E	2565.68FSL	1730.59FWL	0-13	N.P.	13-66	66-517
WIPP-15	3269.34	18	23S	35E	2426FNL	1793FWL			543-2726 (Chinle)	
WIPP-16	3383	5	21S	30E	2355FSL	140FWL	(0-114S)Rubble?			
WIPP-18	3456.47	20	22S	31E	983.58FNL	11.45FEL	0-9	N.P.	9-138	138-613
WIPP-19	3433.13	20	22S	31E	2987.34FSL	12.68FEL	0-14	N.P.	14-96	96-589
WIPP-21	3417.00	20	22S	31E	1551.08FSL	11.74FEL	0-12	12-39	39-73	73-56C
WIPP-22	3425.83	20	22S	31E	2544.45FSL	11.94FEL	0-20	20-25	25-80	80-573
WIPP-25	3212.51	15	22S	30E	1852.72FSL	2838.1FEL	0-10	N.P.	N.P.	10-232
WIPP-26	3151.91	29	22S	30E	2232.27FNL	12.2FEL	0-10	N.P.	N.P.	N.P.
WIPP-27	3177.17	21	21S	30E	89.79FNL	1485.03FWL	0-79		N.P.	79-153
WIPP-28	3346.76	18	21S	31E	98.72FNL	2400.99FEL	0-12	N.P.	N.P.	12-215
WIPP-29	2976.99	34	22S	29E	406.62FSL	1827.54FEL	0-12	N.P.	N.P.	N.P.
WIPP-30	3427.54	33	21S	31E	667.5FNL	177.41FWL		N.P.	N.P.	0-449
WIPP-31	3401.43	35	20S	30E	422.54FSL	1762.24FWL		N.P.	0(Breccia)	38(Breccia)
WIPP-32	3023.00	33	22S	29E	1673FSL	29FEL				
WIPP-33	3323.00	13	22S	30E	1762FSL	2427FWL	0-40			40-398
WIPP-34	3433.00	9	22S	31E	202FSL	2000FWL	0-11		11-154	154-657
B-25	3408.74	20	22S	31E	N 9414.91 *N.M. State Coordinates	E 6693.11*	0-10 10-14 Mescalero Caliche	14-34.7	34.7-44.8	44.8-533

Depth of rock							
Rustler Formation	Magenta Dolomite Member of Rustler Formation	Culebra Dolomite Member of Rustler Formation	Top of Salado Formation	Top of salt in Salado Formation	Top of McNutt potash zone	Top of Castile Formation	Test hole depth in feet
663-951	727-750	844-867	951	951(S)		2330	3580.6
628-955	690-715	810-835	955	857(R) 955(S)		2727	2777.8
517-844	564-583	701-724	844	774(R) 918(S)			1025
							810.5
1148-1300+	1189-1199	1153-1176					1300
613-928	672-696	786-808	928	829(P) 928(S)			1060
589-894	647-672	756-777	894	894(S)			1038
560-868	618-641	729-753	868	770(R) 868(S)			1045
573-883	630-654	742-764	883	785(R) 884(S)			1450
232-565	302-328	447-472	565	600(S)			655
10-309	70-99	186-209	309	320(S)			503
153-416	176-194	292-318	416	508(S)			592
215-531.9	285-310	420-446	531	589 (S)			801
N.P.	N.P.	12-42	143	251(S)			376
449-749	513-537	631-654	749	749(S)			913
750(Breccia)	1981(Breccia)		N.P.				1981
0-166	19-36	61-90	166-390				390
398-675	449-468	550-578	657-840				840
657-973	718-741	834-860	973-1820+				1820
533-842.9	592.7-617	704.1-728	842.9				901

Table 2.—Selected chemical and radiochemical analyses of water from test holes at and near the proposed Waste Isolaiton Pilot Plant site

[GEOLOGIC UNIT: 231SNSR, Santa Rosa Sandstone; 313BLCN, Bell Canyon Formation; 312RSLRL, Rustler-Salado residuum; 312CLBR, Culebra Dolomite Member; 310MGNT, Magenta Dolomite Member. GM/ML AT 20 C: Grams per millimeter at 20 degrees Celsius; MG/L: milligrams per liter; UG/L: micrograms per liter; PCI/L: picocuries per liter.]

WELL	DATE OF SAMPLE	GEOLOGIC UNIT	DENSITY (GM/ML AT 20 C)	PH (UNITS)	ALKALINITY FIELD (MG/L AS CACO3)	BICARBONATE FET-FLD (MG/L AS HCO3)	CARBONATE FET-FLD (MG/L AS CO3)	NITROGEN, NO2+NO3 DISSOLVED (MG/L AS N)	SULFIDE TOTAL (MG/L AS S)	HARDNESS (MG/L AS CACO3)
H-5C	78-05-24	231SNRS	--	--	200	240	--	.36	--	150
AEC-7	79-04-28	3138LCN	1.130	--	43	--	--	--	--	35000
AEC-8	77-09-27	3138LCN	1.060	6.3	--	--	--	--	--	--
ERDA-10	77-09-29	3138LCN	1.165	7.7	90	110	0	3.1	.2	19000

WELL	HARDNESS, NONCARBONATE (MG/L CACO3)	CALCIUM DISSOLVED (MG/L AS CA)	MAGNESIUM, DISSOLVED (MG/L AS MG)	SODIUM, DISSOLVED (MG/L AS NA)	POTASSIUM, DISSOLVED (MG/L AS K)	CHLORIDE, DISSOLVED (MG/L AS CL)	SULFATE DISSOLVED (MG/L AS SO4)	FLUORIDE, DISSOLVED (MG/L AS F)	SILICA, DISSOLVED (MG/L AS SIO2)	BORON, DISSOLVED (UG/L AS B)	SOLIDS, RESIDUE AT 105 DEG. C, DISSOLVED (MG/L)
H-5C	150	56	51	280	25	120	530	1.2	11.0	890	1200
AEC-7	35000	9700	2600	55000	970	110000	1800	1.4	14.0	76000	180000
AEC-8	--	--	--	--	--	--	--	--	--	--	230000
ERDA-10	19000	5300	1300	89000	720	150000	2400	0.3	3.4	20000	270000

Table 2.—Selected chemical and radiochemical analyses of water from test holes at and near the proposed Waste Isolation Pilot Plant site — Continued

WELL	DATE OF SAMPLE	GEO-LOGIC UNIT	DENSITY (GM/ML AT 20 C)	PH (UNITS)	ALKA-LINITY FIELD (MG/L AS CACO3)	BICAR-BONATE FET-FLD (MG/L AS HCO3)	CAR-BONATE FET-FLD (MG/L AS CO3)	NITRO-GEN, NO2+NO3 DIS-SOLVED (MG/L AS N)	SULFIDE TOTAL (MG/L AS S)	HARD-NESS (MG/L AS CACO3)
H-1	77-02-23	312RSLRL	--	7.9	554	575	0	.29	--	160000
H-2C	77-02-23	312RSLRL	--	5.9	163	199	0	1.1	--	130000
H-3	77-02-23	312RSLRL	--	7.6	383	467	0	.77	--	150000
H-4C	79-03-16	312RSLRL	--	--	1	1	0	.27	--	130000
H-5C	79-05-16	312RSLRL	--	--	180	300	--	--	--	340000
H-6C	79-04-09	312RSLRL	--	--	1	--	--	--	--	97000
H-7C	80-03-20	312RSLRL	1.049	6.8	35	--	--	.03	--	10000
H-8C	80-09-06	312RSLRL	--	7.6	21	--	--	.00	.6	4300
H-9C	80-05-20	312RSLRL	1.202	7.0	24	--	--	1.1	--	6800
H-10C	80-05-19	312RSLRL	1.198	6.3	53	--	--	.84	--	49000
P-14	77-02-24	312RSLRL	--	7.2	182	222	0	.34	--	6400
P-15	79-04-03	312RSLRL	--	--	45	--	--	--	--	3400
P-17	79-05-11	312RSLRL	--	--	650	--	--	.04	--	200000
P-18	80-05-20	312RSLRL	1.260	6.0	400	--	--	.06	.0	290000
WIPP-25	80-03-19	312RSLRL	1.173	7.2	80	--	--	.04	--	15000
WIPP-26	80-03-18	312RSLRL	1.078	8.5	160	--	--	.05	--	12000
WIPP-27	80-05-21	312RSLR	1.205	7.6	25	--	--	.17	--	4500
WIPP-28	80-03-20	312RSLRL	1.140	7.0	230	--	--	.03	--	13000
WIPP-29	80-03-18	312RSLRL	1.068	7.3	130	--	--	.23	--	10000
WIPP-30	80-03-19	312RSLRL	1.201	7.0	320	--	--	.04	--	12000

WELL	HARD-NESS, NONCAR-BONATE (MG/L CACO3)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	SULFATE DIS-SOLVED (MG/L AS SO4)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	SILICA, DIS-SOLVED (MG/L AS SIO2)	BORON, DIS-SOLVED (UG/L AS B)	SOLIDS, RESIDUE AT 105 DEG. C, DIS-SOLVED (MG/L)
H-1	160000	13000	30000	56000	17000	210000	520	--	<.1	110000	480000
H-2C	130000	9200	25000	66000	9100	200000	1300	--	2.0	150000	450000
H-3	150000	15000	25000	59000	14000	210000	370	--	1.0	1900	--
H-4C	130000	8300	27000	66000	8600	210000	1400	1.7	1.3	360000	--
H-5C	340000	2100	82000	14000	21000	290000	2000	<.1	1.6	67000	--
H-6C	97000	4200	21000	80000	8000	200000	2000	1.0	1.4	200000	--
H-7C	10000	2600	910	22000	210	41000	2900	.8	7.2	3100	--
H-8C	4700	1200	430	46000	660	70000	5300	.4	.8	1300	--
H-9C	6300	1300	870	130000	1200	190000	2600	.1	3.8	19000	--
H-10C	49000	1500	11000	100000	4000	190000	3300	.7	3.2	120000	--
P-14	6200	570	1200	120000	1300	180000	10000	--	2.0	1700	350000
P-15	3300	770	350	24000	1400	38000	2800	1.3	1.3	3700	--
P-17	200000	15000	40000	23000	8800	130000	1200	3.8	15	880	--
P-18	290000	31000	51000	20000	16000	250000	260	2.3	3.2	160000	--
WIPP-25	15000	650	3200	90000	2400	130000	12000	.0	2.6	35000	--
WIPP-26	12000	2700	1300	52000	1000	68000	7600	.0	2.5	30000	--
WIPP-27	4700	900	610	130000	390	230000	8400	.2	2.5	9400	--
WIPP-28	13000	750	2700	71000	2600	120000	5200	.2	3.5	38000	--
WIPP-29	10000	850	2000	32000	1000	49000	12000	.9	3.5	21000	--
WIPP-30	11000	850	2300	120000	1500	170000	7000	.0	3.5	77000	--

Table 2.—Selected chemical and radiochemical analyses of water from test holes at and near the proposed Waste Isolation Pilot Plant site — Continued

WELL	DATE OF SAMPLE	GEOLOGIC UNIT	SELENIUM, TOTAL (UG/L AS SE)	GROSS ALPHA, DISSOLVED (PCI/L AS U-NAT)	GROSS ALPHA, SUSP. TOTAL (PCI/L AS U-NAT)	GROSS BETA, DISSOLVED (PCI/L AS CS-137)	GROSS BETA, SUSP. TOTAL (PCI/L AS CS-137)	RADIUM 226, DISSOLVED, RADON METHOD (PCI/L)	URANIUM DISSOLVED, EXTRACTION (UG/L)	GROSS ALPHA, DISSOLVED (UG/L AS U-NAT)
H-1	77-02-23	312RSLRL	<1	--	--	16000	160	66	.02	<6300
H-2C	77-02-23	312RSLRL	<1	--	--	8400	91	4.8	2.4	<5000
H-3	77-02-23	312RSLRL	1	--	--	12000	26	51	.06	<6000
H-4C	79-03-16	312RSLRL	<1	<7500	3.3	8900	<.4	340	1.2	<11000
H-5C	79-05-16	312RSLRL	1	<13000	.7	15000	.6	310	<.04	<19000
H-6C	79-04-09	312RSLRL	1	<7500	.9	6800	<.7	280	<.04	<11000
H-7C	80-03-20	312RSLRL	--	<950	--	<580	--	65	1.9	<1400
H-8C	80-09-06	312RSLRL	--	<1600	--	<1100	--	18	.04	<2600
H-9C	80-05-20	312RSLRL	--	<5400	--	7600	--	.31	.45	<8000
H-10C	80-05-19	312RSLRL	--	<5600	--	7200	--	10	.37	<9200
P-14	77-02-24	312RSLRL	1	--	--	<2000	2.3	15	1.3	<3700
P-15	79-04-03	312RSLRL	<1	<1000	<.3	1300	<.4	.59	.08	<1500
P-17	79-05-11	312RSLRL	<1	<7500	6.8	13000	2.8	340	<.02	<11000
P-18	79-05-11	312RSLRL	<1	<8800	<.3	9800	<.4	11	.05	<13000
WIPP-25	80-03-19	312RSLRL	--	<5200	--	<3600	--	2.7	.29	<7700
WIPP-26	80-03-18	312RSLRL	--	<3200	--	<1700	--	12	5.2	<4700
WIPP-27	80-05-21	312RSLR	--	<1200	--	<7100	--	2.4	.07	<1800
WIPP-28	80-03-20	312RSLRL	--	<4100	--	<2700	--	3.6	2.7	<6000
WIPP-29	80-03-18	312RSLRL	--	<1100	--	740	--	1.2	2.0	<1600
WIPP-30	80-03-19	312RSLRL	--	<7500	--	<4500	--	98	<.01	<11000

WELL	GROSS ALPHA, SUSP. TOTAL (UG/L AS U-NAT)	GROSS BETA, DISSOLVED (PCI/L AS SR/YT-90)	GROSS BETA, SUSP. TOTAL (PCI/L AS SR/YT-90)
H-1	290	12000	120
H-2C	190	6700	76
H-3	68	9600	21
H-4C	4.9	8100	<.4
H-5C	1.1	14000	.6
H-6C	1.3	6200	<.7
H-7C	--	<570	--
H-8C	--	<1100	--
H-9C	--	<7200	--
H-10C	--	<6900	--
P-14	6.3	<1600	1.9
P-15	<.4	1200	<.4
P-17	10	12000	2.5
P-18	<.4	9800	<.4
WIPP-25	--	<3800	--
WIPP-26	--	<1800	--
WIPP-27	--	<15000	--
WIPP-28	--	<2800	--
WIPP-29	--	730	--
WIPP-30	--	<4500	--

Table 2.—Selected chemical and radiochemical analyses of water from test holes at and near the proposed Waste Isolation Pilot Plant site – Continued

WELL	DATE OF SAMPLE	GEO-LOGIC UNIT	DENSITY (GM/ML AT 20 C)	PH (UNITS)	ALKA-LINITY FIELD (MG/L AS CACO3)	BICAR-BONATE FET-FLD (MG/L AS HCO3)	CAR-BONATE FET-FLD (MG/L AS CO3)	NITRO-GEN, NO2+NO3 DIS-SOLVED (MG/L AS N)	SULFIDE TOTAL (MG/L AS S)	HARD-NESS (MG/L AS CACO3)
H-1	76-06-02	312CL3R	--	7.6	86	105	0	--	.0	3100
H-2B	77-02-22	312CL8R	--	8.4	57	59	5	.01	--	2400
H-3	77-03-17	312CL8R	--	7.4	94	115	0	.07	--	6500
H-4B	78-12-14	312CL8R	--	7.6	48	59	--	.02	--	2200
H-5B	78-12-19	312CL8R	--	6.8	34	41	--	.01	--	8700
H-6B	78-12-20	312CL8R	--	7.3	85	--	--	.02	--	7000
H-7B	80-03-20	312CL8R	1.001	7.0	100	--	--	.40	--	2000
H-9B	80-02-11	312CL8R	1.000	7.3	61	--	--	.95	--	2100
H-9B	80-02-05	312CL8R	--	7.3	90	--	--	.13	--	2100
H-10B	80-03-21	312CL8R	1.045	8.3	37	--	--	.01	--	8100
P-14	77-03-14	312CL8R	--	6.0	290	357	0	.01	--	11000
P-15	79-04-11	312CL3R	--	--	100	--	--	--	--	3100
P-17	77-05-10	312CL8R	--	7.4	63	77	0	.06	--	11000
P-18	77-05-10	312CL8R	--	7.2	254	310	0	.81	--	80000
WIPP-25	80-08-14	312CL8R	1.014	7.3	370	--	--	.67	.8	3300
WIPP-26	80-08-18	312CL8R	1.013	6.9	130	--	--	3.5	.0	4400
WIPP-27	80-08-22	312CL8R	1.094	6.4	150	--	--	4.0	.0	16000
WIPP-28	80-08-21	312CL8R	1.044	6.4	670	--	--	.09	10	4900
WIPP-29	80-08-20	312CL8R	1.178	6.1	210	--	--	.02	.0	26000
WIPP-30	80-08-13	312CL8R	1.072	6.8	74	--	--	1.2	.0	6300

WELL	HARD-NESS, NONCAR-BONATE (MG/L CACO3)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	SULFATE DIS-SOLVED (MG/L AS SO4)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	SILICA, DIS-SOLVED (MG/L AS SIO2)	BORON, DIS-SOLVED (UG/L AS B)	SOLIDS, RESIDUE AT 105 DEG. C, DIS-SOLVED (MG/L)
H-1	3000	780	280	9400	190	12000	7400	5.1	2.7	2400	--
H-2B	2300	690	160	2100	91	2800	3000	2.0	1.7	9500	9700
H-3	6400	1530	670	19000	630	29600	5700	.5	1.2	20000	62000
H-4B	2200	180	430	5800	180	7500	4000	1.9	5.2	19000	--
H-5B	8700	360	1900	53000	1400	86000	510	1.4	2.1	36000	--
H-6B	6900	1200	970	18000	500	28000	3800	1.5	8.5	9500	--
H-7B	1900	590	130	210	1.4	350	1900	1.4	39	780	--
H-9B	2100	570	170	82	4.7	57	2000	2.4	19	580	--
H-9B	2000	580	150	210	1400	320	2000	3.0	26	730	--
H-10B	8100	1600	1000	21000	520	36000	5600	1.3	1.5	13000	--
P-14	11000	3100	760	7600	600	20000	1400	.9	33	700	38000
P-15	3000	780	280	29000	7200	48000	7000	1.6	.6	5200	--
P-17	11000	1700	1600	30000	120	54000	5300	1.5	1.0	1700	97000
P-18	80000	5600	16000	9200	6200	80000	980	1.2	1.0	100000	420000
WIPP-25	3000	920	250	5100	.9	8300	2400	1.4	29	1900	--
WIPP-26	4300	1200	340	3600	2.0	8200	2300	1.5	20	1800	--
WIPP-27	16000	3100	2000	39000	100	77000	3900	.5	13	1900	--
WIPP-28	4300	1200	470	21000	4.0	30000	3200	1.1	28	5400	--
WIPP-29	25000	810	5700	79000	150	140000	13000	.7	11	1300	--
WIPP-30	6300	1100	870	37000	8.2	64000	2800	.5	1.5	23000	--

Table 2.—Selected chemical and radiochemical analyses of water from test holes at and near the proposed Waste Isolation Pilot Plant site — Continued

WELL	DATE OF SAMPLE	GEO-LOGIC UNIT	SELE-NIUM, TOTAL (UG/L AS SE)	GROSS ALPHA, DIS-SOLVED (PCI/L AS U-NAT)	GROSS ALPHA, SUSP. TOTAL (PCI/L AS U-NAT)	GROSS BETA, DIS-SOLVED (PCI/L AS CS-137)	GROSS BETA, SUSP. TOTAL (PCI/L AS CS-137)	RADIUM 226, DIS-SOLVED, RADON METHOD (PCI/L)	URANIUM DIS-SOLVED, EXTRAC-TION (UG/L)	GROSS ALPHA, DIS-SOLVED (UG/L AS U-NAT)
H-1	79-03-13	312CL3R	<1	<200	<.3	410	<.4	1.7	.16	<290
H-2B	77-02-22	312CL3R	2	--	--	120	110	4.6	--	330
H-3	77-03-17	312CL3R	2	--	--	850	<.4	57	.09	<880
H-4B	78-12-14	312CL3R	<1	--	--	310	--	67	2.9	720
H-5B	79-12-19	312CL3R	<1	2700	--	1100	--	290	1.0	4000
H-6B	78-12-20	312CL3R	5	--	--	<420	--	6.6	4.3	<1200
H-7B	80-03-20	312CL3R	--	<38	--	19	--	.98	9.7	<56
H-8B	80-02-11	312CL3R	--	62	<.3	<19	<.4	3.4	7.4	91
H-9B	80-02-05	312CL3R	--	--	--	<25	--	7.3	34	<100
H-10B	80-03-21	312CL3R	--	<1100	--	<590	--	29	.08	<1600
P-14	77-03-14	312CL3R	1	--	--	790	<.4	68	<.01	<390
P-15	79-04-11	312CL3R	4	<1300	<.3	4700	<.4	11	2.2	<1900
P-17	77-03-10	312CL3R	1	--	--	1300	<.4	84	.10	2900
P-18	77-03-10	312CL3R	<1	--	--	7700	.5	190	.33	<4300
WIPP-25	80-03-14	312CL3R	--	<200	--	<170	--	17	6.1	<290
WIPP-26	80-03-19	312CL3R	--	<260	--	<220	--	18	12	<380
WIPP-27	80-08-22	312CL3R	--	<1800	--	6300	--	79	4.9	<2600
WIPP-28	80-08-21	312CL3R	--	<1100	--	<1100	--	40	1.3	<1600
WIPP-29	80-08-20	312CL3R	--	<7500	--	18000	--	17	18	<11000
WIPP-30	80-08-13	312CL3R	--	<880	--	<660	--	64	.29	<1300

WELL	GROSS ALPHA, SUSP. TOTAL (UG/L AS U-NAT)	GROSS BETA, DIS-SOLVED (PCI/L AS SR/YT-90)	GROSS BETA, SUSP. TOTAL (PCI/L AS SR/YT-90)
H-1	<.4	390	<.4
H-2B	380	97	88
H-3	<.4	710	<.4
H-4B	--	290	--
H-5B	--	1000	--
H-6B	--	<390	--
H-7B	--	19	--
H-8B	<.4	<18	<.4
H-9B	--	<23	--
H-10B	--	<610	--
P-14	<.4	620	<.4
P-15	<.4	4300	<.4
P-17	<.4	1000	<.4
P-18	<.4	6100	.5
WIPP-25	--	<160	--
WIPP-26	--	<210	--
WIPP-27	--	6100	--
WIPP-28	--	<1000	--
WIPP-29	--	17000	--
WIPP-30	--	<600	--

Table 2.—Selected chemical and radiochemical analyses of water from test holes at and near the proposed Waste Isolation Pilot Plant site — Continued

WELL	DATE OF SAMPLE	GEOLOGIC UNIT	DENSITY (GM/ML AT 20 C)	PH (UNITS)	ALKALINITY FIELD (MG/L AS CACO3)	BICARBONATE FET-FLD (MG/L AS HCO3)	CARBONATE FET-FLD (MG/L AS CO3)	NITROGEN, NO2+NO3 DISSOLVED (MG/L AS N)	SULFIDE TOTAL (MG/L AS S)	HARDNESS (MG/L AS CACO3)
H-1	76-06-04	310MGNT	--	7.4	75	92	0	--	.0	3300
H-2A	77-02-22	310MGNT	--	8.6	61	74	0	.04	--	2700
H-3	77-05-10	310MGNT	--	8.0	42	51	0	.08	--	5000
H-4A	78-12-14	310MGNT	--	8.0	52	63	--	.01	--	2200
H-5A	78-12-14	310MGNT	--	7.8	41	50	--	.01	--	1300
H-6A	79-12-20	310MGNT	--	7.3	42	51	--	.03	--	2000
H-8A	80-02-12	310MGNT	1.006	9.3	26	--	--	.06	--	2200
H-9A	80-02-05	310MGNT	1.003	8.5	35	--	--	.02	--	2100
H-10A	80-03-21	310MGNT	1.175	7.1	0	--	--	.03	--	17000
WIPP-25	80-09-04	310MGNT	1.010	7.5	150	--	--	.64	1.2	3300
WIPP-27	80-07-24	310MGNT	1.080	6.8	57	--	--	.32	--	11000
	80-09-20	310MGNT	--	6.5	180	--	--	.40	1.8	17000
WIPP-30	80-09-24	310MGNT	--	8.8	62	--	--	.00	.0	2400

WELL	HARDNESS, NONCARBONATE (MG/L CACO3)	CALCIUM DISSOLVED (MG/L AS CA)	MAGNESIUM, DISSOLVED (MG/L AS MG)	SODIUM, DISSOLVED (MG/L AS NA)	POTASSIUM, DISSOLVED (MG/L AS K)	CHLORIDE, DISSOLVED (MG/L AS CL)	SULFATE DISSOLVED (MG/L AS SO4)	FLUORIDE, DISSOLVED (MG/L AS F)	SILICA, DISSOLVED (MG/L AS SIO2)	BORON, DISSOLVED (UG/L AS B)	SOLIDS, RESIDUE AT 105 DEG. C, DISSOLVED (MG/L)
H-1	3300	890	270	5700	70	8000	3900	2.8	1.3	2200	--
H-2A	2700	820	170	2700	81	4100	2400	--	6.0	220	12000
H-3	4900	1200	480	9300	250	15000	3400	1.8	6.4	13000	32000
H-4A	2100	210	410	7000	130	7500	7000	2.5	6.4	13000	--
H-5A	1300	240	170	1500	53	830	3200	2.8	9.0	11000	--
H-6A	2000	520	160	1100	46	1200	2700	1.4	7.7	2500	--
H-8A	2200	870	17	2400	84	3500	2100	.7	.9	3100	--
H-9A	2000	550	170	800	28	750	2700	1.8	3.3	2600	--
H-10A	17000	2500	2600	93000	510	160000	2700	1.3	1.9	3900	--
WIPP-25	3100	910	240	3100	.8	5600	1900	1.5	25	1900	--
WIPP-27	11000	1100	1900	34000	1800	61000	9400	.0	1.7	26000	--
	17000	3600	2000	43000	10000	95000	2900	.4	13	230	--
WIPP-30	2400	690	170	5500	190	8700	3200	1.9	.7	12000	--

Table 2.—Selected chemical and radiochemical analyses of water from test holes at and near the proposed Waste Isolation Pilot Plant site — Concluded

WELL	DATE OF SAMPLE	GEOLOGIC UNIT	SELENIUM, TOTAL (UG/L AS SE)	GROSS ALPHA, DISSOLVED (PCI/L AS U-NAT)	GROSS ALPHA, SUSP. TOTAL (PCI/L AS U-NAT)	GROSS BETA, DISSOLVED (PCI/L AS CS-137)	GROSS BETA, SUSP. TOTAL (PCI/L AS CS-137)	RADIUM 226, DISSOLVED, RADON METHOD (PCI/L)	URANIUM DISSOLVED, EXTRACTION (UG/L)	GROSS ALPHA, DISSOLVED (UG/L AS U-NAT)
H-1	77-05-10	310MGNT	1	--	--	940	<.4	170	.60	<400
H-2A	77-02-22	310MGNT	1	--	--	69	2.6	6.1	.80	<160
H-3	77-05-10	310MGNT	7	--	--	330	<.4	44	--	550
	79-05-10	310MGNT	1	<420	.3	1300	.4	10	.24	<620
H-4A	78-12-14	310MGNT	<1	--	--	<100	--	9.3	.08	<320
H-5A	78-12-14	310MGNT	<1	--	--	53	--	17	1.0	160
H-6A	78-12-20	310MGNT	1	--	--	43	--	11	6.7	110
H-8A	80-02-12	310MGNT	--	<140	<.3	130	<.4	1.9	.08	<200
H-9A	80-02-05	310MGNT	--	--	--	<38	--	9.4	.15	<150
H-10A	80-03-21	310MGNT	--	<5300	--	<3500	--	480	<.10	<7800
WIPP-25	80-09-04	310MGNT	--	<160	--	<140	--	12	8.4	<230
WIPP-27	80-07-24	310MGNT	--	--	--	1900	--	12	--	--
	80-09-20	310MGNT	--	<2000	--	6000	--	24	5.8	<2900
WIPP-30	80-09-24	310MGNT	--	<300	--	<200	--	26	.02	<440

WELL	GROSS ALPHA, SUSP. TOTAL (UG/L AS U-NAT)	GROSS BETA, DISSOLVED (PCI/L AS SR/YT-90)	GROSS BETA, SUSP. TOTAL (PCI/L AS SR/YT-90)
H-1	<.4	790	<.4
H-2A	12	55	2.0
H-3	<.4	260	<.4
	.4	1200	.4
H-4A	--	<92	--
H-5A	--	48	--
H-6A	--	39	--
H-8A	<.4	130	<.4
H-9A	--	<35	--
H-10A	--	<3600	--
WIPP-25	--	<130	--
WIPP-27	--	1800	--
	--	5800	--
WIPP-30	--	<190	--

Table 3.--Stratigraphic summary of rock units of Permian (Guadalupian and Ochoan) and younger age underlying the proposed Waste Isolation Pilot Plant site and adjacent areas

Age				Rock unit	Thickness (feet)	Description
Quaternary	Holocene			Alluvium and sand of Mescalero surface	0-19	Dune sand, uniformly fine grained, light-brown to reddish-brown
						UNCONFORMITY
				Mescalero caliche	0-5	Limestone, chalky, includes fragments of underlying rock
						UNCONFORMITY
	Plio-cene (?)			Gatuna Formation	0-32	Sandstone and siltstone, poorly indurated, dominantly reddish-orange
						UNCONFORMITY
Triassic	Late Triassic			Chinle Formation	0-800	Mudstone, shaly with lenses of sandstone and conglomerate
				Santa Rosa Sandstone	0-255	Sandstone, medium- to coarse-grained, commonly cross-stratified, gray and yellowish-brown, contains conglomerate and reddish-brown mudstone
						UNCONFORMITY
Permian	Ochoan			Dewey Lake Red Beds	250-541	Siltstone and sandstone, very fine to fine-grained, reddish-orange to reddish-brown, contains interbedded reddish-brown claystone, small-scale lamination and cross-stratification common
						UNCONFORMITY
				Rustler Formation	298-462	Anhydrite and halite with subordinate dolomite, sandstone, claystone, and polyhalite; includes Magenta Dolomite and Culebra Dolomite Members
				Salado Formation	2,000±	Halite with subordinate anhydrite, polyhalite, potash ores, sandstone, and magnesite
				Castile Formation	1,300±	Anhydrite and halite with subordinate limestone
	Guadalupian	Guadalupian reef complex	Delaware Mountain Group	Bell Canyon Formation	1,000±	Sandstone, brown and gray, with minor limestone and shale
				Cherry Canyon Formation	1,000±	Sandstone, gray and brown, with limestone and minor shale
				Brushy Canyon Formation	1,000±	Sandstone, gray, with brown and black shale and brown limestone

Modified from Bachman, 1980

Table 4.—Summary of drill-stem tests at test holes AEC-7, AEC-8, and ERDA-10, upper Bell Canyon Formation, in the vicinity of the proposed Waste Isolation Pilot Plant site

Test number	Date of test	Tested interval, in feet below	Type of test	Hydrostatic pressure, in pounds per square inch (gage)		Flow period in minutes	Bottom hole flowing pressure, in pounds per square inch (gage)		Shut-in period, in minutes	Bottom hole shut-in pressure, in pounds per square inch (gage)		Calculated hydraulic conductivity, in feet per day	Static bottom hole pressure (extrapolated), in pounds per square inch (gage)	Fluid density, in grams per cubic centimeter
				Initial	Final		Initial	Final		Initial	Final			
Test Hole AEC-7														
1	4-23-79	4520-4583 (Lamar)	Standard	2,841	2,462	30	30	23	60	23	23	Insufficient Data to Make Calculation	–	–
						120	23	23	360	23	25			
						360	25	21	480	21	23			
2	4-27-79	4609-4714 (Ramsey)	Standard	2,547	2,531	25	127	395	60	395	1,814	4×10^{-2}	1,883	1.130
						60	460	804	120	804	1,808			
						120	861	1,270	335	1,270	1,839			
3	4-28-79	4493-4714 (Upper Bell Canyon)	Standard	2,479	2,466	10	120	314	60	314	1,764	4×10^{-2}	1,811	1.130
						60	352	717	120	717	1,737			
						120	770	1,188	350	1,188	1,768			
Test Hole AEC-8														
1	8-15-77	4844-4800 (pre Ramsey lower sand)	Modified	–	–	–	–	–	–	–	–	2×10^{-2}	2,037	1.147
2	9-27-77	4821-4827 (upper sand)	Modified	–	–	–	–	–	–	–	–	7×10^{-3}	2,044	1.060
7	7-24-76	4304-4405 (Lamar)	Standard	2,445	–	30	13	18	121	18	1,761	2×10^{-6}	1,813	–
						58	24	32	748	32	1,788			
Test Hole ERDA-10														
9	9-19-77	3860-3927 (Lamar)	Standard	2,083	2,054	30	51	58	120	58	1,708	4×10^{-4}	1,783	–
						120	75	106	360	106	1,684			
						480	112	215	240	215	1,511			
10	9-29, 30-77	4127-4430 (Ramsey)	Modified	–	–	–	–	–	–	–	–	5×10^{-2}	1,820	1.165

Table 5.—Major cations and anions in water from test holes AEC-7, AEC-8, and ERDA-10 completed in the upper part of the Bell Canyon Formation, in the vicinity of the proposed Waste Isolation Pilot Plant site

[meq/L, milliequivalent per liter; mg/L, milligrams per liter; percent, percentage composition]

Test Hole AEC-7

Cations											Anions					
Calcium			Magnesium			Sodium			Potassium			Chloride			Sulfate		
mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent
9,700	484	7.7	2,600	213.9	3.4	55,000	2,392.5	37.8	970	24.8	0.4	110,000	3,103.1	49	1,800	37.5	0.6

Test Hole AEC-8

Cations											Anions					
Calcium			Magnesium			Sodium			Potassium			Chloride			Sulfate		
mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent
10,000	499	8.1	2,500	205.7	3.3	55,000	2,392.5	38.6	860	22	.4	120,000	3,068.4	49.5	240	5	.1

Test Hole ERDA-10

Cations											Anions					
Calcium			Magnesium			Sodium			Potassium			Chloride			Sulfate		
mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent
5,300	264.5	3.1	1,300	106.9	1.3	89,000	3,871.5	45.3	720	18.4	.2	150,000	4,231.5	49.5	2,400	50	.6

Table 6.—Measured and density-corrected water levels in selected test holes completed in the Rustler-Salado contact residuum at and near the proposed Waste Isolation Pilot Plant site

Test Hole	Altitude of land surface, in feet above sea level	Water level		Density, in grams per cubic centimeter	Freshwater equivalent corrected water level	
		Feet below land surface	Altitude, in feet above sea level		Feet below land surface	Altitude, feet above sea level
H-2c	3,397.7	343	3,035	1.225	258	3,140
H-4c	3,333.5	411	2,923	1.215	365	2,969
H-6c	3,347.9	410.5	2,937	1.210	345	3,003
H-7c	3,163.5	205.7	2,958	1.048	197	2,967
H-8c	3,433.0	463	2,970	1.129	421	3,012
P-14	3,359.6	389	2,971	1.126	351	3,009
P-15	3,309.5	313.9	2,996	1.160	278	3,032
P-17	3,335.9	365	2,971	1.193	297	3,039
W-25	3,212.5	238.4	2,974	1.093	206	3,007
W-26	3,151.9	191.7	2,960	1.189	168	2,984
W-27	3,177.2	192	2,985	1.207	126	3,051
W-28	3,346.8	303	3,044	1.152	259	3,088
W-29	2,977	17.6	2,959	1.129	+12	2,989
W-30	3,427.5	307	3,121	1.204	218	3,210

Table 7.—Values of transmissivity and storage coefficient for water-bearing zones in the Rustler Formation penetrated by selected test holes at and near the proposed Waste Isolation Pilot Plant site

[Transmissivity is expressed in feet squared per day]

Test hole	Magenta Dolomite Member		Culebra Dolomite Member		Rustler-Salado Contact	
	Transmissivity	Storage	Transmissivity	Storage	Transmissivity	Storage
H-1	0.05	-	0.07	10^{-4}	0.0003	-
H-2a	.01	10^{-4}				
H-2b			0.4	10^{-9}		
H-2c					0.0001	-
H-3	.1	10^{-5}	19.0	-	0.0003	10^{-4}
H-4a	.06	10^{-6}				
H-4b			0.9	10^{-9}		
H-4c					0.0006	10^{-4}
H-5a	.1	10^{-5}				
H-5b			0.2	10^{-5}		
H-5c					.00003	10^{-3}
H-6a	.3	10^{-5}				
H-6b			73.0	-		
H-6c					.003	10^{-6}
H-7a	Dry	-				
H-7b			1000+	-		
H-7c					0.73	-
H-8a	.006	10^{-5}				
H-8b			16.0	-		
H-8c					0.003	-
H-9a	1.0	10^{-9}				
H-9b			231	-		
H-9c					0.0002	-
H-10a	0.01	10^{-3}				
H-10b			0.07	10^{-4}		
H-10c					0.00009	-
P-14			140	-	0.05	-
P-15			0.07	10^{-4}	0.0004	-
P-17			1.0	10^{-6}	0.0002	10^{-4}
P-18			0.001	-	0.00003	10^{-5}
W-25	375	-	270	-	5.0	10^{-3}
W-26	Dry	-	1250	-	0.4	-
W-27	53	-	650	-	0.0002	-
W-28	Dry	-	18	-	0.87	-
W-29	Not present		1000	-	8	-
W-30	0.004	-	0.3	10^{-4}	0.2	10^{-4}

Table 8.—Major cations and anions in water from the Rustler Formation, Magenta Dolomite Member, Culebra Dolomite Member, and Rustler-Salado contact residuum at and near the proposed Waste Isolation Pilot Plant site

[meq/L, milliequivalent per liter; mg/L, milligrams per liter; percent, percentage composition]

	Cations											Anions					
	Calcium			Magnesium			Sodium			Potassium			Chloride			Sulfate		
	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent
Test Hole H-1																		
*Magenta	890	44.4	7.1	270	22.2	3.6	5,700	248	39.8	70	1.8	0.3	8,000	225.7	36.2	3,900	81.2	13
*Culebra	780	38.9	4	280	23	2.4	9,400	408.9	42.2	190	4.9	.5	12,000	338.5	35	7,400	154.1	15.9
*Rustler-Salado	13,000	648.7	5.4	30,000	2467.8	20.7	56,000	2,436	20.4	17,000	434.7	3.6	210,000	5924.1	49.7	520	10.8	.1
Test Hole H-2A																		
*Magenta	820	40.9	12	170	14	4.1	2,700	117.5	34.5	81	2.1	.6	4,100	115.7	34	2,400	50	14.7
Test Hole H-2B																		
*Culebra	690	34.4	12.2	160	13.2	4.7	2,100	91.4	32.3	91	2.3	.8	2,800	79	27.9	3,000	62.5	22.1
Test Hole H-2C																		
*Rustler-Salado	9,200	459.1	4.1	25,000	2056.5	18.2	66,000	2,871	25.4	9,100	232.7	2.1	200,000	5,642	50.2	1,300	27.1	.2
Test Hole H-3																		
*Magenta	1,200	59.9	6.0	480	39.5	3.9	9,300	404.6	40.3	250	6.4	.6	15,000	423.2	42.1	3,400	70.8	7.1
*Culebra	1,500	74.9	3.9	670	55.1	2.9	19,000	826.5	42.9	630	16.1	.8	29,600	835	43.3	5,700	118.7	6.2
*Rustler-Salado	18,000	898.2	7.6	25,000	2056.1	17.4	59,000	2566.5	21.7	14,000	358	3	210,000	5924.1	50.2	370	7.7	.1

*Hydrologic unit

Table 8.—Major cations and anions in water from the Rustler Formation, Magenta Dolomite Member, Culebra Dolomite Member, and Rustler-Salado contact residuum at and near the proposed Waste Isolation Pilot Plant site – Continued

	Cations											Anions					
	Calcium			Magnesium			Sodium			Potassium			Chloride			Sulfate		
	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent
Test Hole H-4A																		
*Magenta	210	10.5	1.5	410	33.7	4.8	7,000	304.5	42.9	130	3.3	.5	7,500	211.6	29.8	7,000	145.7	20.5
Test Hole H-4B																		
*Culebra	180	9	1.5	430	35.4	5.9	5,800	252.3	42.3	180	4.6	.8	7,500	211.6	35.5	4,000	83.3	14
Test Hole H-4C																		
*Rustler-Salado	8,300	414.2	3.5	27,000	2,221	19	66,000	2,871	24.6	8,600	219.9	1.9	210,000	5924.1	50.7	1,400	29.1	.2
Test Hole H-5A																		
*Magenta	240	12	6.5	170	14	7.6	1,500	65.3	35.5	53	1.4	.7	880	24.8	13.5	3,200	66.6	36.2
Test Hole H-5B																		
*Culebra	360	18	.4	1,900	156.3	3.2	53,000	2305.5	46.5	1,400	35.8	.7	86,000	2426.1	48.9	810	16.9	.3
Test Hole H-5C																		
*Rustler-Salado	2,100	104.8	.6	82,000	6745.3	41.6	14,000	609	3.8	21,000	537	3.3	290,000	8180.9	50.4	2,000	41.6	.3
Test Hole H-6A																		
*Magenta	520	25.9	14.6	160	13.2	7.4	1,100	47.9	26.9	46	1.2	.7	1,200	33.9	19	2,700	56.2	31.5
Test Hole H-6B																		
*Culebra	1,200	59.9	3.3	970	79.8	4.4	18,000	783	43.4	500	12.8	.7	28,000	789.9	43.8	3,800	79.1	4.4
Test Hole H-6C																		
*Rustler-Salado	4,200	209.6	1.9	21,000	1727.5	15.3	80,000	3,480	30.8	8,000	204.6	1.8	200,000	5,642	49.9	2,000	41.6	.4

*Hydrologic unit

Table 8.—Major cations and anions in water from the Rustler Formation, Magenta Dolomite Member, Culebra Dolomite Member, and Rustler-Salado contact residuum at and near the proposed Waste Isolation Pilot Plant site – Continued

	Cations											Anions					
	Calcium			Magnesium			Sodium			Potassium			Chloride			Sulfate		
	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent
Test Hole H-7A																		
*Magenta (Dry)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Test Hole H-7B																		
*Culebra	590	29.4	29.7	130	10.7	10.8	9.1	18.5	9.2	1.4	0.03	0.1	350	9.9	10	1,900	39.6	40
Test Hole H-7C																		
*Rustler-Salado	2,600	129.7	5.4	910	74.9	3.1	22,000	957	40.1	210	5.4	.2	41,000	1156.7	48.5	2,900	60.4	2.4
Test Hole H-8A																		
*Magenta	870	43.4	14.8	1.4	.9	.5	2,400	104.4	35.5	84	2.1	.7	3,500	98.7	33.6	2,100	43.7	14.9
Test Hole H-8B																		
*Culebra	570	28.4	31.8	170	14	15.7	82	3.6	4	4.7	.1	.1	57	1.6	1.8	2,000	41.6	46.6
Test Hole H-8C																		
*Rustler-Salado	1,200	59.9	.2	430	35.4	.8	46,000	2001	47.7	660	16.9	.4	70,000	1974.7	47	5,300	110.3	2.6
Test Hole H-9A																		
*Magenta	550	27.4	17.8	170	14	18.2	800	34.8	22.6	28	.7	.1	750	21.2	13.7	2,700	56.2	36.4
Test Hole H-9B																		
*Culebra	580	28.9	21.2	150	12.3	9	210	9.1	6.7	1,400	35.8	26.2	320	9	6.6	2,000	41.6	30.5

*Hydrologic unit

Table 8.—Major cations and anions in water from the Rustler Formation, Magenta Dolomite Member, Culebra Dolomite Member, and Rustler-Salado contact residuum at and near the proposed Waste Isolation Pilot Plant site – Continued

	Cations										Anions					
	Calcium			Magnesium			Sodium			Potassium			Chloride			Sulfate		
	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent
Test Hole H-9C																		
*Rustler-Salado	1,300	64.9	.1	870	71.6	.6	130,000	5,665	50.5	1,200	30.7	.3	190,000	5359.9	47.8	2,600	54.1	.5
Test Hole H-10A																		
*Magenta	2,500	124.7	1.4	2,600	213.9	2.4	93,000	4045.5	45.1	510	13	.1	160,000	4513.6	50.3	2,700	56.2	.6
Test Hole H-10B																		
*Culebra	1,600	79.8	3.6	1,000	82.3	3.7	21,000	913.5	41.1	520	13.3	.6	36,000	1015.6	45.7	5,600	116.6	5.2
Test Hole H-10C																		
*Rustler-Salado	1,500	74.9	.7	11,000	904.9	8.1	100,000	4,350	38.8	4,000	102.3	.9	190,000	5359.9	47.8	3,300	68.7	.6
Test Hole P-14																		
*Culebra	3,100	154.7	13.4	760	62.5	5.4	7,600	330.6	28.6	600	15.3	1.3	20,000	564.2	48.8	1,400	29.2	2.5
*Rustler-Salado	570	28.4	.3	1,200	98.7	.9	120,000	5,220	48.9	1,300	33.2	.3	180,000	5077.8	47.6	10,000	208.2	2
Test Hole P-15																		
*Culebra	770	38.4	5	63	5.2	.7	6,900	300.2	39.3	1,700	43.5	5.7	11,000	310.3	40.6	3,200	66.6	8.7
*Rustler-Salado	770	38.4	1.7	350	28.8	1.3	24,000	1,044	45.8	1,400	35.8	1.6	38,000	1,072	47.1	2,800	58.3	2.6
Test Hole P-17																		
*Culebra	1,700	84.6	2.6	1,600	131.6	4.1	30,000	1,305	41.4	120	3.1	.1	54,000	1,523	48.3	5,000	104.1	3.3

*Hydrologic unit

Table 8.—Major cations and anions in water from the Rustler Formation, Magenta Dolomite Member, Culebra Dolomite Member, and Rustler-Salado contact residuum at and near the proposed Waste Isolation Pilot Plant site – Continued

	Cations										Anions					
	Calcium			Magnesium			Sodium			Potassium			Chloride			Sulfate		
	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent
Test Hole P-17 – Continued																		
*Rustler-Salado	15,000	748.5	7.2	40,000	3290.4	31.7	23,000	1000.5	9.6	8,800	22.5	2.2	180,000	5077.8	50	1,200	25	.2
Test Hole P-18																		
*Culebra	5,600	279.4	6.3	16,000	1316.2	29.7	9,200	400.2	9	6,200	158.5	3.5	80,000	2256.8	50.9	98	20.4	0.5
*Rustler-Salado	10,000	499.8	4.1	37,000	3043.6	25	48,000	2,088	17.2	12,000	306.8	2.5	220,000	6,206	57.1	480	10	.1
Test Hole W-25																		
*Magenta	910	45.4	11.4	240	19.7	5	3,100	134.9	33.9	0.8	.02	.1	5,600	158	39.7	1,900	39.6	10
*Culebra	920	45.9	8	250	20.6	3.6	5,100	221.9	38.7	.9	.02	.1	8,300	234.1	40.6	2,400	50	8.7
*Rustler-Salado	650	32.4	.4	3,200	263.2	3.2	90,000	3,915	47.8	2,400	61.4	.7	130,000	3667.3	44.8	12,000	250	3.1
Test Hole W-26																		
*Magenta (Dry)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Culebra	1,200	59.9	11.4	340	28	5.3	3,600	156.6	29.9	2	.05	.1	8,200	231.3	44.2	2,300	47.9	9.1
*Rustler-Salado	2,700	134.7	2.6	1,300	106.9	2.1	52,000	2,262	43.8	1,000	25.6	.5	88,000	2482.5	48	7,600	158.2	3.1
Test Hole W-27																		
*Magenta	3,600	179.6	3.6	2,000	164.5	3.3	43,000	1870.5	38	10,000	255.7	5.2	85,000	2397.9	48.7	2,900	60.4	1.2

*Hydrologic unit

Table 8.—Major cations and anions in water from the Rustler Formation, Magenta Dolomite Member, Culebra Dolomite Member, and Rustler-Salado contact residuum at and near the proposed Waste Isolation Pilot Plant site – Concluded

	Cations										Anions					
	Calcium			Magnesium			Sodium			Potassium			Chloride			Sulfate		
	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent
Test Hole W-27 – Continued																		
*Culebra	2,700	134.7	3.3	1,740	143.1	3.5	38,500	1674.8	40.8	714	18.3	.4	73,300	2069.8	50.3	3,300	68.7	1.7
*Rustler-Salado	1,160	57.9	.6	1,040	85.6	.9	102,000	4437.3	48.8	2,570	65.7	.7	154,000	4344.3	47.7	5,190	108.1	1.2
Test Hole W-28																		
*Magenta (Dry)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Culebra	1,200	59.9	3.1	470	38.7	2	21,000	913.5	47.4	4	.1	.1	30,000	846.3	44	3,200	66.6	3.5
*Rustler-Salado	615	30.7	.5	2,070	170.3	2.8	65,000	2877.5	45.7	2,070	52.9	.8	102,000	2877.4	46.5	11,000	229.1	3.7
Test Hole W-29																		
*Not present	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Culebra	698	34.8	.5	3,750	308.5	4.2	67,600	2940.6	40.2	12,700	324.7	4.4	123,000	3469.8	47.6	11,200	232.2	3.2
*Rustler-Salado	850	42.4	1.3	2,000	164.5	5.1	32,000	1,392	42.7	1000	25.6	.8	49,000	1382.3	42.4	12,000	250	7.8
Test Hole W-30																		
*Magenta	690	34.4	5.7	170	14	2.3	5,500	239.3	39.6	190	4.9	.1	8700	245.4	40.6	3,200	66.6	11
*Culebra	1,010	50.4	1.5	804	66.1	2	35,500	1544.3	45.7	888	22.7	.7	56,500	1593.9	47.1	5,050	105.1	3.1
*Rustler-Salado	850	42.4	.4	2,300	189.2	1.8	120,000	5,220	50	1,500	38.4	.4	170,000	4,795	45.9	7,000	145.7	1.4

*Hydrologic unit

Table 9.—Measured and density-corrected water levels in selected test holes completed in the Culebra Dolomite Member of the Rustler Formation at and near the proposed Waste Isolation Pilot Plant site

Test Hole	Altitude of land surface, in feet above sea level	Water level		Density, in grams per cubic centimeter	Freshwater equivalent corrected water level	
		Feet below land surface	Altitude, in feet above sea level		Feet below land surface	Altitude, feet above sea level
H-1	3,397.7	382.5	3,015	1.016	378	3,020
H-2b	3,377.7	348.7	3,029	1.012	345	3,033
H-3	3,389.5	397.0	2,992	1.024	289	3,000
H-4b	3,332.9	340.8	2,992	1.024	237	2,996
H-5b	3,505.9	485.2	3,021	1.106	439	3,067
H-6b	3,347.6	298.8	3,049	1.040	287	3,061
H-7b	3,163.6	170.2	2,993	1.001	170	2,993
H-8b	3,433.8	443.7	2,990	1.0035	443	2,991
H-9b	3,405.6	425.8	2,980	1.002	426	2,980
H-10b	3,687	697.8	2,989	1.044	667	3,020
P-14	3,359.6	320.1	3,040	1.018	316	3,044
P-15	3,309.5	305.4	3,004	1.080	295	3,014
P-17	3,335.9	367.3	2,967	1.082	348	2,986
P-18	-	-	-	-	-	-
W-25	3,212.5	165	3,048	1.010	162	3,051
W-26	3,151.9	146	3,006	1.013	145	3,007
W-27	3,177.2	105	3,072	1.094	85	3,092
W-28	3,346.8	277	3,070	1.044	270	3,077
W-29	2,977	8.2	2,969	1.178	2	2,975
W-30	3,427.5	412	3,016	1.072	395	3,033

Table 10.—Measured and density-corrected water levels in selected wells completed in the Magenta Dolomite Member of the Rustler Formation at and near the proposed Waste Isolation Pilot Plant site

Test Hole	Altitude of land surface, in feet above sea level	Water level		Density, in grams per cubic centimeter	Freshwater equivalent corrected water level	
		Feet below land surface	Altitude, in feet above sea level		Feet below land surface	Altitude, feet above sea level
H-1	3,397.7	246.50	3,151	1.021	240	3,158
H-2a	3,377.9	233.07	3,145	1.012	230	3,148
H-3	3,389.5	238.30	3,151	1.010	234	3,155
H-4a	3,332.9	189.3	3,144	1.017	186	3,147
H-5a	3,506.2	344.5	3,162	1.008	342	3,165
H-6a	3,347.3	289.8	3,056	1.007	287	3,059
H-7a	-	-	-	-	-	-
H-8a	3,433.0	405.1	3,028	1.008	404	3,029
H-9a	3,405.4	282.0	3,123	1.004	281	3,124
H-10a	3,686.5	586.8	3,100	1.171	469	3,218
W-25	3,212.5	159.0	3,054	1.010	158	3,055
W-27	3,177.2	102.0	3,075	1.095	93	3,084
W-28	3,346.8	202.8	3,144	1.048	198	3,149

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IMPLEMENTATION OF THE RESOURCE DISINCENTIVE IN 40 CFR Part 191.14(e) AT THE WASTE ISOLATION PILOT PLANT

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LIST OF ACRONYMS

ADM	Action Description Memorandum
AEC	Atomic Energy Commission
AECL	Atomic Energy Commission Limited (Canada)
BLM	Bureau of Land Management
BMI	Battelle Memorial Institute (Columbus, Ohio)
BNWL	Battelle Northwest Laboratory
C&C	Consultation and Cooperation Agreement
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
DOE	Department of Energy
DOE-WPIO	U.S. Department of Energy Waste Isolation Pilot Plant Project Integration Office
DOE-WPO	U.S. Department of Energy Waste Isolation Pilot Plant Project Office (now DOE-WPSO)
DOE-WPSO	U.S. Department of Energy Waste Isolation Pilot Plant Project Site Office
EEG	Environmental Evaluation Group
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
ERDA	Energy Research and Development Administration
ESAB	EPA Scientific Advisory Board
FEIS	Final Environmental Impact Statement
FSAR	Final Safety Analysis Report
FSEIS	Final Supplement Environmental Impact Statement
GCR	Geologic Characterization Report
IAEA	International Atomic Energy Agency
NAS	National Academy of Sciences
NEPA	National Environmental Policy Act
NMBM&MR	New Mexico Bureau of Mines and Mineral Resources
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
RDR	Resource Disincentive Requirement
ROD	Record of Decision
SAR	Safety Analysis Report
SNL	Sandia National Laboratories
SPDV	Site and Preliminary Design Validation
TRU	Transuranic
USBM	United Stated Bureau of Mines

LIST OF ACRONYMS
(continued)

USGS	United States Geological Survey
WIPP	Waste Isolation Pilot Plant
WPIO	See DOE-WPIO
WPO	See DOE-WPO
WPSO	See DOE-WPSO

1.0 INTRODUCTION

1.1 Purpose

In 1986, the U.S. Department of Energy (DOE) Waste Isolation Pilot Plant (WIPP) Project Office (WPO) (DOE-WPO) prepared a strategy[1] for complying with the Environmental Protection Agency's (EPA's) Standards for the management of transuranic (TRU) waste.[2] Section 3.2.2.2 of the DOE's report addressed compliance with the Assurance Requirements found in 40 CFR §191.14[3]. One of the Assurance Requirements addresses the selection of repository sites that contain recoverable natural resources. The requirement, referred to as the Resource Disincentive Requirement, reads as follows:

> *Places where there has been mining for resources, or where there is a reasonable expectation of exploration for scarce or easily accessible resources, or where there is significant concentration of any material that is not widely available from other sources, should be avoided in selecting disposal sites. Resources to be included shall include minerals, petroleum or natural gas, valuable geologic formations, and ground waters that are either irreplaceable because there is no reasonable alternative source of drinking water available for substantial populations or that are vital to the preservation of unique and sensitive ecosystems. Such places shall not be used for disposal of the wastes covered by this part unless the favorable characteristics of such places compensate for their greater likelihood of being disturbed in the future.*[4]

The DOE states, in the strategy document, that the "*natural resources requirement has been addressed during the course of the WIPP Project. A finding will be prepared to show that the favorable characteristics of the disposal site compensate for the greater likelihood of disturbance because of the presence of natural resources.*"[5] This position was developed based on both EPA and Environmental Evaluation Group (EEG) comments to the draft of the compliance strategy. Specifically, the EPA stated, with regard to the comparison of favorable characteristics and resources, that the "*two factors must not only be 'weighed' and 'summarized', but a finding must be documented that the favorable characteristics compensate for the greater likelihood of WIPP being disturbed because of the presence of the natural resources.*"[6] Likewise, the EEG stated that "*something more than a 'summarized' discussion will be needed*" and that they expect "*a detailed report*

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[1] Westinghouse Electric Corp., 1989.

[2] U. S. Environmental Protection Agency, 1985a.

[3] U.S. Environmental Protection Agency, 1985a, pp. 38086.

[4] U.S. Environmental Protection Agency, 1985a, p. 38086.

[5] Westinghouse Electric Corp., 1989, pp. 35-36.

[6] U.S. Environmental Protection Agency, 1987.

analyzing the valuable and rare resources available at WIPP compared to any favorable characteristics."[7]

This document addresses 40 CFR §191.14 (e). The approach is to first summarize the development of the resource requirement to provide a proper perspective for evaluation of WIPP compliance. In addition, a summary of the discussions regarding resources at the WIPP is provided to demonstrate the extent to which the topic has been discussed between the DOE and various oversight groups. Finally, the process of selecting the WIPP site as a repository is shown to be in compliance with the resource disincentive requirement.

This report recognizes that in 1987, 40 CFR 191 was vacated and remanded by the First Circuit Court (National Resources Defense Council, et al. v. United States Environmental Protection Agency, et al.). The DOE believes that when a new standard is promulgated, the Assurance Requirements of 40 CFR 191 will remain intact, and therefore need to be addressed by the WIPP. In the second modification to the Consultation and Cooperation (C&C) Agreement with the state of New Mexico, it is stated that "*DOE agrees to continue its performance assessment planning as though the provisions of 40 CFR Part 191 effective November 19, 1985, remain applicable*"[8]

This report documents that the site selection process for the WIPP facility did indeed comply with the natural resource disincentive requirement in 40 CFR §191,14(e) at the time selected and therefore complies with the standard at this time. Thus, it shall be shown that it is reasonably certain that the WIPP site provides better **overall protection** than **practical alternatives** that were available when the site was selected. It is important to point out here, and it will be discussed later in the report, that the resource disincentive requirement is a preliminary siting criterion that requires further evaluation of sites that have resources (i.e, hydrocarbons, minerals and groundwater) in the vicinity or on the site. This further evaluation requires that for sites that do have resources, a qualitative determination must be made that the site will provide better **overall protection** than **practical alternatives.** The purpose of this report is not to provide a quantitative evaluation for selection of the WIPP site. A further discussion on the difference between the qualitative analysis required under 40 CFR §191.14(e) and the quantitative analysis under other sections of 40 CFR 191 is provided in §2.1 of this report.

1.2 Background

When the Congress of the United States enacted the National Environmental Policy Act (NEPA) of 1969, they recognized the conflict over the management of natural resources. Congress mandated that federal agencies find a balance between the social, economic, and other requirements of present and future generations of Americans and the critical importance of restoring and maintaining environmental quality. Federal agencies are required by the law to "*achieve a balance between population and resource use...*"[9] In

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[7] Environmental Evaluation Group, 1987.

[8] U.S. Department of Energy, 1987, p. 5.

[9] U. S. Congress, 1969.

this regard, federal agencies must provide statements which address "*Any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented.*"[10] The vehicle for documenting the consideration of resource conflicts and the commitment of resources is the Environmental Impact Statement (EIS) prepared for a federal project.

For waste repositories, such as the WIPP, consideration of "resource conflicts" in the decision making process, as required by the NEPA, is multifaceted. Of course, consideration must be given to the resources consumed by the construction and operation of the facility (e.g., building materials, fuels, and land resources). These considerations are the most common resource commitments that federal agencies address in their EISs. In addition to these, resources associated with the WIPP must be considered from two additional aspects. First, there are **denied resources.** These are resources that cannot be developed because such development may conflict with the long-term goal of waste isolation. Second, there are the risks associated with **resource attractiveness.** That is, resources associated with the location may be attractive to future generations, who may elect to exploit them, and thereby create the potential for a release of waste into the biosphere.

Resource attractiveness concerned the EPA when they promulgated the natural resources assurance requirement in 40 CFR 191.[11] Compliance with this part of 40 CFR 191 is the subject of this paper.

In 1985, nearly ten years after the Los Medanos site was identified for a transuranic (TRU) waste facility, the EPA issued federal regulations establishing criteria for the management and disposal of radioactive waste. These standards included limited guidelines regarding the selection of a site for a radioactive waste repository. These regulations are contained in 40 CFR 191 and consist of two subparts: Subpart A, "Environmental Standards for Management and Storage"; and Subpart B, "Environmental Standards for Disposal." Subpart B contains an assurance requirement that has the purpose of discouraging the location of disposal sites where minable resources are available.[12] The requirement is referred to as the Resource Disincentive Requirement (RDR).

The following sections of this report include a discussion of the development of the resource disincentive provision in the EPA's standard, including a discussion of WIPP specific issues associated with resources (Section 2.0); a brief description of the WIPP Project (Section 3.0); an overview of the WIPP site selection process, including a summary of the documentation that resources were considered in the WIPP Project decision-making process by the DOE (Section 4.0); and conclusions regarding the DOE's compliance with the RDR (Section 5.0).

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[10] U.S. Congress, 1969, Title I, Sec. 102, (2), (C), (v).

[11] U. S. Environmental Protection Agency, 1985a, §191.14(e), p. 38086.

[12] U.S. Environmental Protection Agency, 1985a, p. 38086.

2.0 DEVELOPMENT OF THE STANDARD

Nearly every federal entity associated with radioactive waste isolation has established natural resource conflicts as an important consideration in the selection of repository sites. Donna Goad, the author of EEG-1[13], summarized the criteria stated by the Atomic Energy Commission (AEC), the Energy Research and Development Administration (ERDA), the DOE, the Nuclear Regulatory Commission (NRC), the United States Geological Survey (USGS), the Oak Ridge National Laboratory (ORNL), Battelle Institute (BMI and BNWL), Sandia National Laboratories (SNL), the National Academy of Sciences (NAS), the Atomic Energy Commission Limited (AECL) (Canada), and the International Atomic Energy Agency (IAEA). Ms. Goad's discussion is presented in Appendix A. The criteria can be summarized by the following two statements:

> Selecting sites with natural resources may result in the denial of access to important raw materials.
>
> Selecting sites with natural resources may lead to future disturbance of the geological/hydrological system through exploration or production, including direct intrusion into the repository.

2.1 Development of the EPA Resources Assurance Requirement

The EPA took the recommendations of these technical experts to heart when they promulgated the proposed 40 CFR 191 rules.[14] This is evident by the "prohibition" type statement that the EPA included in the proposed rule. It is as follows:

> *(f) Disposal systems shall not be located where there has been mining for resources or where there is a reasonable expectation of exploration for scarce or easily accessible resources in the future. Furthermore, disposal systems shall not be located where there is a significant concentration of any material which is not widely available from other sources.*[15]

In the preamble to the proposed standard, the EPA explained the application of the requirement by way of a comparison. On one hand the EPA points out that salt domes may have numerous uses such as salt production, oil storage, and others. Many of these uses would be in conflict with the long-term goals of waste isolation. On the other hand, the EPA cites salt bed structures as being of much less concern because bedded salt deposits are much more common. In addition, the EPA stated that they "*particularly seek comment on this provision because it could rule out sites which might otherwise be advantageous in meeting all of our other requirements.*"[16]

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[13] Environmental Evaluation Group, 1979.

[14] U. S. Environmental Protection Agency, 1982.

[15] U.S. Environmental Protection Agency, 1982, §191.14(f), p. 58205.

[16] U.S. Environmental Protection Agency, 1982, p. 58201.

Among the comments that the EPA received regarding the resource disincentive assurance requirement were written comments from the EEG[17] and testimony to the EPA's Science Advisory Board (ESAB) by a representative of the WIPP Project.[18]

In their comments, the EEG ties the natural resources assurance requirement to the "*...important concept that human intrusion is perhaps the most likely cause of significant repository releases and that the probability of human intrusion and the expectation of resource presence are interrelated to some extent.*"[19] The EEG goes on to point out that the restrictive wording in the requirement should be changed to allow more discretion in evaluating this requirement. The EEG states that there are two parts to the issue. These are the loss of the resources to society and the health and safety issues associated with the attractiveness of the resources. The EEG suggests that the first part "*is perhaps best handled by the NEPA process,*"[20] and that it may be possible to address the second part by evaluating "*the increased probability of human intrusion that would result from the presence of known mineral resources and use this in the decision-making process.*"[21]

The WIPP Project testimony to the ESAB expressed concern that the restrictions in the requirements "*could be construed to rule out most bedded and domed salt formations for permanent isolation of radioactive wastes, since such areas frequently contain hydrocarbons and other useful resources.*"[22] The testimony goes on to point out that human intrusion scenarios "*have been analyzed in the WIPP Final Environmental Impact Statement (FEIS), the WIPP Safety Analysis Report (SAR), and the analysis of a brine release from beneath the site as a result of human intrusion (Reference 2). The results project no significant impact on the public health and safety.*"[23] The WIPP Project recommended to the ESAB that resources "*should be considered in safety and environmental assessments of a potential site and should be discussed in an Environmental Impact Statement (EIS) or licensing document, but should not be arbitrarily specified as part of a standard, regulating releases from nuclear waste repositories.*"[24]

The ESAB formed a working group to address the Assurance Requirements. In a draft report, made available to the WIPP during an ESAB meeting in July 1983, the working

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[17] Environmental Evaluation Group, 1983a.

[18] WIPP Project, 1983.

[19] Environmental Evaluation Group, 1983a, p. 6.

[20] Environmental Evaluation Group, 1983a, p. 6.

[21] Environmental Evaluation Group, 1983a, p. 7.

[22] WIPP Project, 1983, pp. 2-3.

[23] WIPP Project, 1983, p. 3.

[24] WIPP Project, 1983, pp.3-4.

group indicates their thinking regarding the resource disincentive.[25] In their report, the working group recommends that the EPA allow for an analysis to demonstrate "*that the overall safety of the repository would not be jeopardized by the presence of the resources.*"[26] In their rationale for the modification to the Assurance Requirements, the working group acknowledged that the two concerns still exist (resource denial and resource attractiveness); however, the mere presence of natural resources should not automatically cause the site to be eliminated, particularly if other characteristics of the site are favorable. The group points out that "*it may be possible by suitable engineering techniques to recover the resources without disturbing a nearby repository or to mitigate the effects of potential human intrusion. The site and engineered barriers should be seen as a system, and a single weakness in a site should not automatically foreclose use of it, if the remaining characteristics are highly favorable and can compensate for the weakness.*"[27] The working group recommended the modified language that was ultimately incorporated into the final rule.

The ESAB had two findings with regard to the natural resources assurance requirement. These are as follows:

> *Finding 27:* "*We recommend that EPA not preclude consideration of a potential site because natural resources are at or near the site, but rather should note that the presence of such resources is a highly unfavorable factor which should be included in the site evaluation.*"
>
> *Finding 28:* "*No site type should be precluded on the basis of site characteristics alone. Consideration of all factors, including engineered barriers, transportation, availability of utilities and labor, etc., may lead to different choices amongst acceptable sites and isolation technologies than those dictated by site characteristics alone.*"[28]

In response to these findings, the EPA, for the most part, agreed with the recommendations. Their rationale is a follows:

> *Response (Findings 27 and 28): Because of the inherent uncertainties in the site selection and evaluation process, and because of the desirability of evaluating a variety of alternatives to increase the chances of achieving exceptional environmental protection, the Agency now agrees that automatically precluding a potential site because of one disadvantage is not desirable. At the same time, the Agency still believes that proximity to important or unique resources is a serious problem because of the potential for unplanned human intrusion, since institutional controls cannot be counted on over these periods of time to prevent such intrusion. Therefore the Agency has modified the assurance requirement in the final rule to*

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[25] Assurance Requirement Working Group, 1983.

[26] Assurance Requirements Working Group, 1983, p. 7.

[27] Assurance Requirements Working Group, 1983, p. 8.

[28] U.S. Environmental Protection Agency, 1985b.

indicate that proximity to resources should be considered a serious disadvantage, but not an outright prohibition, for site selection.[29]

In the preamble to the final rule, the EPA reiterated their logic with regard to the purpose of the requirement. They state that "*this assurance requirement has been revised in the final rule to identify resource potential as a disincentive but not as an outright prohibition for site selection.*"[30] The EPA also commented that this assurance requirement wording "*implies a qualitative comparison, because the Agency is not aware of quantitative formulas comprehensive enough to provide adequate comparisons to govern site selection.*"[31] In order to qualify this statement, the EPA points out that it is not enough to merely identify a few site features that might be more favorable. Instead, the EPA expects that sites with resources would be used only "***if it is reasonably certain that they would provide better overall protection than the practical alternatives that are available.***"[32] Thus, this becomes the ultimate test under the resource disincentive requirement (RDR).

It is important to note at this point that all quantitative analyses will be performed under other aspects of 40 CFR 191 (i.e., the containment requirements and other provisions of Subpart B) and not under 40 CFR §191.14(e). Any comparison of the overall protection afforded by one site to the overall protection of another, for purposes of compliance with §191.14(e), should be done on a purely qualitative basis. As stated in §1.1, the resource disincentive requirement is a preliminary siting criteria. Thus, its primary purpose is to distinguish between potentially acceptable and potentially unacceptable sites. It is then the purpose of the containment requirements, the other assurance requirements, the individual protection requirements and the groundwater protection requirements to determine the ultimate acceptability of the site as a disposal system for radioactive wastes.

2.2 Comments Relative to Resources at the WIPP Site

There has been significant discussion regarding the resources that exist beneath and in the vicinity of the WIPP site. This discussion is presented under four topics in the following paragraphs. These are (1) site characterization and the preparation of the initial NEPA documentation of the WIPP site; (2) the development of the DOE resource policy, including the WIPP Natural Resources Study; (3) the information and conclusions from the Site and Preliminary Design Validation (SPDV) program; and (4) supplemental NEPA documentation, including the Final Supplement Environmental Impact Statement (FSEIS).

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[29] U.S. Environmental Protection Agency, 1985b, p. 2-16.

[30] U.S. Environmental Protection Agency, 1985a, p. 38081.

[31] U.S. Environmental Protection Agency, 1985a, p. 38081.

[32] U.S. Environmental Protection Agency, 1985a, p. 38081.

2.2.1 Site Characterization and the Preparation of the Environmental Impact Statement

Consideration of the resources at the WIPP site was part of the WIPP program from the outset. These evaluations date back to 1974[33] and include evaluations of potash,[34,35,36] caliche, salt, brine, sulfur, uranium, gypsum,[37] and hydrocarbons.[38,39,40] A summary of these results is presented in the Geological Characterization Report (GCR) for the WIPP site prepared by SNL in 1978.[41] The WIPP site characterization activity was conducted to collect the information needed to evaluate the location relative to the site selection criteria established for the WIPP site. (A summary of the site selection process and the appropriate references for the criteria is included in Chapter 3.0.) The specific site selection factor, with regard to natural resources is stated in the GCR as follows:

> *Natural Resources - Unavoidable conflict of the repository with actual or potential resources will be minimized to the extent possible.*[42]

The GCR presents the following conclusions with regard to the resources at the WIPP site:

> *Potassium salts and fluid hydrocarbons are the only two resources thought to be economically significant in the WIPP site area.*
>
> *If reasonable technologic and economic restraints are considered for extracting, processing and marketing the resources, then both the amounts and types of exploitable deposits are greatly reduced. Only potash and natural gas are considered to be significant in this respect.*
>
> *Caliche, salt, and gypsum are also present, but the abundance of these minerals throughout the region leads to the conclusion that land withdrawal for the WIPP will have little effect on present or future requirements for them.*

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[33] New Mexico Bureau of Mines, 1974.

[34] U.S. Geological Survey, 1978a.

[35] U.S. Geological Survey, 1978b.

[36] U.S. Bureau of Mines, 1977.

[37] New Mexico Bureau of Mines and Mineral Resources, 1978.

[38] Sipes, Williamson, and Aycock, 1976.

[39] G.J. Long and Associates, 1976.

[40] Permian Exploration Co., 1976.

[41] Sandia National Laboratories, 1978.

[42] Sandia National Laboratories, 1978, p. 2-20.

Consideration was also given to the possible presence of uranium in the redbed-type sediments that overlie the evaporites. The conclusion is that no significant uranium deposit exists.

Lithium occurs in a brine reservoir within the Castile formation northeast of the present site and may be present in a similar reservoir to the southwest. However, care has been taken to avoid such brine reservoirs within the site area.

Consideration was also given to the possible existence of metalliferous deposits in the Precambrian basement under the site. However, the depth (about 18,000 feet below the ground surface) to Precambrian rocks would preclude mining even if mineral concentrations were present.[43]

The GCR became the principal source for the natural resource evaluation in Section 7.3.7 of the FEIS.[44] The Record of Decision (ROD), which resulted from the FEIS, documents that the DOE concluded, based on the information available at the time, and based on a comparison of alternatives, that the "*environmental impacts predicted for Alternative 2 are generally small and the Los Medanos site appears acceptable for long-term disposal of TRU waste with minimal risk of any release of radioactivity to the environment. There is no indication that an alternative site for the demonstration would pose reduced risk.*"[45]

Publication of the FEIS and the ROD stimulated considerable additional discussion with regard to natural resources. This discussion served the purpose of providing additional public comment and clarification with regard to the impacts due to resource denial and resource attractiveness. The DOE's responses to comments on the FEIS were published in two separate reports. In the first, the DOE responded to five consolidated comments from four organizations. The most significant of these had to do with the DOE's plans regarding the outermost WIPP control zone (Control Zone IV), and the potential radiation risks associated with future mining. These comments and responses follow:

1. *Comment:*

   The New Mexico EEG and the Southwest Research and Information Center stated that the DOE should clarify the restrictions it plans to place on gas recovery from Control Zone IV and from deviated drilling beneath the inner control zones. Furthermore, clarification is needed relative to the possibility of potash mining at the site. The EEG questioned the DOE confidence that such activities can be conducted without disturbing the integrity of the site. The EEG believes they should be party to decisions related to resource extraction at the site.

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[43] Sandia National Laboratories, 1978, pp. 8-20 to 8-21.

[44] U.S. Department of Energy, 1980.

[45] U.S. Department of Energy, 1981a, p. 9163.

Response:

The DOE recognizes that the language in the FEIS describing resource recovery at the WIPP is tentative. Detailed programs for resource recovery have not yet been formulated. However, to mitigate the adverse impacts of resource denial at the site, the DOE has committed to the policy of allowing maximum resource recovery at the site consistent with protection of site integrity. For purposes of environmental impact analyses, the scenarios discussed in the WIPP waste isolation assessment (FEIS Section 9.7) bound the potential consequences of resource extraction at the Los Medanos site in the long term. These scenario results demonstrate that the consequences of future events, including resource extraction, are acceptably small. The New Mexico EEG will be involved in future decisions regarding resource extraction at the Los Medanos site through their review of documented analyses.

2. Comment:

The New Mexico EEG emphasized the need to quantify potential radiation risks of resource extraction at the Los Medanos site. The SRIC stated that the potash mining at the site may lead to subsidence with water intrusion into the salt.

Response:

For purposes of environmental impact analysis, the scenarios presented in the WIPP long-term waste isolation assessment (FEIS Section 9.7) bound the potential consequences of resource extraction at the Los Medanos site. These analyses present a consequence rather than a risk assessment; the assumption is that the probability of occurrence is unity and the event will occur. The results of these analyses demonstrate that the consequences of resource extraction beyond the period of institutional control are insignificant.[46]

In the second report, the EEG raised an additional question regarding the interpretation of the data in the FEIS. In addition, a new issue surfaced with regard to the loss of revenues from royalties normally paid to the state of New Mexico. The comments and responses are reproduced below.

1. Comment:

The EEG stated that the DOE must provide more detailed information on the future control of the mineral hydrocarbon resources at or near the WIPP site. In addition, the EEG requested that the DOE provide the results of the hazard analyses that led to the conclusion that resources at the site can be safely extracted.

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[46] U.S. Department of Energy, 1981b, pp. 14-16.

Response:

The DOE recognizes that the FEIS language describing resource recovery at the WIPP site is tentative. Detailed programs for resource recovery have not yet been formulated; however, to mitigate the potential adverse impacts of resource denial at the site, the DOE has committed to the policy of allowing maximum resource recovery at the site consistent with the protection of site integrity. Final plans for resource recovery will be developed after in-situ data are acquired through the SPDV program.

For purposes of environmental impact analyses, the postulated breaching events discussed in the WIPP long-term isolation assessment (FEIS Section 9.7) bound the potential effects of breaching due to resource extraction at the Los Medanos site in the long term. This assessment provides a consequence (rather than risk) assessment; the assumption is made that the probability of occurrence is unity and the event will occur. The results of the consequence analysis demonstrate that the effects of future events, including resource extraction beyond the period on institutional control, are acceptably small.

2. *Comment:*

The EEG challenged the FEIS statement that very little potash exists above the WIPP (Zone II) itself stating that this assertion conflicts with data provided in the SAR. Specifically, SAR Figure 2.7-6 (i.e., the general lithology of the ERDA-9 core) states that the McNutt member of the Salado Formation at the site "contains potassic rock rich in sylvite, langbeinite, and other hydrous minerals." The EEG also stated the FEIS Figure 9-1 would suggest that at least one third of Control Zone II contains lease-grade sylvite.

Response:

As indicated in the FEIS Table 9-19, the sylvite resources within the WIPP inner control zones are considered subeconomic by the U.S. Department of the Interior, Bureau of Mines; significant resources are present but these are not classifiable as reserves. Lithologically, these deposits are potassic minerals, but they do not constitute economic mineral reserves. Accordingly, the lithological descriptions given in SAR Figure 2.7-6 are not inconsistent with the FEIS statements concerning the lack of sylvite reserves within the inner control zones at the WIPP site. FEIS Figure 9-1 is a composite map of mineralization in various ore zones that include lease-grade deposits of both sylvite and langbeinite. As indicated in Table 9-19, there are significant langbeinite reserves within the inner control zones at the WIPP site.

3. Comment:

> *The New Mexico Commissioner of Public Lands expressed concern that New Mexico could forego an estimated hydrocarbon royalty reserve of about $5 million and potash royalty reserve of about $15 million. These losses could be mitigated by a land exchange between the federal government and the state.*

Response:

> *If current expectations are realized, resource recovery could occur without affecting the integrity of the WIPP and royalties would not be lost. Furthermore, the BLM [Bureau of Land Management] and the state are currently negotiating an exchange of federal lands for the state lands located within the site areas. The DOE expects that this exchange will be effected to the satisfaction of the site.*[47]

2.2.2 DOE Resource Policy and the WIPP Natural Resources Study

Preparation of the FEIS caused the DOE to rethink its natural resource policy with regard to the control and possible denial of extractable minerals at the WIPP site. The DOE committed to the state of New Mexico to perform a study on the possible effects of recovering natural resources present at the WIPP site.[48] As a basis for conducting this study, called the Natural Resources Study,[49] the DOE issued an interim policy statement on resource recovery at the WIPP.[50] This interim policy reiterated the DOE's commitment to "*maximize the opportunity for resource recovery at the WIPP Site, consistent with the requirements to isolate the emplaced radioactive wastes from the biosphere.*"[51] The interim policy established by the department prohibited resource development in all control zones, pending the analysis completion to determine the possible radiation dose consequences resulting from resource development in Control Zone IV. The DOE committed to issue a revision to its natural resources policy in accordance with the results of the Natural Resources Study. The conclusions from this study are as follows:

> *The conclusion of this study is that activities related to potash and hydrocarbon resource extraction and solution mining from within (and outside of) Control Zone IV, using currently available and applicable technology, will not compromise the integrity of the WIPP waste emplacement facility and increase the likelihood of a breaching event.*

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[47] U.S. Department of Energy, 1981c, pp. 9-10.

[48] U.S. District Court, 1981.

[49] Westinghouse Electric Corp., 1982a.

[50] U.S. Department of Energy, 1981d.

[51] U.S. Department of Energy, 1981d.

Specific conclusions drawn from this study follow:

- *The DOE policy for natural resource recovery is only important when considering communication events that could occur during the time period when this policy is in effect. After the loss of institutional controls, the types and magnitudes of events that could occur, such as those analyzed in the SAR, are fundamentally independent of former resource recovery restrictions at the site. Considering waste decay and geosphere transport rates, the DOE resource recovery policy has little influence on the time of waste isolation before a plausible waste-release event could occur and/or on the radiation dose consequences of such an event.*

- *The disturbances induced by potash exploration and conventional mining or solution mining in Control Zone IV are physically too far removed to affect the integrity of the WIPP facility. Breaching the waste storage area by these activities is not credible and induced changes in host rock hydraulic conductivity are not discernible.*

- *Exploration and production of hydrocarbons from within Control Zone IV likewise would not affect the waste emplaced in the WIPP facility. The extent of disturbance induced by production stimulation in the form of hydrofracing or acidizing is controlled by the specific design and execution of this operation. Evaluations of what can be considered typical operations, as discussed in this report, indicate no impact to the integrity of the WIPP facility.*

- *The communication events, including the types of breaching mechanisms, flow paths, and driving forces analyzed in the WIPP SAR, are applicable to current resource extraction technology in Control Zone IV and beneath Control Zones I, II, and III (for hydrocarbons). The SAR events represent, in fact, the potential effects of developing resources within the area of the WIPP facility itself, after institutional controls are lost.*

In summary, the DOE could reevaluate its interim policy to prudently allow resource recovery in Control Zone IV. This is supported by an evaluation of the consequence analyses for resource extraction, as discussed in this report, and the additional consideration that any resource recovery operation will be reviewed by the Bureau of Land Management (BLM) (for surface claims) and the Minerals Management Service (for underground claims) prior to its implementation. In this fashion, any planned activities will be evaluated on a case-by-case basis to ensure that the integrity of the WIPP facility will not be jeopardized.[52]

Subsequent to the publication of the Natural Resources Study, the DOE issued a revision to their policy on resource recovery. In this revision,[53] the DOE relinquished any resource development control over Zone IV. This policy is included as Appendix B. The criterion that the DOE used in developing this policy is that permanent denial resources should be

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[52] Westinghouse Electric Corp., 1982, pp. 64-65.

[53] U.S. Department of Energy, 1982a.

limited to those areas in which extraction activities could potentially lead to measurable effects on the WIPP facilities or whose protection is needed for institutional considerations. All extraction activities that would not lead to measurable effects are allowable under the policy.[54]

Both the EEG and the Governor's Task Force commented on the interim policy, the Natural Resources Study, and the revised interim policy. These comments served to focus the policy and to clarify issues such as the extent and authority of DOE control of lands outside the WIPP site boundary. The EEG stated that they were "*generally satisfied with the revised Policy Statement*"; however, they requested that they be notified if anyone seeks to develop resources within one mile of the WIPP site boundary.[55]

The governor's office responded with the preparation of a report entitled Natural Resources at the Waste Isolation Pilot Plant (WIPP) Site. This report was compiled by the Subcommittee on Natural Resources at the WIPP site, a subcommittee formed by the Radioactive Waste Consultation Task Force.[56] The thrust of the state's report was the assessment of the resources that potentially exist at the WIPP site, and an estimate of the economic impacts associated with their denial. The summary addressed three issues, all of which dealt with resource denial. These were:

1. Exchange of State Trust Lands Within the WIPP Site Boundary for Federal Lands.

2. Compensation for Loss of Potential Revenues From State Trust Lands Within the WIPP Site Boundary.

3. Compensation for the Loss of Potential Revenues From Withdrawn Federal Lands.[57]

Finally, natural resource development was addressed in the first modification to the C&C Agreement between the DOE and the state of New Mexico.[58] This modification included a ban on resource development within the WIPP site boundary during the construction and operation of the WIPP facility, and allowed for the development of hydrocarbons beneath the WIPP site, provided they were accessed from outside the WIPP site boundary and that entry within the WIPP site boundary occurred below 6,000 feet. In addition, the agreement requires the DOE to reconsider the resources policy at least one year before decommissioning to determine necessary changes for long-term control of the site. Further discussion of the resources policy resulted in a second modification of the C&C Agreement and the imposition of the policy as it exists today. In this modification, the

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[54] U.S. Department of Energy, 1982a.

[55] Environmental Evaluation Group, 1983b.

[56] New Mexico Energy and Minerals Department, 1984.

[57] New Mexico Energy and Minerals Department, 1984, pp. 28-31.

[58] U.S. Department of Energy, 1984.

DOE agreed to the following language:

> *D. The DOE will not permit subsurface mining, drilling, or resource exploration unrelated to the WIPP Project on the WIPP site during facility construction, operation, or after decommissioning. This prohibition also precludes slant drilling under the site from within or outside the site.*[59]

2.2.3 Resource Issues Addressed During the SPDV

In 1981, the DOE initiated a program to provide confirmation of the characteristics of the then-proposed WIPP site. The program included the construction of shafts and tunnels at the location selected for the facility. Data collected during this investigation, referred to as the SPDV program, was to be used in making a decision regarding the full construction of the WIPP facility.[60] In a subsequent revision to the program plan, the SPDV was expanded to include stratigraphic studies in the vicinity of the site with the intent of issuing basic data reports on drill holes in the vicinity of the site.[61] The SPDV activity was summarized in a report that covered all site selection activities up to and including the SPDV. The report, which was prepared by SNL, included a section regarding natural resources, since natural resources were among the site selection criteria used for evaluation of the WIPP site. The summary report states the natural resources criterion as follows:

> *14.1 The site should be located so that losses of natural resources are reduced to acceptable levels, which shall be determined by the value of the resources and the alternative sources for these commodities.*[62]

The conclusion drawn in the summary document is that the WIPP site is qualified with respect to the criterion on natural resources. The rationale for drawing this conclusion is stated as follows:

> *In summary, some potash resources may be denied by present restrictions, but occurrences of potash and its possible attraction for future generations does not present a breach threat to the WIPP. Natural gas resources are not denied by present restrictions, but their possible presence and the overall geologic setting makes drilling through the WIPP a more likely occurrence than in a nonsedimentary geologic setting. Possible drilling breaches of the WIPP confinement integrity have been analyzed and shown to result in relatively benign consequences. It is therefore concluded that the site should not be ruled unacceptable because of potential resource conflicts; this potential is outweighed and compensated by the*

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[59] U.S. Department of Energy, 1987.

[60] Westinghouse Electric Corp., 1980.

[61] Westinghouse Electric Corp., 1982b.

[62] Sandia National Laboratories, 1983, p. 12.

very favorable hydrologic regime at the WIPP.[63]

The DOE published the results of the SPDV in a report inviting the public to provide comments that the DOE would use in making its decision on full WIPP construction.[64] Comments from the public and the state of New Mexico were handled separately by the DOE. In the volume summarizing the public's comments, the DOE discussed nine comments and provided responses.[65] For the most part, these comments dealt with the concerns of resource denial and resource attractiveness. In several of the responses, the DOE reiterated the fact that the decision-making process implemented through the FEIS did satisfy the requirements for evaluating the amounts of resources, the impacts of resource denial, the attractiveness to future generations, and a comparison of alternatives. The DOE did commit to working out arrangements with the BLM to assure that the DOE receives notification of resource development proposals in the vicinity of the WIPP site.[66] In the second volume of comments and responses, the DOE addressed input from the state of New Mexico.[67] As with the public's comments, the DOE was asked to clarify the issues of resource denial and resource attractiveness. In addition, the DOE was requested to comment on the topic of compensation for denied royalties that would normally be given to the state in the event minerals were mined. The DOE's responses on the first two topics were consistent with its previous positions, namely that the issues were adequately considered in the FEIS and were part of the decision-making process. With regard to resource attractiveness, the DOE pointed out that "*studies by both the DOE and the EEG (U.S. DOE, 1980; Woolfolk, 1982; Channell, 1982) show that future human intrusion in search of mineral resources will not significantly impact public health and safety.*"[68] Regarding resource denial, the DOE defined acceptable levels of loss of natural resources as "those levels at which the loss is exceeded by the expected benefits of the existence and operation of the WIPP. The extent of loss of natural resources that would be expected...is described in the WIPP FEIS. The result of the comparison indicating that the losses are acceptable was presented by issuance of the ROD to proceed with the WIPP Project (46 FR 9162)."[69] Finally, with regard to compensation to the state of New Mexico for lost revenues from foregoing future mineral production, the DOE responded that the issue "*merits further discussion.*" Further, the DOE adds that "*the State should recognize that very significant revenues that will be received for the engineering, construction, and operation of the WIPP facility in the state of New Mexico. These will*

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[63] Sandia National Laboratories, 1983, p. 25.

[64] U.S. Department of Energy, 1983a.

[65] U.S. Department of Energy, 1983b, pp. 3-16 to 3-19.

[66] U.S. Department of Energy, 1983b, p. 3-17.

[67] U.S. Department of Energy, 1983c, pp. 3-17 to 3-19, 6-3, 7-3.

[68] U.S. Department of Energy, 1983c, p. 3-81.

[69] U.S. Department of Energy, 1983c, p. 3-81.

likely far surpass the mineral revenue lost."[70]

The EEG published their own analysis of the results of the SPDV program.[71] In this report, the EEG devoted a chapter to the natural resources at the WIPP. They considered the subject very broadly, including the nature and extent of resources, a discussion of important criteria and standards, the DOE interim resource policy, and the potential effect of resource removal. The EEG focused their attention on the resource denial and the resource attractiveness concerns. In Chapter 2 of their report,[72] the EEG concludes for several reasons that caliche, halite, and gypsum are not of concern with regard to repository integrity. Likewise, lithium from brines is unlikely to be competitive on the world market. Even if it were of interest, it is bounded by other resource extraction scenarios. The EEG concluded that both potash and hydrocarbons represented denied resources that could be attractive for future development. In Chapter 3 of their report,[73] the EEG addresses the proposed EPA standard (see Section 2.1 above) and the NRC standards with regard to natural resources. Both agencies consider the presence of resources to be a potentially adverse condition. The EEG concluded that "*the WIPP site appears to have adverse conditions by virtue of the natural resources. It was on this basis that the EEG recommended that the DOE indicate its plans for control of exploration and recovery of the resources, and analyze the consequences of such exploration and recovery.*"[74] With regard to the DOE interim resource recovery policy, discussed in Chapter 4 of the EEG's report, the report states that "*the State intends to negotiate with BLM to obtain notification from BLM of any applications for mining activity within 1 mile of the Zone III boundary. Upon notification, EEG plans to evaluate such proposals and provide appropriate comments, if any, to BLM and DOE, concerning the potential effects on the repository horizon.*"[75] The EEG also raised the issue that the DOE did not consider the production of either halite or lithium as viable resources. Both, according to the EEG, are "*unlikely*" to be produced as resources and both are "*bounded*" by existing analyses.[76] In their Conclusions and Recommendations chapter, the EEG recommended that the mining of potash in Control Zones I, II, and III be "*banned indefinitely*" to minimize the possible future risk to the repository.[77] With regard to natural gas, however, the EEG concluded that "*the removal of natural gas does not present any radiological problems*" since natural

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[70] U.S. Department of Energy, 1983c, p. 7-3.

[71] Environmental Evaluation Group, 1983c.

[72] Environmental Evaluation Group, 1983c, pp. 94-107.

[73] Environmental Evaluation Group, 1983c, p. 98-100.

[74] Environmental Evaluation Group, 1983c, p. 100.

[75] Environmental Evaluation Group, 1983c, p. 101.

[76] Environmental Evaluation Group, 1983c, p. 103.

[77] Environmental Evaluation Group, 1983c, p. 142.

gas could be recovered using slant drilling techniques.[78]

The National Academy of Sciences (NAS) Panel on the WIPP produced a report at the end of the SPDV program.[79] The panel examined the body of information available with regard to potash and hydrocarbon. They credit the release of Zone IV for resource development as a major step in eliminating what appeared to be a "*major flaw in the case for site suitability.*"[80] The panel accepted the conclusion in the Natural Resources Study that the consequences of resource development should not be serious as long as the exploitation is limited to Zone IV and with the "*proviso that each proposal to develop resources should be carefully examined, with the burden of proof as to its safety, made the responsibility of the proposer.*"[81] Consequently, the NAS concluded that "*the presence of hydrocarbon and potash resources at the WIPP site is not a seriously adverse feature... .*"[82]

2.2.4 Natural Resource Considerations in NEPA Documentation Subsequent to the FEIS

Subsequent to the publication of the FEIS, there were three separate occasions where the DOE addressed the topic of natural resources in NEPA documentation. First, in 1982, the DOE prepared an environmental analysis to address an ambitious cost reduction program of the WIPP Project.[83] A part of the analysis included the proposal to release Control Zone IV for resource exploitation. The basis used in this environmental analysis was the Natural Resources Study. This environmental analysis formalized the DOE decision-making process for the release of the resources in Control Zone IV. DOE's NEPA Office reviewed the proposed actions with regard to cost reductions, including the proposed release of Control Zone IV and the revised DOE resource recovery policy. It concluded that the "*proposals would result in no new potential for significant environmental impacts from that described in the EIS for the WIPP facility as currently designed, and in fact, should result in an overall decrease in the potential for environmental impacts.*"[84]

The second NEPA review occurred after the completion of the SPDV and was conducted in support of the decision to proceed with full facility construction. Public comments were solicited regarding the results of the SPDV as discussed above. Based on the results and the comments, the DOE prepared an Action Description Memorandum (ADM) for full

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[78] Environmental Evaluation Group, 1983c, p. 142.

[79] National Academy of Sciences, 1984.

[80] National Academy of Sciences, 1984, p. 8.

[81] National Academy of Sciences, 1984, p. 11.

[82] National Academy of sciences, 1984, p. xii.

[83] U.S. Department of Energy, 1982b.

[84] U.S. Department of Energy, 1982c.

facility construction.[85] In Section III of the ADM, the topics of natural resource denial and natural resource attractiveness were addressed. In both cases, the DOE points out that the changes since the publication of the FEIS have resulted in no increases in risks or impacts. The DOE/NEPA office stated after their review of the ADM that "*we have determined, after consultation with the Office of General Council, that there are no significant new circumstances or information relevant to environmental concerns and bearing on the proposed action or its impacts, within the meaning of NEPA and the Council on Environmental Quality (CEQ) regulations. Additional investigations since issuance of the WIPP Final EIS, including the SPDV activities, have generally confirmed the understanding of site characteristics and environmental impacts presented in the Final EIS...we concur with the proposed decision to proceed with the full WIPP facility construction based on available information.*"[86]

The topic of natural resources was included in the SEIS.[87] The SEIS examined new information regarding the facility and provided an opportunity for the DOE to obtain public comment regarding the implementation of a Test Phase for the WIPP Project. No new information was presented with regard to natural resources. However, by the time the SEIS was published, the DOE and the state of New Mexico had agreed to the language in the second modification to the C&C Agreement whereby the DOE would not allow any resource development at the WIPP site during construction, operations, or after decommissioning.[88] In general, the public comment on the SEIS, with regard to resources, requested further clarification of DOE land management policy, including the future regulation of resource development.[89] The SEIS did provide an update of the consequence analysis regarding the impacts of an inadvertent human intrusion into the repository related to resource development. Under some of the assumptions, the results exceeded the allowable EPA standard; in other cases, compliance was demonstrated. The uncertainty associated with these calculations were, in part, instrumental in the DOE's decision to proceed with the Test Phase as a means of addressing the uncertainty. An additional SEIS will be performed, prior to the initiation of the Disposal Phase, to evaluate the effects of intrusion into the repository motivated by resource development. If the impacts exceed the applicable environmental standards, alternative approaches to disposal (such as waste processing) will be evaluated.

2.3 Summary

The development of the RDR has involved a significant amount of discussion and thought, both scientific and nonscientific. The final version of the requirement does not automatically eliminate any sites that may contain resources. Instead, it provides the implementing agency with the opportunity to demonstrate that the favorable conditions of

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[85] U.S. Department of Energy, 1983d.

[86] U.S. Department of Energy, 1983e.

[87] U.S. Department of Energy, 1990a.

[88] U.S. Department of Energy, 1990a, p. 7-3.

[89] U.S. Department of Energy, 1990a, Vol. 3, pp. 193-195.

the site outweigh the potential increased risk associated with using the site. This demonstration involves a qualitative comparison of the risks associated with the site and the alternatives to using the site.

Concern for both resource denial and resource attractiveness has been evident in the technical and decision-making documents that the DOE has prepared for the WIPP site on the topic of natural resources. These documents have undergone a significant amount of public scrutiny, which served to focus the issues of resources. Two basic concerns have emerged: resource denial and resource attractiveness. The DOE's policy with regard to resource denial has been evolutionary, to the extent that initial restrictions have proven to be unnecessary, based on analysis in the Natural Resources Study. Consequently, the DOE has reduced the amount of denied resources significantly since the publication of the FEIS. With regard to resource attractiveness, the DOE has performed analyses to assess the impacts of unintentional disruption of the WIPP facility as the result of resource development. As the DOE's understanding of the facility, the surrounding geological and hydrological systems, and the waste has increased, the need for additional information has increased, and is to be addressed during the Test Phase. The DOE has obtained control over the surface and subsurface above 6,000 feet by successfully eliminating all mineral leases that could potentially lead to problems with the long-term isolation capability of the facility. In addition, the Congress has recently permanently withdrawn the land for the operation of the WIPP.

The following chapters discuss the qualitative comparison that was performed in the FEIS[90] prepared for the WIPP. Key to this comparison was the evaluation of the societal impacts of resource denial and the increased risks associated with the potential for human intrusion. Furthermore, the latter consideration is the subject of an ongoing assessment being prepared for the WIPP facility. Updates to the analysis in the FEIS were published in the SEIS.[91] In addition, SNL has the responsibility to complete the performance assessment required under other parts of 40 CFR 191. These performance assessments consider the risks associated with a human intrusion motivated by resource exploitation.[92]

It is important to note that the WIPP site was selected before the Assurance Requirements were issued in either proposed or final form. Consequently, it is not possible to reconstruct a compliance approach that is directed specifically at the EPA's standards. Instead, it is the purpose of the following sections to demonstrate that the extent to which the DOE considered resources was sufficient and that the intent of these requirements has been met. Furthermore, the decision to use the WIPP facility as a final disposal facility has not been made and will not be made until the DOE can demonstrate that even with increased risks associated with resource attractiveness, the site can meet the environmental protection requirements in 40 CFR 191.

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[90] U.S. Department of Energy, 1980.

[91] U.S. Department of Energy, 1990a.

[92] Sandia National Laboratories, 1990a.

3.0 THE WIPP PROJECT

3.1 Location

The WIPP facility is located in Eddy County, New Mexico, 26 miles east of Carlsbad (Figure 1). The WIPP site boundary encompasses 16 square miles (10,240 acres) located in an area known as the Los Medanos (the dunes). It consists of Sections 15-22 and 27-34 of Township 22 South, Range 31 East.[93] The area originally withdrawn for the WIPP facility covered 18,960 acres and was organized into four control zones (Figure 2).[94] The control zones were established so that the containment integrity of the salt beds used for disposal could be protected from mining and resource exploitation activities.[95] In 1982, a decision was made by the DOE to release control of the outermost control zone, effectively reducing the WIPP site boundary to the configuration in Figure 3.[96] As the result of an agreement with the state of New Mexico,[97] resource exploitation that could be harmful to the WIPP facility is not allowed within the 10,240 acres that lie within the WIPP site boundary.

3.2 WIPP Mission

Public Law 96-164 defines the WIPP mission as "*a defense activity...for the express purpose of providing a research and development facility to demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States exempted from regulation by the Nuclear Regulatory Commission.*"[98] The DOE is responsible for all aspects of the WIPP Project.

3.3 Overview of the WIPP Project

From 1973 to 1975 a site selection program was conducted to locate a site, within the Carlsbad area of eastern New Mexico, that would be suitable for a radioactive waste repository. During this period, there were no federal regulations that established criteria for selecting a radioactive waste repository site, but there were informal criteria.[99,100,101] These informal criteria were used to evaluate several candidate sites.

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[93] U.S. Department of Interior, 1991.

[94] U.S. Department of Energy, 1980, p. 8-4.

[95] Oak Ridge National Laboratory, 1973a.

[96] U.S. Department of Energy, 1982c.

[97] U.S. Department of Energy, 1987.

[98] U.S. Congress, 1979.

[99] Oak Ridge National Laboratory, 1973a.

[100] Sandia National Laboratories, 1978.

The Los Medanos site was selected for the WIPP Project. Appendix D of the FEIS summarizes the site selection criteria that were specifically applied to the selection of the location of the WIPP facility. These are included in this report as Appendix C.[102]

Upon selection of the Los Medanos site, a site characterization program was initiated.[103] Extensive studies (geophysical surveys, borehole corings, etc.) were conducted to verify that the site was as adequate as the criteria indicated. At the same time, in accordance with the NEPA, aspects of how the WIPP would impact the environment were evaluated. The results of these studies are summarized in the WIPP FEIS, a two-volume document issued in 1980.[104]

In 1981, the DOE decided to proceed with the WIPP Project, as authorized, at the Los Medanos site.[105] With this decision, mining at the WIPP facility commenced and the SPDV program was initiated.[106] The SPDV program provided additional proof of the favorable characteristics of the site as a mined geological repository.[107]

On June 28, 1983, the DOE rendered the decision to proceed with full construction of the WIPP facility.[108] As construction proceeded, the DOE continued to evaluate the geotechnical and hydrological characteristics of the site. In 1988, the impact of the human intrusion scenario on the site was reevaluated by SNL based on new information regarding the transmissivity of fluids in the Rustler Formation, the expected quantities of brine that could collect in the repository before closure, and the gas permeability of the in-situ salt. Based on this new information, and uncertainties surrounding the selection of model parameters for numerically evaluating the long-term performance of the repository, the DOE decided to initiate a Test Phase for the WIPP. The Test Phase was to provide an opportunity for the DOE to evaluate certain waste characteristics under controlled experimental conditions.[109,110,111,112] The NEPA documentation for the Test Phase

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[101](...continued)
[101] U.S. Department of Energy, 1980.

[102] U.S. Department of Energy, 1980, Volume 2, Appendix D, pp. D-1 to D-10.

[103] Sandia National Laboratories, 1978.

[104] U.S. Department of Energy, 1980.

[105] U.S. Department of Energy, 1981a.

[106] Westinghouse Electric Corp. 1980.

[107] Sandia National Laboratories, 1983.

[108] U.S. Department of Energy, 1983e.

[109] U.S. Department of Energy, 1990b.

[110] Sandia National Laboratories, 1990b.

was completed in 1990.[113] The DOE currently expects to begin the Test Phase experiments in the last quarter of 1993.

[111](...continued)
[111] Sandia National Laboratories, 1990c.

[112] Sandia National Laboratories, 1990d.

[113] U.S. Department of Energy, 1990a.

4.0 WIPP SITE SELECTION AND NATURAL RESOURCES

4.1 Summary of Site Selection Activities

As stated in §2.1, the ultimate test for site suitability under the resource disincentive requirement is that sites with resources present would be used only "*if it is reasonably certain that they would provide better overall protection than the practical alternatives that are available*".[114] This section sets forth the site selection process for the WIPP and how that process complied with the resource disincentive requirement.

As will be discussed, the WIPP site selection process consisted of four distinct stages. An important aspect to keep in mind when going through this process is the comparison to practical alternatives requirements mentioned in the standard. It will be shown that at each stage of the site selection process practical alternatives were analyzed, and with the elimination of the various alternatives, the Los Medanos site in southeastern New Mexico was ultimately selected as the most favorable site of all of the practical alternatives.

4.1.1 General Description of the Site Selection Process Used to Select the WIPP Facility Location

A deductive-reasoning process was used to select the WIPP site. This process has been described as four distinct stages.[115] The following is a summary of the process.

STAGE 1: In stage 1, a geologic media, which in this case is salt, was selected and geographic regions that contain this media were identified. This was accomplished by gathering and evaluating existing information concerning rock types and geographic availability. A set of desirable criteria was established and a list of the most favorable regions was developed.

STAGE 2: In stage 2, a careful study of the literature relevant to stage 1 was performed to narrow down the number of regions identified in stage 1. Once a region was selected, candidate sites within the region were chosen. Selection criteria were used to compare the sites. Those sites which satisfied the most criteria were selected for further evaluation. Typically, resource conflict considerations are applied on a broad scale at this stage of site selection.

STAGE 3: In stage 3, the candidate sites identified in stage 2 undergo further investigations which cover geology, hydrology, archaeology, historical surveys, demography, and biology. The results of all the site evaluations were compared, and the site that best met the selection criteria (the Los Medanos site) was selected for Site Characterization. At this stage, the type and amount of resources were considered in detail.

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[114] U. S. Environmental Protection Agency, 1985a, p. 38081.

[115] U.S. Department of Energy, 1980, p. 2-7.

STAGE 4: In stage 4, a detailed full system analysis was performed. Full-system refers to the specific geologic environment, the waste forms, the plant design, and the potential failure modes in respect to radiation safety and environmental impacts.

Typically, the results of all of the studies performed to select and characterize the site are summarized in an EIS prepared in accordance with the NEPA. The EIS was made available to all interested parties. Public comments were incorporated into the decision that determines whether or not to proceed with the project, as defined, at the location selected.

4.1.2 Selection of Salt as a Disposal Media

The rationale for preferring salt as the disposal medium for nuclear waste, in general, and for the WIPP facility, specifically, resulted from two decades of repository program activities. In 1955, the NAS National Research Council (NAS-NRC) was asked by the AEC to examine the issue of permanent disposal of radioactive waste. In a report published in 1957,[116] the committee stated that it was "*convinced that radioactive waste can be disposed of safely*" and concluded that "*the most promising method of disposal of high level waste at the present time seems to be in salt deposits.*"[117]

Salt was determined to be the most promising disposal medium because of its unique thermal and physical properties. Salt has a relatively high thermal conductivity, which serves to rapidly conduct heat away from waste. Salt has favorable plastic, or creep, properties which permit sizeable strains to be absorbed without fractures.[118] The existence of large salt deposits demonstrates isolation from circulating groundwaters for long periods of geologic time. The depositional nature and preservation of large salt deposits demonstrate regional stability for long periods of geologic time.

From 1957 to 1961, the AEC sponsored research at the ORNL on the suitability of salt as a disposal medium for defense generated radioactive waste.[119] In 1962, the USGS completed a study that summarized rock salt deposits in the United States as possible storage sites for radioactive waste.[120]

In 1963, an existing salt mine in Lyons, Kansas, was selected for further study. The ORNL began a large-scale field program known as Project Salt Vault. Simulated wastes (irradiated fuel elements), supplemented by electric heaters, were placed in the mine for observation.

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[116] National Academy of Sciences, 1957.

[117] National Academy of Sciences, 1957, pp. 3-4.

[118] Oak Ridge National Laboratory, 1973a, p. 3.

[119] U.S. Department of Energy, 1980, p. 2-6.

[120] U.S. Geological Survey, 1962.

Conclusions made from the studies that took place from 1963 to 1970 were favorable and, in 1970, the Lyons site was selected by the AEC as a potential location for a radioactive waste repository. The NAS endorsed this recommendation. However, subsequent studies identified some technical problems and, in 1972, the integrity of the site was judged to be unacceptable. There were too many drill holes in the area that could not be positively located, and solution mining, which was taking place nearby, was experiencing unexplainable water losses.[121]

Table 4-1 provides a comparison of the geologic media considered for the WIPP.[122] As stated in the FEIS, "*salt is the best understood of all candidate geologic media with respect to its possible use as a waste-repository medium, and it offers advantages in thermal properties and plasticity. It is found in many places in the United States.*"[123] Therefore, of the disposal media considered for the WIPP site (limestone, shale, and salt), salt was selected the **best of the practical alternatives.**

4.1.3 Selection of Eastern New Mexico

The WIPP site selection process began in 1973, when the AEC, ORNL, and the USGS began seeking a repository site to replace the site abandoned in Lyons, Kansas. A nationwide survey was conducted to locate a region that contained a salt deposit suitable for use as a repository.[124,125,126,127,128,129,130]

Of the areas in the United States underlain with bedded salt, the Salina Basin in portions of New York, Pennsylvania, West Virginia, Ohio, Michigan, and southern Ontario, and the Permian Basin including parts of Kansas, Oklahoma, Texas, Colorado, and New Mexico, were considered for further study under the waste management program.[131] The Permian Basin was eventually selected over the Salina Basin. The reason for this was

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[121] U.S. Department of Energy, 1980,p. 2-7.

[122] U. S. Department of Energy, 1980, p. A-4.

[123] U. S. Department of Energy, 1980, p. A-5.

[124] U.S. Geological Survey, 1962.

[125] U.S. Geological Survey, 1973a.

[126] U.S. Geological Survey, 1973b.

[127] U.S. Geological Survey, 1973c.

[128] U.S. Geological Survey, 1973d.

[129] U.S. Geological Survey, 1973e.

[130] U.S. Geological Survey, 1974a.

[131] U. S. Department of Energy, 1980, p. 3-9.

because potential areas in the Salina Basin were *"much more densely populated, the land is more intensively used, and the complex hydrologic characteristics are likely to be much more difficult to define and evaluate."*[132] Thus of the alternatives in bedded salt, the Permian Basin was determined to the **best of the practical alternatives.**

The most promising region identified within the Permian Basin was located in the Delaware Basin of eastern New Mexico. This region was selected because the salt is shallow and flat. Although the Delaware Basin is a known oil and gas producer, the eastern New Mexico area is not very productive, and has not been subjected to a lot of drilling.[133] Selection of this area of the Delaware Basin was consistent with the criterion of avoiding locations in known oil and gas production trends. Thus, of the alternatives in the Permian Basin, eastern New Mexico was considered to the **best of the practical alternatives.**

4.1.4 Selection of the Carlsbad Area

An extensive literature study was performed to locate an area in eastern New Mexico for further evaluation. Three areas in eastern New Mexico were chosen for further study: (1) the Carlsbad area;[134] (2) the Clovis-Portales area;[135] and (3) the Mescalero Plains of Chaves County.[136]

The Clovis-Portales area was disqualified because the salt being studied was too shallow and clayey. The Mescalero Plains area was disqualified because of excessive resource development (oil production) in the area. The Carlsbad area, in the northern portion of the Delaware Basin, was ultimately selected as the **best of the practical alternatives.**[137]

4.1.5 Selection of the Los Medanos Site

Site selection efforts within the Carlsbad area were initiated in 1972 by ORNL, the USGS, and the AEC. A plan issued by ORNL, in October of 1973,[138] states that resource-high areas should be avoided. Specifically, the plan states:

> *Significant quantities of potash ore and extensive deposits of oil and gas occur in selected localities of southeastern New Mexico. To preclude conflicts of interest in the economic development of the region, the rocks underlying the study area should*

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[132] U. S. Department of Energy, 1980, p. 3-10.

[133] U.S. Department of Energy, 1980, p. 2-10.

[134] U.S. Geological Survey, 1972.

[135] U.S. Geological Survey, 1974b.

[136] U.S. Geological Survey, 1974c.

[137] U.S. Department of Energy, 1980, p. 2-10.

[138] Oak Ridge National Laboratory, 1973b.

preferably have a low potential for oil and gas development and should not contain extensive high-grade potash ores.[139]

Appendix D of the WIPP FEIS[140] lists the criteria used to select the Los Medanos site, and explains how well the WIPP site fares against these criteria (see Appendix C of this paper). These criteria evolved through the selection and abandonment of a Project Salt Vault in Lyons, Kansas.

The first site selected for characterization within the Carlsbad area (ORNL site) had to be abandoned. It was centered on Sections 10 and 11 of Township 22 South, Range 31 East. Characterization studies showed that (1) rock strata were much shallower than expected; (2) beds showed severe distortion; (3) structural dips were as high as 75 degrees; (4) the site contained leasable grades of potash (AEC Nos. 7 and 8); and (5) a pocket of pressurized brine was encountered at a depth of 2,710 feet within the Castile Anhydrite.[141,142]

It was determined that the site was located too close to the Capitan Reef. Structural influence by the reef caused the actual geologic character to vary from the predicted geologic behavior.[143] Extensive drilling would have been required to thoroughly document the structure of the site, which is contrary to the principle of minimizing the number of holes drilled into the repository.

In late 1975, the USGS and the Energy Research and Development Administration (ERDA) went back to stage 2 of the site selection process, and began looking for an alternative location within the Carlsbad Area of the Delaware Basin. Site selection criteria and characterization factors were revised to include knowledge gained from several studies.[144,145,146,147,148,149] These revised criteria are referred to as stage 2 siting

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[139] Oak Ridge National Laboratory, 1973a, p. 3.

[140] U.S. Department of Energy, 1980, Vol. 2, Appendix D.

[141] U.S. Department of Energy, 1980, p. 2-10.

[142] Sandia National Laboratories, 1978.

[143] U.S. Geological Survey, 1973d.

[144] Oak Ridge National Laboratory, 1974a.

[145] U.S. Geological Survey, 1973b.

[146] Oak Ridge National Laboratory, 1973c.

[147] U.S. Geological Survey, 1975.

[148] Oak Ridge National Laboratory, 1974b.

[149] Sandia National Laboratories, 1978, p. 2-11.

criteria.[150] The following is an abbreviated listing of the most restrictive stage 2 siting criteria:[151,152]

1. Avoid areas that are within one mile of any borehole that extends through the Ochoan evaporites and into the Delaware or deeper formations. (This automatically assures that a site will not be located over an existing oil or gas field.)

2. Salt of high purity at a depth between 1,000 and 3,000 feet.

3. Avoidance of areas where dissolution had advanced to the top of the Salado or deeper levels, by establishing a distance of one mile or more from dissolution fronts at the top of the Salado.

4. Avoidance of possible salt deformation in a belt six miles wide basin-ward from the Capitan Reef.

5. Avoidance of pronounced known anticlinal structures.

6. Avoidance of known oil and gas trends.

7. Avoidance of the known potash enclave above the repository and minimize conflict with the known enclave in the buffer zone.

Only two of the proposed alternatives withstood the stage 2 siting criteria. Alternative I, the Los Medanos site, was selected as the preferred location because seismic data indicated that the site was in a syncline, making the accumulation of oil, gas, and geopressurized brines less favorable. Alternative II was located adjacent to shallow oil fields where water flooding for secondary recovery was a possibility.[153]

Selection of the Los Medanos site did not prove that the "perfect" site had been selected. The selection criteria used, however, was sufficient to establish that the site selected was adequate, safe, and acceptable.[154] An effort was made to avoid resource-rich areas. This goal could not be completely satisfied by the Los Medanos site. Thus the Los Medanos site was selected as the best of the practical alternatives for the location of a waste repository.

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[150] Sandia National Laboratories, 1978, p. 2-22.

[151] Sandia National Laboratories, 1978, pp. 2-21 and 2-22.

[152] Sandia National Laboratories, 1977.

[153] Sandia National Laboratories, 1978, pp. 2-22 and 2-23.

[154] Sandia National Laboratories, 1978, p. 2-15.

The site contains potential economic quantities of both potash and hydrocarbons.[155] These resources will be discussed subsequently.

4.2 Resources at the WIPP Site

The language in the EPA's resource disincentive defines resources[156] that are of interest to include "*minerals, petroleum or natural gas, valuable geologic formations, and ground waters that are either irreplaceable because there is no reasonable alternative source of drinking water available for substantial populations or that are vital to the preservation of unique and sensitive ecosystems.*"[157] Accordingly, the following discussion centers on the specific resources defined in the standard. This includes a discussion of hydrocarbon resources, which include oil, gas, and distillate; minerals, which include potash, halite, and construction materials such as sand, gravel, and caliche; and groundwater.

4.2.1 Hydrocarbons

The New Mexico Bureau of Mines and Mineral Resources (NMBM&MR) conducted a hydrocarbon resource study in southeastern New Mexico under contract to the ORNL.[158] The NMBM&MR study was based on the known reserves[159] of crude oil and natural gas in the region and on the probability of discovering new reserves. A fundamental assumption of this study was that the WIPP area has the same potential for resources as the much larger region. The estimates do not take into account the economic value or the recoverability of the hydrocarbons. The NMBM&MR estimated that each section (640 acres) could contain 1.266 million barrels of oil, 16.544 billion cubic feet of gas, and 0.193 million barrels of distillate.[160] The SNL hired a consulting firm to prepare an estimate of the hydrocarbon reserves (economically producible resources) within the area.[161] Since there were no resource wells within the inner three control zones at the WIPP site, the study relied on information gained from nearby exploration. The study was updated just prior to the publication of the draft EIS for the WIPP. Based on the updated study, the reserve estimates in Table 4-1 were projected.[162]

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[155] U.S. Department of Energy, 1980, p. 8-8.

[156] The term "resources" means concentrations of materials in a form that makes their extraction currently or potentially feasible.

[157] U.S. Environmental Protection Agency, 1985a, p. 38086.

[158] New Mexico Bureau of Mines, 1974.

[159] The term "reserves" applies to resources that can be extracted profitably by existing techniques and under present economic conditions.

[160] U.S. Department of Energy, 1980, pp. 7-68 to 7-70.

[161] Sipes, Williamson, and Aycock, 1976.

[162] Sipes, Williamson, and Associates, 1979.

In order to gain control over the development of hydrocarbons within the WIPP site area, the DOE acquired the oil and gas leases within all the WIPP control zones. These acquisitions were necessary to keep the salt beds intact.[163] The only leases that are still intact are in Section 31. These leases only allow the production of resources by entry below 6,000 feet. The upper 6,000 feet of the leases were taken by the DOE through condemnation in 1979. This action was consistent with the developing policy on resource recovery.[164] Current policy would not allow any resource development inside the WIPP site boundary.[165] Table 4-2 puts the resources and the reserves into perspective. This table has been modified from Table 9-14 in the FEIS[166] to include the differentiation between the resources in the inner three control zones and those in Control Zone IV.

4.2.2 Mineral Resources

A comprehensive discussion of the nonhydrocarbon mineral resources affected by the WIPP site is included in the FEIS[167] and is based on information gathered for the GCR.[168] The conclusion in these documents is that the principal mineral resources that underlie the WIPP facility are caliche, gypsum, salt, lithium from brines, sylvite, and langbeinite. Potassium salts (sylvite and langbeinite), which occur in strata above the repository, are the only mineral resources of practical significance and are considered to be economically extractable (that is, reserves).[169,170]

When the Los Medanos site was initially screened for the WIPP Project, it was thought that the facility was positioned outside of the Known Carlsbad Potash District, and would therefore have a minimal impact on potash resources.[171] Information from studies

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[163] U.S. Department of Energy, 1980, pp. 8-8 to 8-10.

[164] U.S. Department of Energy, 1982a.

[165] U.S. Department of Energy, 1987.

[166] U.S. Department of Energy, 1980, p. 9-19.

[167] U.S. Department of Energy, 1980, Chapters 7, 8, and 9.

[168] Sandia National Laboratories, 1978.

[169] U.S. Department of Energy, 1980, p. 9-18.

[170] Environmental Evaluation Group, 1983, pp. 95-98.

[171] U.S. Department of Energy, 1980, p. 2-15.

conducted after site selection[172,173,174] has caused an enlargement of the Known Carlsbad Potash District to include most of the Los Medanos site.[175]

Table 4-3 illustrates the significance of the amount of potash mineral resources that cannot be mined or extracted because of the WIPP site. The mineral of greatest interest is langbeinite, which is used to manufacture a fertilizer. Denying the exploitation of langbeinite resources on the WIPP site does impact regional and national resources. Langbeinite is a relatively rare evaporite mineral that is found in commercial quantities only in the Carlsbad area and in eastern Europe. It contains soluble potassium, magnesium, and sulfur.[176]

The chief importance of langbeinite is as a fertilizer. It is desirable for soils which require soluble potassium, magnesium, and sulfur, but which cannot tolerate chlorine. The principle beneficial ingredient is potassium sulfate. Some langbeinite is sold as a refined mineral but some is mixed with sylvite to produce potassium sulfate.[177]

Substitutes for the principal beneficial ingredient of langbeinite (potassium sulfate) are available. Some langbeinite produced from Carlsbad is transformed into potassium sulfate by a base-exchange process between langbeinite and sylvite. Potassium sulfate can also be produced by a reaction between sylvite and sulfuric acid. Potassium sulfate is present in the brine water of the Great Salt Lake, Utah, and is now being exploited commercially.[178]

The supply of langbeinite in the Carlsbad potash area is exhaustible. It is projected that langbeinite operations will last another 28 years if reserves are considered, and 46 years if resources are considered. The WIPP Project originally excluded the mining or extraction of resources from 18,960 acres. In 1982, the DOE issued a revised Interim Policy Statement on Resource Recovery at the WIPP Site.[179] This policy states that "*the extraction of potash outside Control Zone III is allowable.*"

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[172] U.S. Geological Survey, 1978a.

[173] U.S. Bureau of Mines, 1977.

[174] Agricultural and Industrial Minerals, 1978.

[175] U.S. Department of Energy, 1980, p. 2-15.

[176] U.S. Department of Energy, 1980, p. 9-21.

[177] U.S. Department of Energy, p. 9-24.

[178] U.S. Department of Energy, 1980, pp. 9-14 to 9-25.

[179] U.S. Department of Energy, 1982a.

4.2.3 Groundwater

Groundwater in the area of the WIPP site has been studied extensively and the results of the studies have been summarized both in the WIPP FEIS[180] and the WIPP Final Safety Analysis Report (FSAR).[181] The following are the principal tasks that were conducted to evaluate the groundwater in the vicinity of the WIPP:

A review of available data and literature resulting from potash, oil and gas, and Pecos River investigations was conducted.

Hydrologic testing was performed in 52 exploration holes.

Extensive field testing programs were conducted, including drill stem tests, flow tests, pump tests, and packer tests.

Water samples from specific rock units have been laboratory tested for physical and chemical parameters.

The studies that were performed confirmed that groundwater exists both above and below the facility horizon. Below the facility horizon, groundwater is found in the Bell Canyon Formation. This groundwater is of very poor quality and, for the most part, can be considered a brine.[182] Groundwater above the facility horizon is found only in limited quantities, and is usually of such poor quality that it is not usable.[183,184,185]

At some locations, the water is of marginal quality and is used for watering livestock. The "Barn Well" (located 5.5 miles south-southeast of the WIPP site) supplies drinking water to a local ranch from the Dewey Lake Red Beds Formation.[186]

The WIPP does not impact any irreplaceable groundwater as defined by 40 CFR 191.14(e), which states that groundwaters are either irreplaceable because (1) "*no reasonable alternative source of drinking water is available for substantial populations*"; or (2) it is "*vital to the preservation of a unique and sensitive ecosystem.*"[187] No substantial population is affected by the WIPP site, and alternative supplies of drinking water are

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[180] U.S. Department of Energy, 1980, Section 7.4.

[181] Westinghouse Electric Corp., 1990.

[182] Sandia National Laboratories, 1978, p. 6-29.

[183] Westinghouse Electric Corp., 1987.

[184] Westinghouse Electric Corp., 1986.

[185] Westinghouse Electric Corp., 1988.

[186] Westinghouse Electric Corp., 1988.

[187] U.S. Environmental Protection Agency, 1985, p. 38086.

available from the wells 30 miles north of the WIPP site which are completed in the Ogallala Formation.[188]

4.3 WIPP Ecosystems

The terrestrial ecology of the WIPP site is characteristic of areas where rainfall is the limiting factor for vegetation. The area lies within a transition zone between the Chihuahuan Desert and the southern Great Plains. As a result, the area shares the floral characteristics of both areas. There are no endangered plant species known to occur within the WIPP site area.[189] Thirty-nine species of mammals have been observed in the area. None are on the threatened or endangered species list.[190] A total of 122 birds have been observed. None are on the endangered species list.[191]

With regard to the impacts on the ecological resources, the FEIS points out that the ecosystems found at the WIPP are not unique. No endangered species of plants or animals are known to inhabit the WIPP site or the vicinity of the site. The area contains vegetation and soil types that are common throughout the region. No unique species or populations have ever been identified at the site.[192]

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[188] Westinghouse Electric Corp., 1990, p. 2.5-1.

[189] U.S. Department of Energy, 1980, pp. 7-3 to 7-7.

[190] U.S. Department of Energy, 1980, p. 7-7.

[191] U.S. Department of Energy, 1980, p. 7-8.

[192] U.S. Department of Energy, 1980, pp. 9-14 to 9-15.

5.0 CONCLUSIONS

In 1981, the DOE decided that the available data, as summarized in the FEIS,[193] supported a decision to proceed with the WIPP project through facility construction. As documented by this paper, the information that the DOE used to make this decision evolved from site selection and site characterization activities, which included resource considerations in compliance with the resource disincentive requirements.

During the site selection process, the Los Medanos site was compared against several other candidate sites. An established list of selection criteria (which included resource considerations) was used to compare candidate sites, and the Los Medanos site best met the selection criteria. Based on the favorable characteristics of the Los Medanos site (good hydrological characteristics, salt medium, moderate depth, salt thickness, low population density, lack of significant economic conflicts, and others),[194] the decision was made to proceed with full construction and operation for the Test Phase. These favorable characteristics more than compensate for the possibility that the site will be disturbed in the future because of the presence of natural resources. The decision for full operations as a permanent disposal facility will be rendered only if the EPA guidelines for radioactive waste isolation are met.

In conclusion, the preliminary site selection intent of the RDR in 40 CFR 191(e) has been met for the WIPP facility. Resource conflicts were given adequate consideration, including extensive public comment. The conclusion is that the favorable characteristics of the site uniquely qualify it for a repository for defense TRU waste. These characteristics more than compensate for the likelihood of a future disturbance.

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[193] U.S. Department of Energy, 1980.

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FIGURES

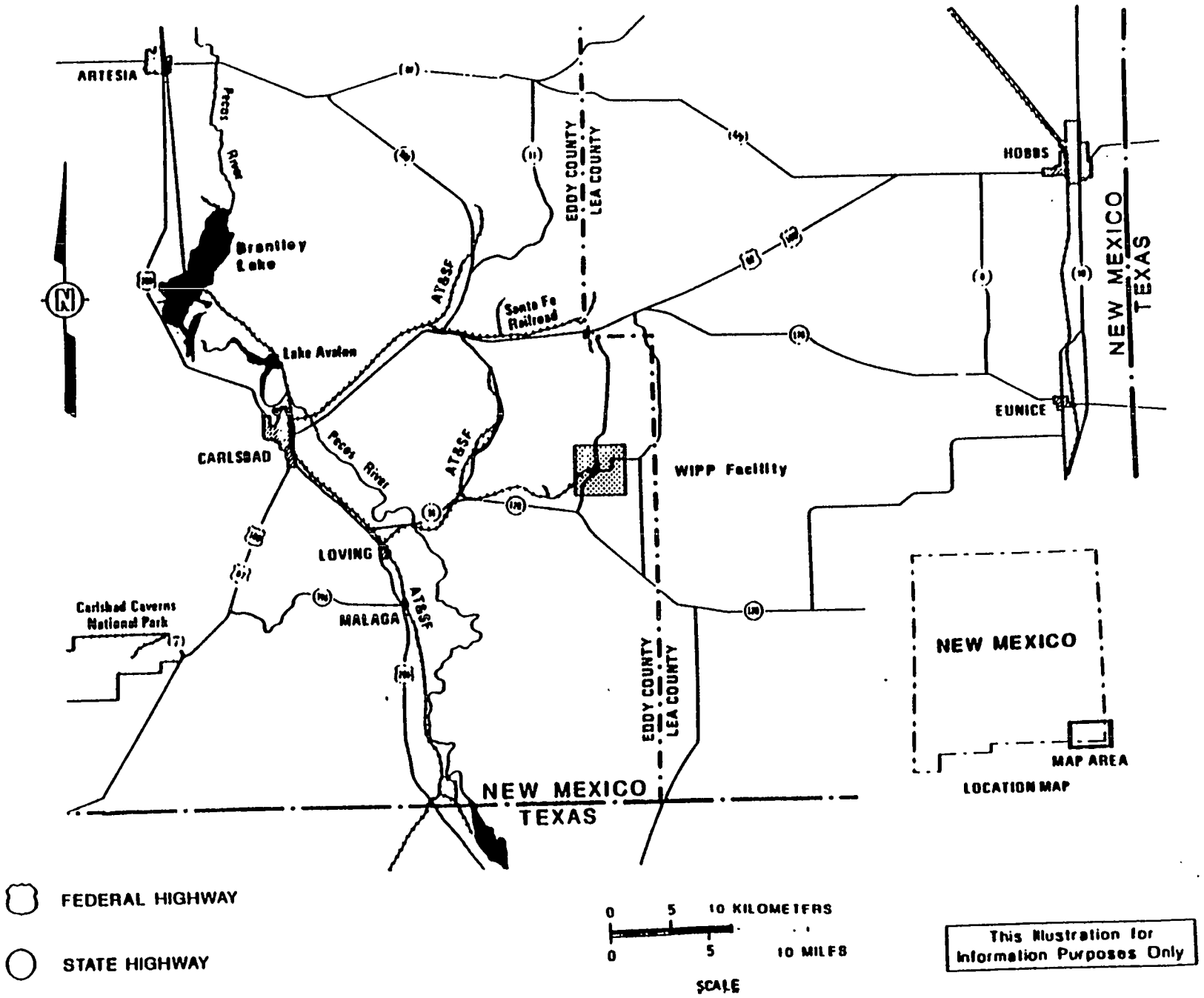


FIGURE 1 GENERAL LOCA N OF THE WIPP FACILITY

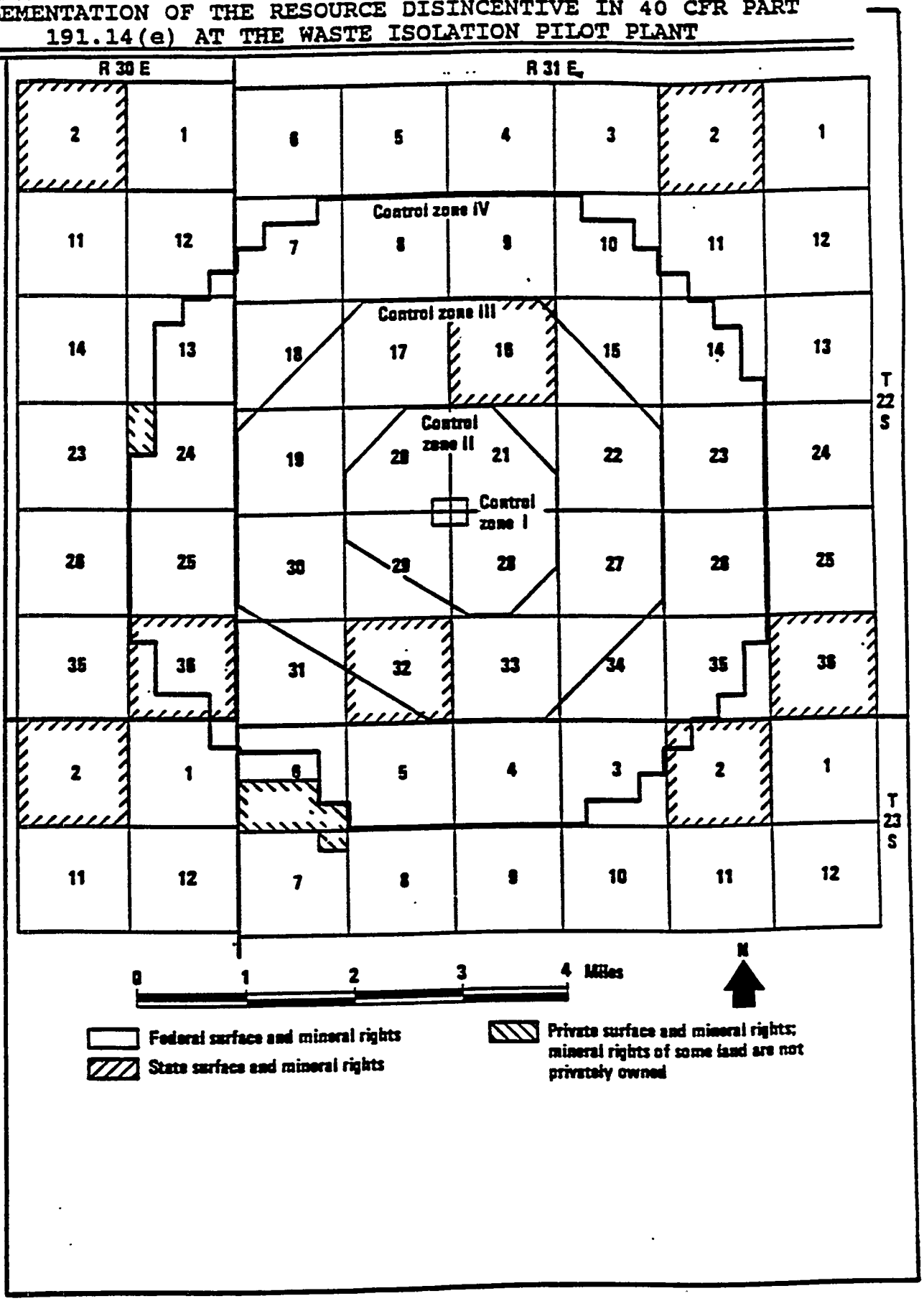


FIGURE 2 ORIGINAL CONTROL ZONES AT THE WIPP SITE

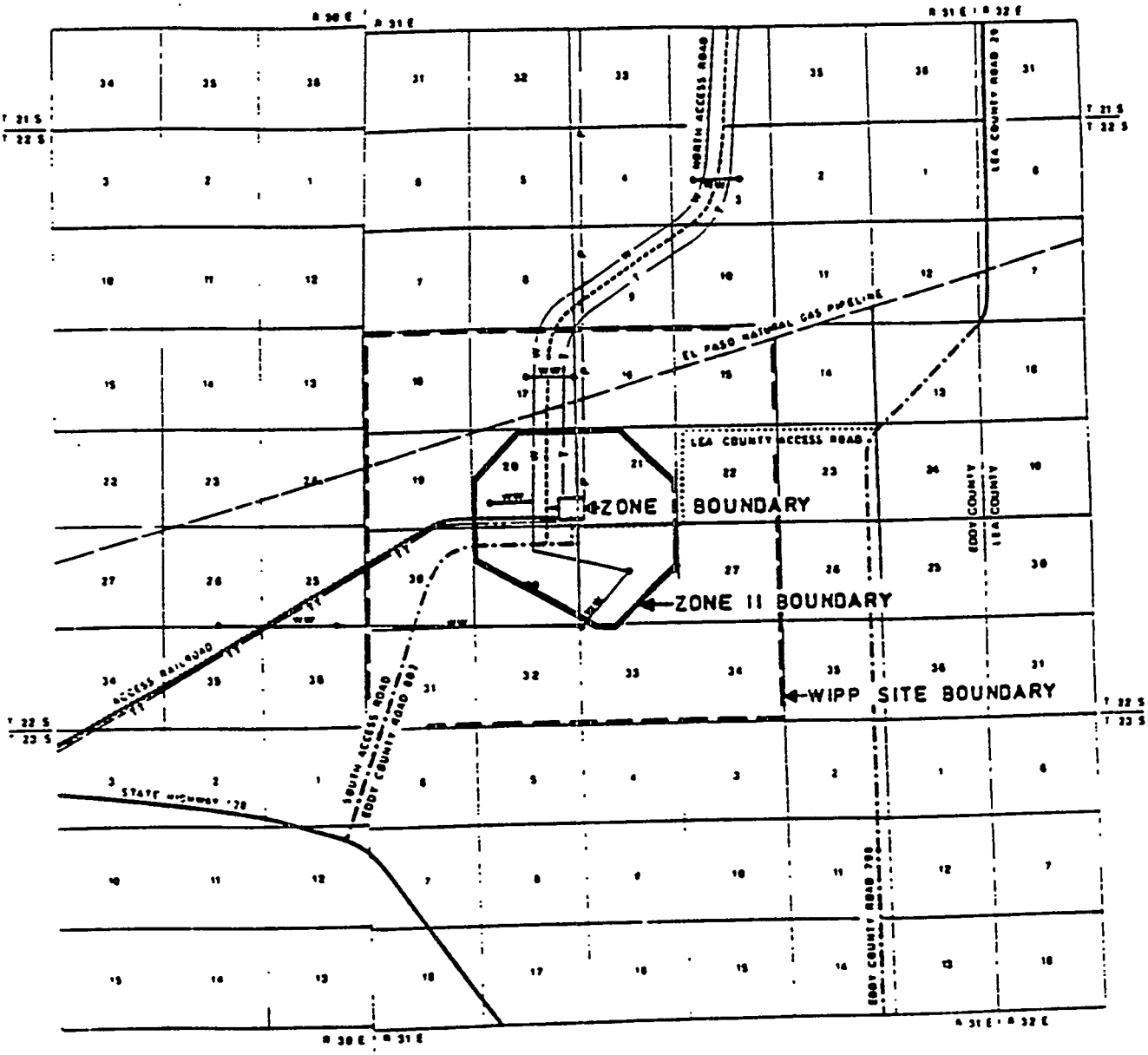


FIGURE 3 CURRENT WIPP FACILITY BOUNDARIES

TABLES

Table 4-1. Comparison of Geologic Media Considered for the WIPP Facility

Property	Salt	Basalt or Granite	Shale
BASIC PROPERTIES			
Plasticity	High	None	Variable
Solubility	High	Very low	Very low
Sorptive Capacity	Low (depends on impurities)	Fair	High
Compressive Strength	Moderate	High	Moderate
Thermal Diffusivity	High	Low	Low
Thermal stability against chemical decomposition	High	High; potential dewatering of clay in basalt	High; potential dewatering of clay
IN-SITU PROPERTIES			
Porosity	0.5%, interstitial	1%, cracks	5-30%, cracks
Permeability	Essentially none	Decreases with depth	Very low
Water presence	Isolated from flowing groundwater	Present, open to flowing groundwater	Present, open to flowing groundwater
Corrosiveness of indigenous fluid	High	Low to moderate	Low to moderate
Tectonic stability	Very stable	Very stable areas can be found	Very stable areas can be found
Geologic structure	Relatively simple areas can be found	Fracture systems often complex	Like salt
Hydrology	Moderately difficult to characterize	Difficult to characterize	Difficult to characterize
PRACTICAL MATTERS			
Availability	Good	Good	Good
Need to use explosives	No	Yes	Possibly
Understanding of medium for repository use	Well studied	Not well studied	Not well studied
Waste rock	Reuse some; pile needs protection from erosion and runoff	Reuse some; pile probably does not need protection	Reuse some; pile needs protection but less that salt
Mathematical modeling	Relatively simple; well developed	Relatively complex; not fully developed	Relatively complex; not fully developed

Source: U. S. Department of Energy, 1980, p. A-4.

Table 4-2. Hydrocarbon Reserves and Resources at the WIPP Site

	Condensate (bbl)			Gas (10^6 ft^3)		
CATEGORY	ZONES I,II,III	ZONE IV	CATEGORY TOTAL	ZONES I,II,III	ZONE IV	TOTAL
Proved but undeveloped reserves	0	81,758	81,758	0	11,610	11,610
Probable reserves	11,640	9,822	21,462	9,050	10,094	19,144
Possible reserves	14,169	1,135	15,304	12,002	1,866	13,868
Total reserves	25,809	92,715	118,524	21,052	23,570	44,622
Unassigned reserves and resources			272,319			39,352
Grand total			390,843			83,974

Source: U.S. Department of Energy, 1980, p. 7-74.

Table 4-3. Summary of the Impacts of Hydrocarbon Resource Denial

RESOURCES

DEPOSIT	SITE TOTAL	REGION	UNITED STATES	WORLD
Natural Gas (bill. ft³)	490	25,013	855,000	N/A
Control Zones I-III	211	0.8 %	0.025 %	
Control Zone IV	279	1.1 %	0.033 %	
Distillate (mill. barrels)	5.72	293	N/A	N/A
Control Zones I-III	2.46	0.84%		
Control Zone IV	3.26	1.11%		
Crude Oil (mill. barrels)	37.5	1915	200,000	N/A
Control Zones I-III	16.12	0.84%	0.008 %	
Control Zones IV	21.38	1.12%	0.0006%	

RESERVES

DEPOSIT	SITE TOTAL	REGION	UNITED STATES	WORLD
Natural Gas (bill. ft.³)	44.62	3865	208,800	2,520,000
Control Zones I-III	21.05	0.54%	0.01 %	0.0008%
Control Zone IV	23.57	0.61%	0.011 %	0.0009%
Distillate (mill. barrels)	0.12	169.1	35,500	N/A
Control Zones I-III	0.03	0.02%	0.00008%	
Control Zone IV	0.09	0.06%	0.00024%	
Crude Oil		471.7	29,486	646,000

Source: Based on U.S. Department of Energy, 1980, p. 9-19 and 9-28.

Table 4-4. Summary of Potash Resources at the WIPP Site

RESOURCES

DEPOSIT	SITE TOTAL	REGION	UNITED STATES	WORLD
Sylvite (mill. tons ore)	133.2	4260	8550	850,000
Control Zones I-III	39.1	0.92%	0.46%	0.0046%
Control Zone IV	94.1	2.21%	1.10%	0.01%
Langbeinite (mill. tons ore)	351.0	1140	N/A	N/A
Control Zones I-III	121.9	10.7 %		
Control Zone IV	229.1	20.1 %		

RESERVES

DEPOSIT	SITE TOTAL	REGION	UNITED STATES	WORLD
Sylvite (mill. tons K_2O)	3.66	106	206	11,206
Control Zones I-III	NIL			
Control Zone IV	3.66	3.45%	1.78%	0.33%
Langbeinite (mill. tons K_2O)	4.41	9.3	9.3	N/A
Control Zones I-III	1.21	13.0 %	13.0 %	
Control Zone IV	3.20	34.4 %	34.4 %	

Source: U.S. Department of Energy, 1980, p. 9-19 and 9-28.

APPENDIX A

LIST OF PUBLICATIONS ADDRESSING SITE SELECTION (FROM EEG-1)

I: No. 8

nflict with Natural Resources

1. Should be taken into account/information useful for site selection/evaluation:
   i. to be considered in making criteria - petrographical and mineralogical composition and economic value, p. 12-13; questions regarding salt as host media: often associated with potash and oil and may be an attractive target for exploratory boreholes, p. 9, AECL Canada 1976, E2
   ii. for salt formation, occurences of petroleum, potash mines, oil and gas production, USGS 4339-1, 1972, B2
   iii. Criteria - future value of potash deposits should be considered, p. 70-71; economic development - potash, ranches, oil and gas fields, p. 45, USGS 4339-6, 1973, B4
   iv. study considered oil and gas deposits, potash, p. 20, USGS 74-190, 1974, B9
   v. criteria considered - oil, gas and recreational potential development, p. 2-3, Supplemental Areas, Kn GS 1972, B11
   vi. in geologic study of areas, range of tasks includes natural resource evaluation, including those items relating to people's activities in the subsurface which would alter the natural geologic conditions, p. 22, OWI/ERDA Program Plan for NWTSP 1976, D19
   vii. petroleum, potash, sulfur - may be present near a salt deposit. Necessary to weigh need for rep and the availability of other sites against present and potential need for mineral resources at site. . . .
   ,- p. 6, OWI/DOE Salt Dep of US 1978, D21
   - p. 48, IAEA SS Factors 1977, E11
   viii. potential for oil and gas - considered since it might attract drilling, ORNL McClain and Boch 1974, D3
   ix. potential sites in salt should be evaluated for potential exploitation and/or contamination of oil, gas, and water resevoirs, and of salt, potash and other valuable or potentially valuable commodities, p. 4.63, HLWM Alternatives, BNWL-1900, 1974, D16
   x. site selection - determine suitability of broad regions in terms of potential for denial of natural resources, p. 13; site evaluation - need detailed definition of distribution of physical properties throughout site (i.e. petrologic and mineralogic features), p. 14; ES aspects of long term risk analysis - need knowledge of processes that affect containment capability: identification of mineral resources that might serve to cause people to penetrate rep, p. 16-17, ESTP USGS and DOE 1979, D24
   xi. events taken into account in risk analysis - human intrusion: gas/oil exploration, mineral exploration, p. 95-103, AD Little, Assessment 1978, C3

2. Formation should not be associated with or be in the immediate vicinity of potentially valuable mineral resources:
   i. no area with present or past history of resource extraction except by surface quarrying should be considered, p. 13-15, NAS/NRC 1978, A1
   ii. to the extent possible, p. 2:10; unavoidable conflict with resources should be minimized to the extent possible (large scale site selection criteria), p. 2:20-21, GCR 1978, D10

iii) p15, Canada AECL 1975, E1

iv) tract considered is most promising since it is 5 miles or more from any center of industrial activity, i.e. gas or oil wells or mines, p 34-35, USGS 4339-7, 1973, B5

v) preferred salt environment -where oil and gas potential is low; unsuitable area - where strata have high oil or gas potential, p 3 USGS 74-158, (B8) 1974; p 4.4, HLWM Alternatives, BWNL - 1900, 1974 (D16)

vi) p 21 AEC, Lyons E. S. 1971, D6

vii) Criteria must be met: waste must not be placed in potentially useful mineral deposits, p 13-14, Deep Rock, Klett/Sandra 1974, D8

viii) SS criteria p 12-13, SS WIPP/Sandia 1977, D9

ix) Site should not offer an attractive resource target p 5; actual or potential resource of site should be such that it will not unduely deprive this or future generations of necessary and valuable resources, p 5-6, Nureg 0353, NRC-State Review 1977, C4

x) Would make site more favorable, p 6, OWI/DOE Salt Dep of US 1978, D21

xi) p 3-4, ORNL, Program Plan for BSPP 1973, D1

xii) Avoid areas where mineral resources are "known to abound" and where resources were "worked out" in formation below rep, Kehnemuyi, Battelle M, 1979, D23

xiii) avoid areas of existing production or extensive exploration as much as possible, p 10, mineral potential should be minimal to minimize probability of future operations. p 11, summary, BSPPSS Factors ORNL 1973, D2

xiv) presence of potentially mineable minerals detract from usefulness of host rock for disposal, p 33, IAEA SS Factors 1977, E11

xv) as much as possible - p 5, Brunton & McClain, OWI/ERDA 1977, D20

xvi) de Marsily, etal, Guarantee Isolation? 1977, E5

xvii) p 2-9, 4-73, ES of WM of LWR Cycle, NRC 1976, C8

Reasons:

a. potential source of raw materials that would be denied:

i) p 13-15, NAS/NRC 1978, A1

ii) proposed criteria: actual or potential resource value of site should be such that it will not unduly deprive this or future generations of necessary and valuable resources, p 5-6 NRC State Review, Nureg-0353 1977, C4

iii) p 36-40, EPA State of Geologic Knowledge 1978, C7

iv) waste disposal facilities shall be sited and operated to avoid as much as possible the foreclosure of future options. p 13, NRC - Proposed Goals for RWM, 1978, C9

b. disturbance of hydrological/geological system by boreholes, shafts, fractures, cavities;
   i) p 13-15, NAS/NRC 78, A1
   ii) p 32 OWI/ERDA, Program Plan for NWTSP 1976, D19
   iii) avoidance of areas over "worked out" mineral deposits because of danger of subsidence, Kenhemuyi, Battelle M, 1979, D23
   iv) site should be located so that existing subsurface operations would be outside buffer zone and to minimize probability of future operations since current technology makes it difficult to predict what the eventual effects of mechanical or solution mining on rep might be. p 11, BSPPSS Factors ORNL 1973, D2
   v) people are now one of the major driving forces for geologic change (erosion, solid movement and water movement for example) p-13, NRC Proposed Goals for RWM 1978, C9
   vi) site should be where intrusion of people in a manner that will change conditions is minimal. p 4.5 HLWM Alternatives, BNWL-1900 1974, D16

c. Attract propspection - exploration that might penetrate rep:
   i) p 13-15, NAS/NRC 1978, A1
   ii) danger of reexploitation of already mined resources; Kehnemuyi, Batelle, M, 1979, D23
   iii) minimize probability of future operations within buffer zone, p 11, BSPP SS Factors, ORNL 1973, D2
   iv) Must have no natural resources in area that would attract prospection deMarsily, et al, Guarantee Isolation? 1977, E5
   v) site should not offer attractive resource target, p 5, NRC, State Review, Nureg 0353, 1977, C4
   vi) Recommendations have been presented p IV-57, KBS Rydberg & Winchester 1978, E9
   vii) People will seek anything of value and are now one of the major driving forces of geologic change - to the extent predictable, we should design and locate facilities so as to avoid motivation for penetrating disposal volume, p 13 NRC-Proposed Goals for RWM 1978, C9
   viii) p 35-40, EPA State of Geologic Knowledge 1978

3. Avoid conflicts with water as a natural resource:
   i) esp in arid areas, groundwater is an important commodity - extensive deposits of fresh water above or below site could adversely affect its availability due to public opinion, p c 10-12, ERDA/BNWL, App c 1976, D18
      p 41, IAEASS Factors 1977, E11
   ii) special care needed if water near site is used by municipalities, industry, agriculture, p 5-6 OWI/DOE Salt Dep of US 1978, D21
   iii) avoid areas where groundwater resources are extensively used and/or have potential for significant future development -Kehnemuyi, Battelle M, 1979, D23
      -SS Factor, BSPPSS Factors, ORNL 1973, D2
      -p 6 Brunton & McClain, OWI/ERDA 1977, D20
      -p 4.4.1 HLWM Alternatives, BNWL-1900 1974, D16

iv) there may be conflict with industrial, recreational, scenic interest in large lakes and streams - p C 10-12, ERDA/BNWL, Alternatives App c 1976, D18
- p 41, IAEA SS Factors 1977, E11
- p 6 Brunton & McClain, OWI/ERDA 1977, D20

4. Waste placed in rep as a natural resource:

i) operation of the rep should not create a potential future source of valuable material; unreprocessed spent fuel elements, potentially highly valuable to future people, should not be placed in non-retrievable storage (temptation to penetrate rep), p 13-15, NAS/NRC 1978, A1

ii) consideration: since uranium ore is limited, it may become desirable to recover unreprocessed fuel rods, so a breach in the rep to recover them could be a serious problem in the future. p 3, p 35-36 State of Geologic Knowledge 1978 EPA, C7

iii) goals for RWM: to the extent predictable, we should design and locate facilities so as to avoid motivation for penetrating the disposal volume. p 13, NRC-Proposed goals for RWM 1978, C9

5. If the rep is located where there are natural resources present or near-by:

i) If possibility exists that some valuable resource is present, it will be necessary to show that credible attempts to recover the resources will not have adverse effects on the effectiveness of the rep, p 5; Proposed criteria: site should have characteristics such that the consequences of unplanned intrusions will be ALARA p 5-6, Nureg 0353, NRC State Review 1977, C4

ii) accidental penetrations should not result in undue hazard. p 2:17 GCR 1978, D10

iii) Resources could be extracted from adjacent regions with proper evaluation and precautions. To be considered in evaluations: compatibility of operations, impact on rep from extraction operations, possibility of contamination of resource by waste. p 48, IAEA SS Factors 1977, E11

iv) "The expectation, but one that cannot yet be guaranteed is that these minerals (at WIPP site in Zone III) may be recovered in decades ahead should they be economically attractive. Certainly the time frame for their development would be within the next century while the rep site is still under administrative control. The small amounts of either resource within zone III would not be of significant interest in the absence of other production in the area." p 10, Letter from Beckner to Schueler, Dec. 1978, D13

v) Rydberg -Though recommendations have been presented that rep be placed in area with no valuable minerals, "it seems probably that a future person, who is capable of mining and drilling to a depth of 500m, also will use instruments capable of detecting radioactivity." p IV-57- KBS Rydberg & Winchester 1978, E9

6. Can we predict the likelihood of intrusion of people into rep in search of resources?

i) Uncertainities are introduced into risk assessments because of uncertainit of probabilities and consequences of human intrusion. p 4-94, ES of WM of LWR Cycle, NRC 1976, C8

ii) Another risk for which no trustworthy probability estimates can be applied-

intrusion at some future date by people in search of minerals (including the uranium and TRU buried in rep) or to satisfy archeological or other curiosity. People's unpredictability far outstrips that of most of the imagined geologic hazards, p. 35-36; as raw materials dwindle there will be an increasingly desperate exploitation of them. What mineral resource exploitation might be like a thousand years from now is impossible to predict - should be considered, p. 36-40, EPA State of Knowledge, 1978, C7

iii. Do we adequately understand how to evaluate current resource conflicts? models tested, applying to specific site (including WIPP), p. 38; Can we estimate the long term effects of future resource conflicts? moderate understanding of principles, developing models, p. 44, ESTP USGS and DOE 1979, D24

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APPENDIX B

DOE REVISED INTERIM POLICY STATEMENT

Department of Energy
Albuquerque Operations Office
P.O. Box 5400
Albuquerque, New Mexico 87115

DEC 2 3 1982

Dr. George S. Goldstein
Chairman, Radioactive Task Force
Health and Environment Department
P.O. Box 968
Santa Fe, NM 87503

Dear Dr. Goldstein:

DOE Revised Interim Policy Statement on Natural Resource Recovery at the WIPP Site

Enclosed for your use and information is the DOE Revised Interim Policy Statement on Natural Resource Recovery at the WIPP Site. Under the terms of this policy statement no potash or other commercial mining in, or commercial drilling from, Control Zones I, II and III will be allowed; however, the DOE will exercise no control over mining or drilling outside Control Zone III. (Control Zone III is being redefined as the area withdrawn for SPDV which is a square containing 16 sections (10,240 acres) surrounding the center of the site.) Additionally, BLM will prohibit permanent inhabitation of Zone IV while the facility is in operation. Hydrocarbon resources below 6000 ft. beneath Control Zones I, II and III can be accessed by deviated drilling from outside the Control Zone III boundary. The DOE will rely on the review of State and Federal regulatory agencies, including the New Mexico Energy and Minerals Department and the U.S. Department of the Interior, Minerals Management Service, to protect the integrity of the WIPP Site boundaries from commercial exploration, mining or other extractive activities. So that the DOE can maintain information on resource recovery near the WIPP Site, the Bureau of Land Management will notify the DOE of any requests for resource recovery permits within one mile of the WIPP Site boundary.

The final DOE policy will be issued when the decision is made regarding retrieval of the waste. Should the DOE decide to retrieve all the radioactive waste, the WIPP Site will become available for complete resource recovery after retrieval and decommissioning are complete.

The initial Interim Policy Statement, which was transmitted to the State of New Mexico on November 3, 1981, was developed to serve as the basis for the performance of the Natural Resources Study. The initial DOE

Interim Policy, as indicated therein, was "temporary denial of all resource extraction within the four control zones of the WIPP Site until the decision is made relative to which, if any, of the emplaced waste will be retrieved." Based on the conclusions of the Natural Resources Study, which was transmitted to the State of New Mexico on October 5, 1982, we have determined that the initial Interim Policy can be revised as indicated above.

Not only does the DOE Revised Policy Statement reflect the conclusions of the Natural Resources Study but it also addresses comments provided by the New Mexico Environmental Evaluation Group on the Policy Statement.

If you require additional information or have questions on this matter, please contact me.

Sincerely,

J. M. McGough
Project Manager
WIPP Project Office

Enclosure

WIPP:JMM 82-0885/6366A

cc: w/encl:
J. K. Otts, Chairman, Radioactive Waste Consultation Committee, Santa Fe, NM
J. Bingaman, Attorney General, Santa Fe, NM
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DOE REVISED INTERIM POLICY STATEMENT ON RESOURCE RECOVERY AT THE WIPP SITE

The policy of the Department of Energy (DOE) concerning resource recovery at the Waste Isolation Pilot Plant (WIPP) site during facility construction and operation is as follows:

- No potash or other mining excluding that conducted for the WIPP Project will be allowed in WIPP Control Zones I, II, and III.

- No drilling excluding that conducted for the WIPP Project will be allowed from Control Zones I, II, and III.

- Drilling from outside Control Zone III to access locations beneath Control Zones I, II, and III at depths greater than 6,000 feet will be allowed if the planes formed by the downward vertical projections of the Control Zone III boundaries are not penetrated above a depth of 6,000 feet.

- DOE will rely on the review of State and Federal regulatory agencies, including the New Mexico Energy and Minerals Department and the Minerals Management Service, U.S. Department of the Interior, to protect the integrity of the WIPP site boundaries from commercial exploration, mining, and other extractive activities.

- If the DOE decides that all radioactive waste is to be retrieved, the WIPP site will become available for complete resource recovery once retrieval and facility decommissioning is accomplished.

This policy may be re-evaluated after facility decommissioning. The following paragraphs provide a measure of clarification of the rationale used to develop the resource recovery policy.

It is the policy of the DOE to maximize the opportunity for resource recovery at the WIPP site, consistent with the requirements to isolate the emplaced radioactive wastes from the biosphere. Within five years after the first emplacement of each type of TRU waste (i.e., contact and remotely handled), separate decisions will be made about the retrieval of each kind of waste. If the DOE decides that all waste is to be retrieved, the WIPP site will become available for complete resource recovery once retrieval and facility decommissioning are accomplished.

The criterion for the DOE policy is that permanent denial of resources should be limited to those areas in which extraction activities could potentially lead to measurable effects[1] on the WIPP facilities or whose protection is needed to satisfy institutional considerations, all extraction activities that would not lead to measurable effects on the WIPP site are defined as "allowable" under the DOE policy.

Potash (sylvite and langbeinite) and hydrocarbons (natural gas and distillate) comprise the resources present at the WIPP site that are of interest considering the technology and market conditions in the foreseeable future. These resources and the methods available to recover them are described in detail in the FEIS (U.S. Department of Energy, 1980).

---

1 Measureable effects are those influences from extraction activities that could cause the assumptions made in the breach scenario consequence analyses (U.S. Department of Energy, 1980) to be unconservative.

Due primarily to institutional considerations, no potash mining in or commercial exploratory drilling (hydrocarbon or other) from Control Zones I, II, and III will be permitted. A study was conducted to investigate the possible effects of resource recovery within Control Zone IV on the WIPP facility (Natural Resources Study, Brausch et al., 1982). The following paragraphs provide a brief summary of the results and conclusions of that study.

The extraction of potash outside Control Zone III is allowable. Potential methods of mining potash include drill-and-blast, continuous mining, solution mining, shortwall, and longwall techniques. Since mining of potash is allowable, it is not reasonable to prohibit those mining techniques that make such an activity economically viable. To prohibit such activities is, in effect, to preclude mining. Accordingly, extraction ratios can be maximized in any mines developed outside Control Zone III of the WIPP site, consistent with mine safety considerations and other state and federal requirements. Solution mining will be allowable outside Control Zone III. Resource extraction by solution mining may be applied to recovery of sylvite. Solution mining for recovery of langbeinite would be ineffective because langbeinite is less soluble than the surrounding minerals (e.g., halite, sylvite). However, the lack of existing solution mining for sylvite in the Carlsbad potash mining district suggests that solution mining for potash within Control Zone IV may not be feasible.

The recovery of hydrocarbon resources outside Control Zone III is allowable. This activity includes drilling, production stimulation, and, possibly, secondary recovery. Resources located outside Control Zone III may be accessed by vertical drilling; resources located beneath the inner three control zones at depths greater than 6,000 feet may be accessed by drilling vertically outside Control Zone III to a depth of 6,000 feet and then deviating from vertical at the angle required to reach the target resource zone.

If oil or gas is found, it is not reasonable to prohibit those techniques available to the producer that maximize recovery. Enhancing the production from drilled wells by hydraulically fracturing the reservoir rock, acidizing the formation, or other applicable techniques would not be expected to affect the WIPP facility.

These types of production stimulation are used primarily to increase the permeability of the rock that contains the hydrocarbons. Secondary recovery methods (techniques used to enhance or replace the natural driving force that "pushes" the oil to the production well) and tertiary methods (techniques used primarily to decrease the viscosity of heavy crude oils) may also be employed but, because the crude oil resources at the site are not reasonably or economically extractable, these techniques are not expected to be useful unless significant technological advances and adaptations are made.

State and federal regulatory agencies, including the New Mexico Energy and Minerals Department and the Minerals Management Service of the U.S. Department of Interior, are responsible for reviewing proposed mining and hydrocarbon exploration plans to prevent injury to adjacent leases or properties. The DOE will rely on this regulatory review process to protect the integrity of the WIPP site boundary from potash mining and hydrocarbon exploration on adjacent properties. The DOE will provide assistance to these agencies during the review process upon request. In addition, the BLM will notify the DOE of any requests for permits for resource recovery activities within one mile of the WIPP site boundary.

This policy will be modified if changes in institutional requirements occur or if significant new data relevant to the policy are obtained during development and operation of the WIPP facility.

APPENDIX C

FINAL ENVIRONMENTAL IMPACT STATEMENT
APPENDIX D,
SELECTION CRITERIA FOR THE WIPP SITE

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Appendix D

SELECTION CRITERIA FOR THE WIPP SITE

This appendix briefly describes how the geologic, hydrologic, and other characteristics of the WIPP site in southeastern New Mexico meet site-selection criteria and factors. The criteria and factors given here are from the Geological Characterization Report (Powers et al., 1978, pp. 2-15ff) and are based on criteria suggested earlier by the Oak Ridge National Laboratory (ORNL, 1973), the International Atomic Energy Agency (1977), and Brunton and McClain (1977).

The site-selection criteria described here were originally formulated under the expectation that the WIPP would be a repository that would contain spent fuel from nuclear reactors. The heat emitted by spent fuel would have had important effects on the salt in which it was emplaced; for that reason, some of the criteria were specifically intended to insure the safety of spent-fuel emplacement. The WIPP mission no longer includes the disposal of spent fuel or any other high-level waste. Furthermore, the design of the WIPP no longer includes the separate mined cavity for high-level waste called the "lower repository" or the "lower horizon" in the criteria. Accordingly, not all the criteria presented here are applicable to the WIPP under its current mission and design. Because the site was, however, actually selected under these criteria, no effort has been made to revise them for this document.

D.1 GEOLOGIC CRITERION AND SITE-SELECTION FACTORS

The geology of the site will be such that the repository will not be breached by natural phenomena while the waste poses a significant hazard to man. The geology must also permit safe operation of the WIPP repository.

Topography. The terrain must permit access for transportation. The effect on inducing salt flow during excavation must be considered. Surface-water flow and the potential for flooding must be evaluated.

The maximum relief over the WIPP repository is 120 feet. The regional relief is low and easily accommodates the required transportation corridors. The location near a broad surface and groundwater divide will minimize the development of future relief. Differential stress in the salt due to surface relief is not a significant factor in causing deformation in the salt. (See Powers et al., 1978, Sections 3.2 and 4.2.)

Depth. Repository horizons should be deeper than 1000 feet to insure that erosion and consequences of surficial phenomena are not a major concern. The depth of suitable horizons will not exceed 3000 feet to limit the rate of salt deformation around the excavations.

The selected repository bed for heat-producing waste varies between depths of 2750 and 2250 feet over the potential excavation area. The bed for TRU

waste ranges from 2200 to 1800 feet deep through the repository region. These depths are based on interpretations of seismic reflection data. (See Powers et al., 1978, Sections 3.3, 4.3, and 9.2.)

Thickness. The total thickness of the salt deposits should be several hundred feet to buffer thermal and mechanical effects. The desired thickness for the repository bed is 20 feet or more to mitigate the thermal and mechanical effects at nonhalite units.

The halite unit in which the heat-producing waste will be placed is about 100 feet thick. The total thickness of the evaporite section provides about a 1300-foot buffer above and below the repository horizons. This distance to the nearest potential aquifers insures that the thermal effects at these aquifers will be insignificant. (See Powers et al., 1978, Sections 4.3.2 and 9.2.)

Lateral extent. The distance to structural or dissolution boundaries must be adequate to provide for future site integrity. For the Los Medanos area a distance of 5 miles to the Capitan reef and 1 mile to regional Salado dissolution has been established.

From seismic data and drill-hole information, the selected horizons are believed to extend well beyond the repository site. The separations from the deformed salt belt parallel to the Capitan reef and from the natural dissolution fronts are adequate to insure the required site integrity. (See Powers et al., 1978, Sections 3.3, 4.3, and 6.3.)

Lithology. Purity of the salt beds is desirable. Brine in the salt could induce geochemical interactions; pending further investigations, 3% brine is established as a desirable upper limit for the heat-producing waste horizon. Additional geochemical interactions must be considered if significant chemical or mineral impurities are present.

The horizon within the lower Salado that will accommodate the heat-producing wastes averages more than 97% halite from the samples analyzed. Brine content averages less than 0.5%. (See Powers et al., 1978, Sections 4.3 and 7.2 through 7.6.)

Stratigraphy. Continuity of beds, character of interbedding, and nature of beds overlying and underlying the salt are important considerations in the construction of the facility; they are also important in insuring the long-term integrity of the repository.

There are no beds of clay or polyhalite near enough to the lower repository horizon to affect repository construction and operation or to affect the long-term performance of the repository. The significant nonhalite beds adjacent to the heat-producing-waste horizons are principally anhydrite, which has favorable thermal, mechanical, and chemical properties for bounding layers. The upper (TRU-waste) level of the repository can also be located to avoid rock-mechanics instabilities due to interbeds of nonhalite rock. (See Powers et al., 1978, Sections 3.3, 3.4, 4.3, and 4.4.)

Structure. Relatively flat bedding (less than 3 degrees) is desirable for operational purposes. Steep anticlines and major faults are to be avoided.

Seismic-reflection data and drill-hole information have been interpreted as showing relatively flat (less than 1 degree) bedding over most of the 3-square-mile repository horizon. Seismic data do show a small anticline at the northern edge of control zone II. Drilling on this anticline (WIPP-12) has shown that the elevation difference of the repository beds, from ERDA-9 at the center of the repository to WIPP-12, is less than 200 feet, an average of about 2 degrees. Photography, satellite imagery, surface mapping, geophysical techniques, and drilling have been used to search for indications of significant faulting. No post-Permian faults are known to exist in the site area. Seismic indications of faulting in older, deeper rocks do not extend through the Permian evaporite section.

The lack of severe structure and recent faulting satisfactorily meets the desired conditions for this factor. (See Powers et al., 1978, Sections 3.4 and 4.4.)

Erosion. While the depth of the repository reduces concern about erosion, it is desirable to avoid features that would tend to localize or accelerate erosion.

The site is located near a broad surface-water divide, and the local base level is at an elevation of about 2900 feet. Consequently, future erosion will proceed less rapidly over the site than in the established drainage channels. The expected erosion rates will not expose the Salado salt within the required lifetime of the repository. Future climatic changes will not alter this assessment, and glaciation is not expected to be a concern at this location. (See Powers et al., 1978, Sections 3.2.3, 3.6, 4.2, and 6.2.)

Dissolution. Regional and/or local dissolution must not breach the repository while the wastes represent a significant hazard to people. While there are various suggestions for the time a repository should remain isolated from the biosphere, a period of 250,000 years (10 half-lives of plutonium-239) is commonly used to represent the time over which the wastes are significantly hazardous.

Studies by the U.S. Geological Survey indicate that the maximum rate of horizontal progression of the salt-dissolution front in Nash Draw, averaged over the past 500,000 years, has been 6 to 8 miles per million years and less than 500 feet vertically per million years. The nearest active solution front is to the west, in Nash Draw. This is far enough from the site to provide repository isolation for more than 2 million years. (See Powers et al., 1978, Section 6.3.6.)

Subsidence. Subsidence due to dissolution of salt will be avoided when the subsidence adversely affects the repository beds or unduly accelerates the rate of dissolution to the jeopardy of the long-term integrity of the repository.

Subsidence has occurred over the western portion of the WIPP site area because of the natural removal of salt from the Rustler Formation. Hydrologic data from this region indicate that the major aquifers in the Rustler have different potential heads, and thus this regional subsidence has not caused them to be interconnected by permeable fractures. No sinks due to localized solutioning are present at the site.

D.2 HYDROLOGIC CRITERION AND SITE-SELECTION FACTORS

The hydrology of the site must provide high confidence that natural dissolution will not breach the site while the waste poses a significant hazard to man. Accidental penetrations should not result in undue hazards to mankind.

Surface water. Present and future runoff patterns, flooding potential, etc., should not endanger the penetrations into the repository while these openings are unplugged.

Because the site is near a broad surface-water divide, lacks established drainage, and is well above the Pecos River, simple construction techniques will prevent flooding of the repository. (See Powers et al., 1978, Section 6.2.)

Aquifers. For the WIPP, the overlying and underlying aquifers represent a secondary barrier if the salt is breached. Consequently, low permeability and transmissivity are desirable but not mandatory. Accurate knowledge of aquifer parameters is important to construction, decommissioning, and realistic calculation of the consequences of failure scenarios.

Aquifers above and below the repository have low transmissivity. Consequently, flooding of the repository during its operation through shafts or drill holes is not credible. These access points can readily be plugged to prevent water inflow after decommissioning.

The quantity of water carried by the major aquifers above and below the WIPP beds is too small to be useful. Furthermore, the water carries too many salts to be potable or otherwise useful.

The hydrologic parameters of the aquifers do not permit rapid flow of water. The low permeability would limit the flow even if heads were to be modified in future pluvial cycles. (See Powers et al., 1978, Section 6.3.)

Hydrologic transport. For the WIPP, this is a secondary factor that must be evaluated to allow quantitative calculations of the consequences of various failure scenarios. Slow transport of isotopes is acceptable if more critical factors have been satisfied.

Calculations based on various postulated failure scenarios show that the transport of radionuclides through the overlying and underlying aquifers would be so slow that a significant hazard to people would not exist even if the salt beds were breached. The nearest natural discharge point is near Malaga Bend on the Pecos River, over 14 miles away. At the maximum measured rate of water movement, it would take about 1700 years after a breach for the first trace of nonretarded nuclides (i.e., iodine-129) to appear at the Pecos. The long-lived transuranic nuclides would be retarded by the sorption of ions and would not begin to appear at Malaga Bend until 35,000 years after a postulated breach of the salt beds. The concentrations of radionuclides (or possible radiation doses) would never reach significant hazard levels in the Pecos River. (See Powers et al., 1978, Sections 6.3, 9.3, and 10.6.)

Climatic fluctuations. Possible pluvial cycles must be considered in estimating the effects of the hydrologic factors.

The dissolution and erosion rates established as averages over the past 500,000 years include the effects of several past pluvial cycles. It is expected that future cycles would also be shorter than the isolation time sought for the repository. Transport rates under different climates (rainfall) can be estimated by appropriate boundary conditions on the hydrologic model. The low permeability of the major aquifers above the site will not be significantly altered by the climatic changes expected for this area, and the resultant flow in the aquifers will not be grossly altered by changed climatic conditions. (See Powers et al., 1978, Sections 3.6 and 4.5, Chapter 6, and Section 10.3.)

Man-made penetrations. The effect of drill holes and mining operations must be included in evaluating the potential effects of dissolution.

The repository and control zone III are free of preexisting boreholes that extend through the salt, shafts, and mining activity. Any existing or future holes in any of the WIPP zones must be adequately plugged when abandoned.

D.3 TECTONIC STABILITY CRITERION AND SITE-SELECTION FACTORS

Natural tectonic processes must not result in a breach of the site while the wastes represent a significant hazard to people and should not require extreme precautions during the operational period of the repository.

Seismic activity. The frequency and magnitude of seismic activity impact facility design and safety of operation. Low levels of seismicity are desirable, but facility design can accommodate higher levels as well.

The WIPP site is in an area of relatively low seismic activity. The nearest seismic activity has been 10 or more miles north of the site and of small magnitude. It is not known whether the three nearest events were tectonic, related to salt dissolution, or a result of human activity. No faulting has been observed in the area of these seismic events. In any case, they and the potential future events pose no hazard for a properly constructed repository and are no threat to its long-term integrity. (See Powers et al., 1978, Chapter 5 and Section 10.5.)

Faulting and fracturing. While open faults, fractures, or joints are not expected in salt, the more brittle units within and surrounding the salt may support such features that can enhance dissolution and hydrologic transport. Major faults and pronounced linear structural trends should be avoided.

No major structural trends of recent geologic age are known to exist in the site area. The nearest recent faulting observed is on the west side of the Guadalupe Mountains, some 70 miles away. Seismic-reflection data have indicated small faults in deep, old rocks below the Salado Formation. There are no known tectonic faults in post-Permian rocks at the site area. Thousands of miles of drift in the potash mines in the Salado salt have not encountered any open fractures or faults through which groundwater had penetrated.

D.4 PHYSICOCHEMICAL COMPATIBILITY CRITERION AND SITE-SELECTION FACTORS

The repository medium must not interact with the waste in ways that create unacceptable operational or long-term hazards.

Fluid content. The repository bed containing high-level waste should not contain more than 3% brine. The limit for TRU waste has not been established, but the value used for high-level waste is acceptable.

The average brine content of the lower repository is less than 0.5% by weight. The average brine content of the upper repository horizon beds is less than 1% by weight. (See Powers et al., 1978, Sections 7.5 and 10.7.8.)

Thermal properties. To avoid undesirable temperature rises, no major natural thermal barriers should exist closer than 20 feet of the repository horizons.

This is of significance to the lower horizon, where the halite unit of interest is about 100 feet thick. The adjoining beds are anhydrite, which, even though far enough away, has similar thermal conductivity and does not represent a thermal barrier in any case. (See Powers et al., 1978, Section 9.2.3.)

Mechanical properties. The medium must safely support excavation of openings even while thermally loaded. Clay seams and zones of unusual structural weakness should be avoided in the selection of the repository horizon.

The halite bed at the lower level is sufficiently thick and devoid of clay seams that stability of openings will not be a problem for repository operation. Clay seams and polyhalite beds are more common in the area selected for the upper repository level, but construction levels can be located to avoid significant structural stability problems from such nonhalite beds. (See Powers et al., 1978, Section 9.2.4.)

Chemical properties and mineralogy. Beds that are of unusual composition or contain minerals with bound water should not occur within 20 feet of the waste horizon. This will lessen the uncertainties with regard to thermally driven geochemical interactions.

The heat-producing waste horizon is quite pure halite, with more than 97% NaCl. No polyhalite, clay, or other water-bearing minerals occur near this horizon. The upper horizon beds are more than 92% NaCl, with impurities being mostly potassium and magnesium salts and clay. These impurities have no known negative implications for TRU-waste isolation and, in fact, have been shown to absorb radionuclides from brine. (See Powers et al., 1978, Sections 4.3 and 7.2 through 7.5.)

Radiation effects. While no unacceptably deleterious effects are postulated, these phenomena are best quantified in halite, and thus the purer rock salt beds are desired for high-level waste.

Salt-flow anticlines. Major deformation of salt beds by flow can fracture brittle rock and create porosity for brine accumulations. Major anticlines resulting from salt flow should be avoided or evaluated to check on brine presence and anhydrite fracturing.

The only anticlines within the site are relatively minor features. Both have been drilled, however, and the cores show little fracturing or porosity and no accumulation of fluids. These small anticlines will not hinder repository construction or jeopardize its long-term safety. (See Powers et al., 1978, Section 4.4.)

Diapirism. An extreme result of salt flow, this feature will be avoided for WIPP siting.

There are no known or indicated diapirs (salt domes) at the WIPP site. (See Powers et al., 1978, Section 4.4.)

Regional stability. Areas of pronounced regional uplift or subsidence should be avoided since such behavior makes prediction of future dissolution, erosion, and salt flow more uncertain.

Geologic mapping has failed to reveal any indicators of regional instability. Caliche formation and attitude indicate stable conditions in the site region over the last half-million years. The lack of scarps and the natural seismicity are consistent with regional stability. (See Powers et al., 1978, Sections 3.4, 4.4, and 10.3.2.)

Igneous activity. Areas of active or recent volcanism or igneous intrusion should be avoided to minimize these hazards to the repository.

No recent igneous activity is known in the region. Geophysical surveys, mining, and drill-hole intercepts have shown that an intrusive dike exists 9 miles northwest of the site. Radiometric dating shows it to be 35 million years old. No other intrusive features are known to exist in the region. (See Powers et al., 1978, Section 3.5.)

Geothermal gradient. Abnormally high geothermal gradients should be avoided to allow construction in salt at 3000 feet. High gradients may also be indicative of recent igneous or tectonic activity.

The geothermal gradient as determined in the AEC-8 drill hole shows a normal geothermal gradient averaging about 0.58°F per 100 feet. The heat flow is about one heat-flow unit. (See Powers et al., 1978, Section 4.4.1.)

Samples of WIPP salt show no characteristics that would produce undesirable effects under irradiation. The low brine content will limit the amount and effects of radiolytic disassociation of water. (See Powers et al., 1978, Chapter 9.)

Permeability. Salt has a very low permeability. It is necessary to evaluate the permeability only of the interbeds and the surrounding media. Low permeability is desirable, but quantitative limits need not be specified for site selection. Salt permeability to gases may be important in establishing waste-acceptance criteria.

Laboratory measurements on cores show very low permeability. On a large scale, measurements at the WIPP horizons have not been made. Experience in other drill holes (absence of aquifers in salt and presence of small high-pressure gas pockets) would argue for very low in-situ permeability on larger scales. (See Powers et al., 1978, Section 9.2.3.)

Nuclide mobility. This is a secondary factor in siting since confinement by the salt and isolation from water are the basic isolation premises. Ion sorption must be determined to allow quantification of safety analyses and to indicate whether engineered barriers (clay) would be beneficial.

The distributed impurities in the rock salt provide significant ion-sorption capability for many radionuclides. The clay layers in higher salt beds will be still more sorptive. These properties will tend to minimize radionuclide migration due to such local mechanisms as brine migration in thermal gradients. (See Powers et al., 1978, Section 9.3.)

D.5 ECONOMIC AND SOCIAL COMPATIBILITY CRITERION AND SITE-SELECTION FACTORS

The site must be operable at reasonable economic cost and should not create unacceptable impacts on natural resources or the biological and social environment.

Natural resources. Unavoidable conflict of the repository with actual or potential resources will be minimized to the extent possible.

This factor is not well satisfied by the WIPP site. Both hydrocarbons and potash exist in potentially economic quantities within the site. While salt itself may be considered a valuable mineral, its economic potential at the site is very low. Since both potash and hydrocarbons may be recovered from control zone IV, the amounts that may be restricted from development within zones I, II, and III are the critical amounts. These quantities are not large in terms of national supply (even the langbeinite product is synthesized in quantity from brine lakes). These minerals may prove an enticement for future exploration and exploitation. For this reason, studies are under way to examine the effects of recovering the potash ore from above control zone III. Very little potash exists above the repository (zone II) itself. Similarly, once adequate borehole plugging is demonstrated, drilling in zone III could be permitted or the same zones developed from zone IV by slant drilling. The expectation, but one that cannot yet be guaranteed, is that these minerals may

be recovered in the decades ahead should they be economically attractive. Certainly the time frame for their development would be within the next century, while the site is still under administrative control. The small amounts of either resource within zone III would not be of significant interest in the absence of other production in the area. (See Powers et al., 1978, Chapter 8.)

Man-made penetrations. Boreholes or shafts that penetrate through the salt into underlying aquifers will be avoided within 1 mile of the repository. Existing mining activity, unrelated to the repository, should not be present within 2 miles of the repository. Future, controlled mining will be allowable up to 1 mile from the repository. Future studies may permit still closer mining and drilling if properly controlled.

The present site adequately fulfills this present restriction on man-made penetrations. (See Powers et al., 1978, Section 2.3 and Chapter 4.)

Transportation. Transportation should be capable of ready development. Avoidance of population centers by transportation routes is not a factor in the siting of the repository.

The present site meets this requirement and would utilize a spur line of the Santa Fe Railroad now running to the Duval mine.

Accessibility. The site should be readily accessible for transportation and utilities.

The site presents no problems for access by road, railroad, or utility lines.

Land jurisdiction. Siting will be on Federal land to the extent possible.

Of the 18,960 acres to be withdrawn by the DOE if this site is approved, 17,200 are Federal land controlled by the Bureau of Land Management and 1760 acres belong to the State of New Mexico. There are no private lands within the site.

Population density. Proximity to population centers and rural habitats will be considered in siting. A low population density in the immediate site area is desirable.

There are 16 permanent residents within 10 miles of the site. There is a transient population at potash mines. The nearest town is Loving, New Mexico, with a population of 1600. Carlsbad is 26 miles west and has a population of 28,600. Low population is not necessary to siting but, all other factors being equal, is desirable.

Effects on ecology and cultural resources. Major impacts on ecology due to construction and operation should not occur. Archaeological and historic features of significance should be preserved.

DRAFT

LONG-TERM MONITORING

CONCEPT DESCRIPTION

MARCH 1995

ABSTRACT:

This report details the techniques and design descriptions which may be used to monitor the long-term performance of the Waste Isolation Pilot Plant (WIPP) repository after the waste is emplaced and the repository is sealed and closed. The current regulatory requirements that govern the monitoring of the facility and the rationale for the proposed technical systems used to monitor the repository are discussed. This report is intended to be used as a technical guide in producing the Long-Term Monitoring (LTM) Plan.

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LONG-TERM MONITORING CONCEPT

DESCRIPTION REPORT

1.0 Introduction

1.1 Facility Description

The Waste Isolation Pilot Plant (WIPP) is a research and development facility of the U.S. Department of Energy (DOE), designed to demonstrate the safe transportation, handling, and disposal of defense generated Transuranic (TRU) radioactive waste. The facility is located 26 miles east of Carlsbad, New Mexico, in a salt deposit, 2,150 feet below ground. Figure 1.1 is a diagram of the general WIPP facility layout. The waste will be shipped to the facility and placed in an underground repository for disposal. After the facility is filled with waste, the repository shafts and access ways will be closed and the surface facilities removed. During construction, operation, and closure of the WIPP, operational monitoring will be performed to protect the public, workers, and the environment in accordance with all regulatory and governing requirements. After closure, monitoring will determine if the repository is performing as expected. This report details monitoring technologies that may be used after the WIPP is sealed and closed to monitor repository performance.

The WIPP facility is currently under development, and is scheduled to be permitted and operational in 1998. When operational, the facility will accept waste for approximately 25 years before closure. The life of the facility will then progress through the decontamination and decommissioning phase and begin the post-closure phase.

1.2 Scope

The scope of this report is to develop specifications and criteria to direct the design and testing/evaluation of the long-term monitoring system. A description of the system will be included in the Long-Term Monitoring (LTM) Plan for the WIPP facility and, as appropriate, the hazardous waste permit application. The scope will be realized by first defining the requirements and then developing specifications for the LTM system. This will also include the development of testing, quality assurance, and quality control (QA/QC) guidelines for this system.

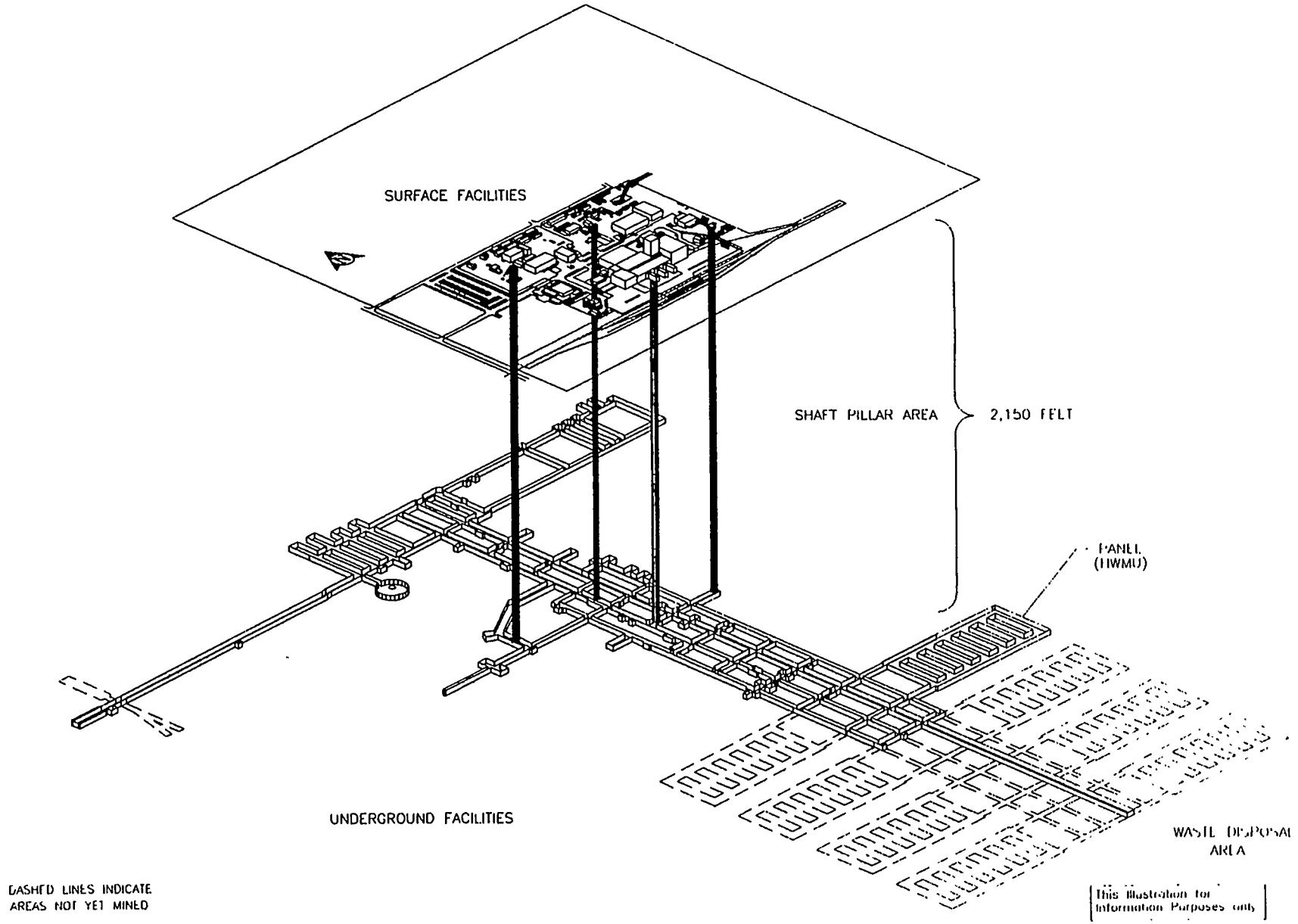


FIGURE 1.1 SPATIAL VIEW OF WIPP REPOSITORY

1.3 Requirements Influencing Long-Term Monitoring

The WIPP is regulated by the U. S. Environmental Protection Agency (EPA) and the state of New Mexico Environment Department (NMED). In addition, the DOE has entered into an agreement with the state of New Mexico for consultation and cooperation regarding the WIPP. Prior to initiating disposal operations, a hazardous waste permit must be granted by the NMED as guided by the Resource Conservation and Recovery Act (RCRA) regulations. Upon receipt and review of the DOE's No-Migration Variance Petition (NMVP), EPA has responsibility for granting or not granting a No-Migration Determination (NMD)in accordance with regulations contained in Title 40 CFR 268.6 . In addition, the EPA must certify that the WIPP is in compliance with the provisions of Title 40 Code of Federal Regulations (CFR) §191 and must make a determination regarding the disposal of transuranic radioactive wastes. Included in the effort of obtaining the permit and demonstrating compliance, applicable regulations require a plan which monitors the repository after waste emplacement and closure. Other requirements imposed on long-term monitoring are associated with the Agreement of Consultation and Cooperation between the State of New Mexico and the DOE (C&C). This agreement details specific post-closure environmental monitoring requirements.

This report uses information found in Sandia National Laboratories (SNL) documents, DOE/WIPP documents (including Westinghouse), Code of Federal Regulations (CFR), and Federal Register (FR) notices which apply to the WIPP LTM.

1.4 Report Approach to LTM

To demonstrate compliance with regulatory requirements, a performance assessment (PA) is used to predict the response of the repository over 10,000 years. The PA will construct scenarios which will then be analyzed for effects on repository performance and the resulting estimates of radioactive releases will be incorporated into probability distributions of cumulative releases. A monitoring program to detect substantial and detrimental deviation from the expected performance of the disposal system is required by 40 CFR §191.14(b). "Monitoring activities will be identified during the course of the performance assessment"[1].

The most viable means for monitoring the WIPP after closure is through geophysical methods. SNL has completed several preliminary PAs for the repository. These assessments use experimental data, computer models, and expert judgement to develop predictions for long-term performance at the WIPP. Several possible repository breach scenarios were developed. In its most recently published

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PA, SNL states that monitoring activities are most likely to include monitoring of hydrological, geological, geochemical, and structural performance [1]. This report will describe a technique for monitoring the WIPP after closure using geophysical methods.

Post-closure monitoring of the repository will use subsidence monitoring as the initial performance indicator. Subsidence monitoring measures the relative changes in surface elevation. Analytical, empirical, and theoretical calculations can estimate the subsidence above and around the repository over time. Subsidence measurements will be taken over a scheduled period and the results will be compared to the predetermined subsidence estimates (predictions).

An indication that the repository may not be performing as expected occurs when the results of a subsidence survey produce data that are not within the bounds of the prediction. At this time, the data will be evaluated to make a judgement with respect to whether or not the evaluated information represents a "substantial and detrimental deviation from expected performance" and if direct repository monitoring and/or intervention is required.

A Baseline Database will be documented consisting of results from surveys and calculations performed during the development and operation of the facility and data from surveys performed shortly after closure of the facility. This database will detail the geomechanical, geochemical, structural, and hydrological characteristics of the repository which are amenable to monitoring. Only survey techniques that are non-intrusive (will not affect the integrity of the repository) will be used. The database will include specific data from experiments performed during the construction and operational phases to provide background information on the facility that will be useful in determining repository performance.

In addition, Radiological Environmental Monitoring will be performed at the same level as was used during the operational phase for the first two years after decontamination and decommissioning, and in a limited fashion, Environmental Monitoring will be conducted for three years thereafter.

2.0 Long-Term Monitoring Requirements

2.1 Regulatory LTM Requirements

The basis for LTM is found in 40 CFR §191, 40 CFR §268, and 40 CFR §264. The preamble to 40 CFR §191 provides guidance in interpreting the regulations. The regulations were reviewed and the areas that apply to LTM are discussed below. An outline of individual design requirements is provided.

2.1.1 40 CFR §191.14 EPA Regulation

The regulations found in 40 CFR §191 outline the requirements for the WIPP repository. Section 191.14(b) states, "Disposal systems shall be monitored after disposal to detect substantial and detrimental deviation from expected performance. This monitoring shall be done with techniques that do not jeopardize the isolation of the wastes and shall be conducted until there are no significant concerns to be addressed by further monitoring".

The regulation states in §191.14(a), "Active institutional controls over the disposal sites should be maintained for as long a period of time as practicable after disposal; however, performance assessments that assess isolation of the wastes from the accessible environment shall not consider any contributions from active controls for more than 100 years after disposal". The regulation defines as an element of Active Institutional Control, "monitoring parameters related to disposal system performance".

The following list summarizes 40 CFR §191 regulations relating to LTM:

- The Disposal Site shall be monitored after disposal to detect substantial and detrimental deviations from expected performance.
- The Monitoring techniques used must not jeopardize waste isolation.
- Monitoring will continue as long as practicable and/or until no significant concerns are to be addressed.

2.1.2 40 CFR §191 Preamble - 50 FR 38066-38089

The preamble to the final rulemaking for 40 CFR §191 is found in 50 FR 38066-38089. This preamble gives insight into the

development and intent of the regulation. The Preamble states, "The Agency has pursued standards that call for the isolation of the waste through the physical characteristics of the disposal system siting and design, rather than through continuous maintenance and surveillance." [2] The preamble further details specifications of the LTM by stating, "Monitoring for radionuclide releases to the accessible environment is not likely to be productive. Even a poorly performing geologic repository is very unlikely to allow measurable releases to the accessible environment for several hundreds of years or more." It also states,"A monitoring system based only on detecting radionuclide releases--a system which would almost certainly not be detecting anything for several times the history of the United States -- is not likely to be maintained for long enough time to be of much use."[2] Thus radiological monitoring is not suggested for LTM.

The preamble further elaborates, "Disposal systems must be monitored to detect substantial changes from the expected performance until the implementing agency determines that there are no significant concerns to be addressed by further monitoring...A disposal system so designed should still be monitored for a long time after disposal to guard against unexpected failures."[2] These statements form the basis of the EPA requirement for disposal system monitoring in §191.14 (b).

In summary, the preamble introduces the following insight on LTM:

- Repository design is responsible for waste isolation.
- The design of the repository, not monitoring and maintenance, is solely responsible for waste isolation.,
- Monitoring techniques that only detect radionuclides are not recommended.
- Monitoring will be performed until the DOE determines monitoring is no longer required.
- Monitoring should be used to detect substantial and detrimental deviations from expected performance.

2.1.3 Resource Conservation and Recovery Act Groundwater Monitoring Regulations

2.1.3.1 WIPP Groundwater

Previous geological exploration and testing have mapped the

geologic strata above and below the repository. Two minor water bearing units are in the Rustler Formation approximately 540 to 850 feet below ground level. The water quality of these units is classified as poor. Exploratory bore holes and hydrocarbon exploration wells in the vicinity of the WIPP site have located isolated pressurized brine reservoirs below the repository level in the Castile Formation, approximately 2,825 to 4,075 feet below ground.

2.1.3.2 Regulatory Groundwater Requirements

Typically, the Resource Conservation and Recovery Act (RCRA) regulations require groundwater monitoring in the uppermost aquifer located directly below a Hazardous Waste Management Unit. The EPA allows this requirement to be waived if it can be proven that the hazardous material in excess of health based limits will not migrate past specified boundaries and that monitoring will not be productive in determining compliance.

An EPA RCRA document [3] provides guidance for developing RCRA permit applications. This document describes hydrological well monitoring at hazardous waste management facilities. In section 10.3 of this document, two LTM items are discussed. The EPA states, "Post-Closure care must provide for a period of at least 30 years after completion of the authorized closure of the repository. If ground-water monitoring systems are utilized during the repository active life, they must also be operated and maintained throughout the post-closure care period".[3] As stated, monitoring groundwater is not always required but when monitoring is required and performed during the operational period, the wells must be monitored for 30 years after closure.

The WIPP is currently installing six groundwater monitoring wells in the Culebra member of the Rustler Formation. Three wells will be located upgradient of groundwater flow to provide background information against which to compare downgradient well data. The other three wells will be located downgradient. One other well will be installed to sample groundwater in the Dewey Lake Formation. The RCRA specifications are used as guidelines in installing the wells to the extent practicable.

This report assumes groundwater well sampling will be performed during the operational period of the repository. It is further assumed that groundwater sampling wells will be maintained after closure. The DOE will petition the NMED to

waive the RCRA groundwater monitoring requirements since the WIPP facility qualifies for such a waiver. Monitoring for contaminant releases from the repository is not likely to be beneficial; such activity is not proposed.

2.1.4 40 CFR §268.6

In §268.6(a)(4), the EPA states, "A monitoring plan that detects migration at the earliest practicable time...." is required when a no migration variance is requested.

The WIPP shall petition for a No Migration Variance (NMV) which, as stated in this regulation, requires a long-term monitoring plan. This LTM plan will be the same plan used to satisfy the requirements of 40 CFR §191 for disposal system performance monitoring since there is no credible pathway for migration to the accessible environment due to the design and deep geologic location of the repository.

2.2 Agreement for Consultation and Cooperation

The Agreement for Consultation and Cooperation is an agreement between the state of New Mexico and the DOE. This agreement defines specific legal areas of responsibility for the two parties. In the agreement, two specific areas relating to LTM are addressed.

1) "The level of environmental radiological surveillance developed during the operational phase shall be continued during and for at least two years following complete decommissioning and decontamination of the surface facilities. This is to include both the State and the Department of Energy's programs. In addition, increased surface soil and vegetation samples will be collected and analyzed to ensure decontamination standards in effect at the time are met."[5]

2) "The final environmental radiological surveillance phase will primarily serve to ensure the public that the re-suspension of contaminated ground surface particles, if any, is not creating a potential long-term inhalation problem. The minimum program projected at this time and to be continued for a period of not less than five (5) years following the termination of the decommissioning and decontamination phase is:

(A) Intermittent operation of the state-operated

high volume air sampling stations.
(B) Four annual soil surface samples.
(C) Four annual water samples.
(D) Thermoluminescent dosimeters (TLDs).[5]

The radiological part of the Environmental Monitoring Plan (EMP) for the WIPP facility fulfills the first requirement (DOE/WIPP 94-024, Section 5.3, Radiological Environmental Monitoring). The total number of samples taken can be increased if the current number is not acceptable. The appropriate section of the EMP can also be used for items (A), (B), and (C). A determination was made by the Environmental Evaluation Group (EEG) to discontinue the environmental TLD efforts at and around the WIPP. They determined that environmental TLDs would not detect releases at the site because they are used primarily to detect penetrating radiation. The waste to be emplaced at the WIPP is mostly alpha emitters (non-penetrating). Therefore, no environmental TLD monitoring will be performed by DOE after closure. [4],[7]

2.3 Long-Term Monitoring Time Requirements

The LTM plan will not be enacted until after WIPP closure. The repository is scheduled to open in 1998 and will operate until 2023; decontamination and decommissioning will be completed within ten years following the final receipt of TRU waste. Long-term monitoring will not be required until after decontamination and decommissioning the WIPP. Technology will advance during that time span and the requirements governing monitoring may also change. During the 25 years the facility will operate, operational monitoring will have created a vast amount of data. Interpretation and analyses of these data may conclude that part or all further LTM will not be necessary. This decision will be made well into the operational phase of the repository. However, this report assumes that LTM will be required. The LTM Plan will include provisions to review the proposed LTM system during the late operational phase to assess advanced monitoring technologies and regulatory requirements and ultimately determine if LTM is required.

2.3.1 Previous DOE/WIPP Proposed Monitoring Assumptions

Several DOE/WIPP and SNL documents provide guidance in developing the LTM plan. Provided below is a list of those DOE/WIPP guidance documents.

- WIPP Regulatory Compliance Strategy and Management Plan, DOE-CAO 94-2003.
- Compliance Status Report, DOE/WIPP 94-019.
- Waste Isolation Pilot Plant Repository Monitoring Program Strategic Plan, DOE/WIPP 93-029.

A review of the listed DOE/WIPP documents was completed. Listed below are the LTM design requirements developed from the assumptions and approaches found in these documents.

- The design of the LTM program will depend in part on the PA results obtained from the operational phase
- Geophysical techniques may be used to identify substantial deviations from expected performance of the repository in the surrounding environment
- Subsidence and Seismic Monitoring may be used to monitor repository performance

2.3.2 Institutional Requirements

After closure, all buildings and above ground facilities will be removed, active controls will be put in place, and the staff will be reduced significantly. LTM techniques shall be designed such that minimal maintenance and facilities are required. The monitoring techniques shall be as stand-alone as possible since power may only be available for part of the post-closure period. The LTM systems shall be accessibly located above ground. Safeguards shall be provided to protect the equipment from vandalism and the environment.

Techniques that obtain useful data at low cost with minimal maintenance over an extended period of time are the most favorable.

In summary, institutional LTM requirements are as follows:

- The LTM system design shall have a low labor requirement.
- System must endure the natural environment.
- System must be cost effective.
- System should not require a large support facility.
- System shall require minimal maintenance and power requirements.
- All components susceptible to vandalism should be isolated and/or protected from public access.

3.0 Long-Term Monitoring System Specifications

All of the LTM system requirements were compiled from Regulatory, Institutional, DOE/WIPP documents, and SNL documents and assumptions to form the LTM specifications. The LTM specifications are listed below:

- The PA shall identify parameters to monitor repository performance.
- The LTM system shall detect deviations from expected repository performance after closure.
- The monitoring technique(s) used must not jeopardize waste isolation and must be non-intrusive.
- Monitoring will continue as long as practicable, and/or until no significant concerns remain to be addressed, or until the DOE determines monitoring is no longer required.
- Monitoring that detects contaminants is not recommended.
- The Radiological aspect of the operational EMP shall be continued for two years past decontamination and decommissioning.
- Four annual soil surface samples and four annual water samples shall be taken for five years after decontamination and decommissioning.
- The design of the LTM program will depend in part on the results of data obtained during the operational phase.
- Subsidence and Seismic Monitoring may be used to monitor disposal system performance.
- LTM system design shall require minimal labor.
- System must endure the natural environment.
- System must be cost effective.
- System should not require a large support facility.
- System should be self-contained.
- All components susceptible to vandalism should be isolated and/or protected from public access.

4.0 System Description

The basic requirements listed in the Section 3.0 were used to define a LTM system which would best fulfill all the applicable requirements. After an evaluation of current geophysical and experimental technologies was completed, Subsidence Monitoring was chosen. Subsidence Monitoring was chosen in part because it was suggested in EPA, DOE, and SNL documents as being a viable long-term monitoring technique that can demonstrate adequate repository performance. Subsidence monitoring is non-intrusive, can detect substantial deviations in repository performance, and meets all the listed requirements in Section 3.0. This monitoring technique is described in Appendix A along with a discussion on determining repository performance.

Subsidence Monitoring is the basic LTM tool that will be supported by several other systems. These systems include a Subsidence Network, a Monitoring Program, a Baseline Database, a Closure Review Study, and a Subsidence Data Study.

The basic LTM system is composed of a Subsidence Network, a Monitoring Program, and a Baseline Database. The Monitoring Program is broken down into two sub-groups, Subsidence and Environmental/Ground Water monitoring. The overall program is the responsibility of the DOE until it decides, and the regulators concur, that no further monitoring is required. The data collection for both the Baseline Database and subsidence data are verified through a QA/QC program to assure data quality. The monitoring program will be documented through a set of operating procedures that are validated and maintained under the QA/QC program. All actions relating to repository performance indications from the subsidence monitoring program will be resolved through the DOE office overseeing the project.

The LTM system will also consist of any pre-existing hydrological wells plus any additional wells deemed useful as the result of the PA. The well monitoring program that was used during the operational phase will be used during the post-closure phase. The frequency of the testing will be modified after closure to include maintenance and well casing replacement as appropriate. Testing intervals will be lengthened if previous data have been relatively constant during the operational phase. The LTM schedule will be determined by a Closure Review Study.

The radiological portions of the operational EMP in place prior to closure will be used in LTM for two years after closure with limited radiological monitoring for the following three years. The PA has determined the most likely release path after closure is not

directly to the surface, therefore monitoring releases at the surface level would not be productive.[1] Results of Decontamination and Decommissioning (D&D) monitoring will be evaluated at closure during the Closure Review Study and a determination will be made whether to continue monitoring for above ground radionuclides and volatile organic compounds (VOC) after the required five year period.

A Subsidence Data Study will be performed during the developmental and operational phases of the WIPP. This study will provide the subsidence prediction data and gather all data for the Baseline Database. The findings will include the predictions and bounding conditions for repository performance and define scenarios that would characterize the repository's condition when the measured subsidence is out of bounds with the predictions. These scenarios will be used in the Baseline Database to provide guidance during an unpredicted event.

A Closure Review Study will be performed during the late operational phase that assesses the condition of the facility at closure. The study will:

- Evaluate the LTM Plan, the data generated during the operational and closure phases and regulatory requirements at the closure date.
- Update the LTM program.
- Evaluate the necessity for monitoring and determine the appropriate repository parameters to be monitored.
- Revise the LTM schedule to account for any impacts on the monitoring frequencies caused by the study findings.

In summary, the LTM program will be composed of the following items:

Subsidence Network
Monitoring Program
Baseline Database
Closure Review Study
Subsidence Data Study

Each item will be discussed in detail in Section 4.1 through 4.5 .

4.1 Subsidence Network

Refer to Appendix A for a description of Subsidence, the past work, and the advantages and disadvantages of its use in LTM.

In order to monitor subsidence, a network of benchmarks must be

placed over the area of interest. Benchmarks have been installed over and around the general vicinity of the WIPP. These benchmarks are adequate for initial data gathering during the developmental and most of the operational phases. However, the current network is too coarse to provide sufficient data points to accurately measure subsidence over the repository for the long-term. From contour plots of expected subsidence in the Backfill Engineering Analysis Report (BEAR), maximum subsidence can occur in a circular area with a radius as small as 1,000 feet; most of the current benchmarks are 1,000 feet apart. Current benchmark locations are shown on drawing E-2700-1. Powers (1993) has recommended placing a network over the repository footprint that would extend 2,000 feet past the four square mile site boundary shown in Figure A-2 of Appendix A. This would encompass the entire predicted subsidence area for angles of draw up to 45 degrees.

Additional benchmarks shall be placed to increase the density over the repository. These new benchmarks shall be installed after completion of the Subsidence Data Study (SDS). The SDS will evaluate and determine the quantity and placement of the benchmarks to best determine subsidence.

After establishing the supplemental benchmark locations, benchmarks will be installed and surveyed that meet the National Geodetic Survey (NGS) Class I, first-order standards. All placement and survey data will be documented in the Baseline Database.

Provisions shall be made to maintain and replace benchmarks when required and to coordinate benchmark placement with the passive markers design. This coordination has been noted in the Permanent Markers Study.

4.2 Monitoring Program (MP)

The LTM concept assumes substantial work will be performed during the operational phase to gather subsidence information and data. The data may be used in PA calculations to predict subsidence for various scenarios of repository performance. All effects that may influence subsidence over the repository such as hydrological extraction, petroleum production, mining, and geological subsidence should be included in these scenarios.

The MP consists of monitoring the subsidence network and, for a limited period, Environmental/Ground Water monitoring. Subsidence monitoring is accomplished with a Class I Leveling Survey. The surveys will be performed every ten years during the operational phase and thereafter in accordance with the LTM schedule. Environmental/Ground Water monitoring will be performed for at

least five years after closure.

The leveling surveys will be performed as described in a QA/QC procedure to insure the data is documented and validated. The data will be included in the Baseline Database. A procedure will be developed to implement the monitoring program.

The MP will be maintained by the DOE. The Closure Review Study will detail the organizational responsibilities and monitoring schedules. This study will also update the LTM Plan and define the MP requirements.

The MP includes the following:

1. Managing the LTM Program
2. Maintaining Monitoring Procedures and QA/QC Documents
3. Performing all monitoring
4. Maintaining the Subsidence Network
5. Maintaining the Monitoring Schedule
6. Baseline Database maintenance and storage
7. Data review and Performance Evaluation
8. Supplemental Monitoring when performance is suspect
9. Eventual decommissioning of the LTM Program
10. Archiving LTM data

4.3 Baseline Database

The Subsidence Data Study will generate subsidence predictions and compile the technical information derived from measurements performed during the developmental and operational phases of the WIPP. This data will be included in a Baseline Database. This baseline will also contain data specific to the repository's geophysical, hydrological, geochemical, and structural nature at the end of the disposal phase when the repository is sealed.

The Baseline Database will also contain data from previous monitoring studies and data from specific surveys and monitoring techniques performed immediately after closure of the repository. These surveys will be performed only once after closure to establish the geologic condition of the area at the start of the post-closure phase. These surveys and techniques are described in Appendix A.

The database will provide the guardians of the WIPP facility with easy access to critical data concerning repository performance and long-term monitoring.

An evaluation of geophysical methods was performed to determine

which methods should be used to establish a baseline for the repository after closure. The following techniques were chosen because they meet the requirements, are specifically non-intrusive, are implemented from the surface, and provide useful data in interpreting the repository's geophysical structural and hydrological condition. All post-closure monitoring techniques that would be physically conducted in the repository were excluded (see Appendix A for discussion on direct repository monitoring).

The following monitoring technologies were chosen to be evaluated as candidates for LTM.

Subsidence Surveys
Seismic Surveys
Gravitational Surveys
Electromagnetic Surveys
Resistivity Surveys
Aerial Radiological Surveys
Experimental
Environmental

Each of these techniques are evaluated in Appendix A and a determination was made to include all past data for geophysical surveys conducted during site selection and operation. At closure, several geophysical surveys will be performed to obtain repository baseline data on the geophysical condition of the repository and surrounding area. Seismic reflection/refraction, gravitational, electromagnetic, and resistivity surveys will be performed. No baseline Environmental surveys are required since a baseline has previously been established. All data and explicit descriptions of the equipment, data reduction techniques, and procedures used will be included in the database. All sensor placements will be surveyed and recorded. Where possible, some of the original survey lines will be used. The Closure Review Study will also determine specific survey lines to be included. Monitoring technologies that may be in the experimental phase of development may be evaluated for applicability.

4.4 Closure Review Study

The initial LTM Plan will be written at least 25 years prior to closing the facility. Technology, regulations, site management, safety requirements, and public opinions will advance and change over this time period. It is assumed that the LTM Plan will not be updated at regular intervals over the operational phase because it is not cost effective to do so. A review of the LTM Plan prior to closure will be necessary to insure compliance and safety. This review may result in modification of the LTM Plan to reflect the

advanced state of repository-specific knowledge resulting from repository operational phase activities.

A Closure Review Study (CRS) will be initiated to evaluate the LTM Plan and update all aspects that are not current. This plan will review the data in the Baseline Database and all governing regulatory issues associated with long-term monitoring of the facility. The CRS will determine what monitoring is required, what will be monitored, what equipment and techniques will be used, and the area/lines that will be monitored. A feasibility study will evaluate technology available at that time that can be used to accomplish this task.

The CRS will update the LTM schedules and define organizational responsibilities. Monitoring frequencies and dates will be revised in these schedules.

4.5 Subsidence Data Study

Several subsidence studies have been completed and are included in the following documents:

1. Final Environmental Impact Statement (FEIS), Waste Isolation Pilot Plant, DOE/EIS-0026, DOE, 1980.
2. Final Safety Analysis Report (FSAR), Waste Isolation Pilot Plant, WP 02-09, WEC, 1990.
3. Preliminary Comparison with 40 CFR §191, Part B for the Waste Isolation Pilot Plant, December 1991, SAND91-0893, Vol 1, Methodology and Results, SNL, 1991.
4. Backfill Engineering Analysis Report (BEAR), IT Corporation, 1994.
5. Report on First-Order Leveling Survey for Sandia Laboratories Waste Isolation Pilot Plant (WIPP) Project, Undated, Rockville, Md. National Geodetic Society
6. Vertical Movement in the Los Medanos and Nash Draw Areas, New Mexico, As Indicated by 1977 and 1981 Leveling Surveys, 1982, NOAA Technical Memorandum NOS NGS 37. Rockville, Md. National Geodetic Society.

These reports evaluate the potential for, and predict subsidence due to the mining of the repository's shafts, drifts, and rooms. These calculations account for a range of waste volumes, waste densities, and backfill types. Subsidence was also calculated for conditions where no backfill would be used.

The BEAR contains the most detailed data on subsidence. Contour maps are included in this report that detail subsidence predictions using Influence Function and National Coal Board Method for

scenarios with and without backfill. The maximum subsidence was also calculated using the Mass Conservation Method.

The studies listed above predict the maximum subsidence expected. These studies were not specifically performed to estimate subsidence for long-term repository performance monitoring and do not account for other factors that may influence subsidence such as local hydrocarbon extraction and local potash mining.

An Subsidence Data Study (SDS) will include subsidence predictions documented in the BEAR and any subsequent subsidence predictive information that may be developed by the PA. The SDS will also investigate factors that influence subsidence to the extent that these factors are identified in the failure scenarios considered in the PA. The goal of the study is to document the most reliable subsidence predictions with respect to time for the repository and define the bounding limits that will indicate poor repository performance.

The SDS will define the most favorable positions for any additional benchmarks and oversee their placement in the network.

5.0 QA/QC Requirements

Various QA/QC requirements exist for the WIPP project and many QA/QC programs are in place. The WIPP is a DOE facility and as such has specific DOE guidelines for QA/QC management. These guidelines are found in the *Quality Assurance Program Description,* CA0-94-1012, 1994. The DOE has agreed to adopt QA/QC guidance from the American Society of Mechanical Engineers Nuclear Quality Assurance (NQA)-1, NQA-2 and NQA-3. The EPA also has imposed QA/QC requirements for the management of data and the LTM plan, specifically requirements in 40 CFR §268.6 (b) (4) and 40 CFR §268.6 (c) (1 through 5). The scientific advisor also has a QA/QC program that is used for data collection which impacts LTM.

For this LTM report, the current QA/QC programs in place are assumed adequate for data collection. The LTM Plan is required to contain the QA/QC plans for LTM management, data collection, analysis, and model validations. These plans will be compiled from the current QA/QC programs.

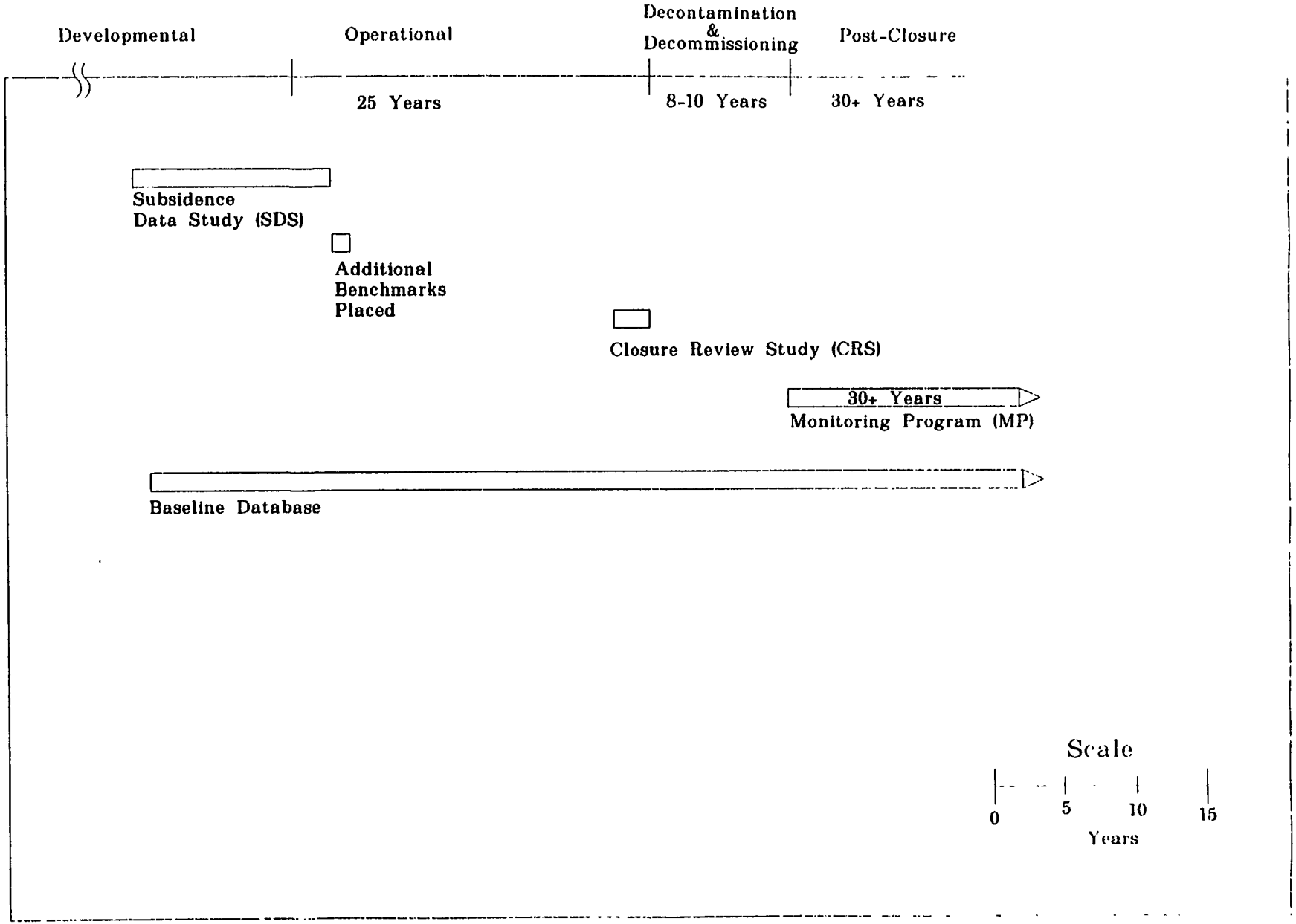
Other QA issues are associated with 40 CFR §268.6 requirements. This regulation requires the LTM plan to contain detailed records of the LTM system and data collection/recording procedures. Specifically, "All sampling, testing, and analytical data must be approved by the Administrator and must provide data that is accurate and reproducible" (40 CFR §268.6 (c) (5) (i)) and, "A quality assurance and quality control plan addressing all aspects of the monitoring program must be provided to and approved by the Administrator" (40 CFR §268.6 (c) (5) (iii)). A LTM quality control plan shall be included as part of the LTM plan.

The overall goal of the QA/QC program associated with LTM is not just to meet all of the regulatory requirement but to provide a defensible, reproducible monitoring system that effectively assesses repository performance.

6.0 Long-Term Monitoring Schedules

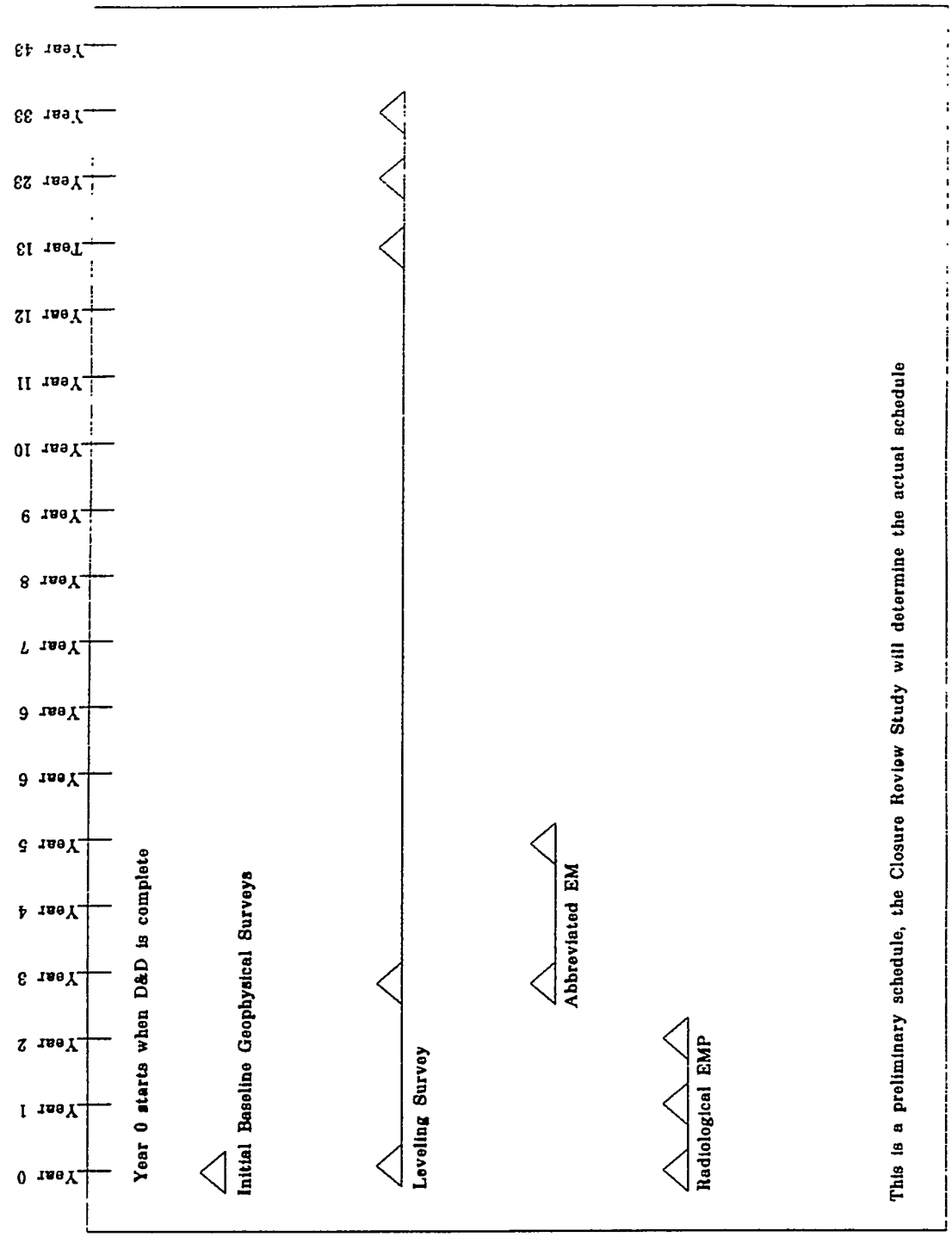
The schedule for the implementation of LTM after D&D will be formalized during the Closure Review Study.

The schedule for LTM is composed of four basic monitoring groups; the initial geophysical survey group, the radiological EMP group, the subsidence monitoring group, and the abbreviated radiological EM group. The initial geophysical survey group will be composed of a seismic survey, a resistivity survey, an EM survey, a gravitational survey, and a radiological aerial survey. The radiological EMP group (a continuation of the Operational Environmental Monitoring Program) will be performed for the first two years only. The Subsidence Monitoring group will include a leveling survey in the first and third year and every ten years thereafter. The last group, the abbreviated radiological EM group, will include only three sample types (airborne particulate, soil, and water) taken on an annual basis for at least three years following cessation of the radiological EMP group. The schedule for the LTM process is detailed in Figure 6.1 and the specific monitoring schedule after closure is shown in Figure 6.2 .



Long-Term Monitoring Program Conceptual Schedule

Figure 8.1



Preliminary LTM Schedule

Figure 6.2

7.0 Recommendations

The LTM requirements are based on regulations, DOE/WIPP, and SNL documentation. From these requirements, physical, chemical, economical, and technical factors must be included in the conceptual approach to designing a LTM system. Such a system can be designed using a monitoring approach composed of a subsidence network, a Monitoring Program, a Baseline Database, a Closure Review Study, and a Subsidence Data Study.

The range of periodic measurements from the subsidence network will be compared to the subsidence predictions. If the measured subsidence does not fall within the predictions, the baseline database can be used as comparison data to determine the nature, extent, and possible cause and ultimately determine if the repository is performing as expected.

The following describes the LTM monitoring design concept.

- Create a baseline database which includes data from developmental and operational phase activities.
- Perform a Subsidence Data Study.
- Compile subsidence predictions and include any PA developed scenarios of repository performance in which falls outside the baseline subsidence predictions. Develop proper benchmark locations over the repository. The subsidence predictions will be developed from the information available in the BEAR and from any additional information provided by the PA.
- Create a subsidence network over and around the facility.
- Perform a Closure Review Study.
- Perform the listed surveys to establish baseline data for the Baseline database.
    - Seismic survey over the waste panels after closure (one time).
    - Resistivity survey over the waste panels after closure (one time).
    - EM survey over the waste panels after closure (one time).
    - Gravitational survey after closure (one time).
    - Subsidence survey (throughout the program lifetime).
    - Obtain and archive core samples from previous core work (one time).

- Initiate the Monitoring Program after closure. Perform periodic leveling surveys of the subsidence network and develop a schedule for future surveys. Perform the radiological environmental monitoring program for two years and the abbreviated program for an additional three years.

- Compare leveling survey data to expected results.

- Perform periodic reviews of the repository performance to determine the monitoring schedule and termination of the monitoring program.

- Perform maintenance on RCRA wells, replacing casings as required or every 25 years until monitoring ceases. Monitor per LTM schedule and LTM Plan requirements.

- Perform maintenance on subsidence network as required (determined during the leveling surveys).

This Monitoring concept is based on current technologies and data for monitoring repository performance. The preliminary PA reports specify that monitoring parameters will be developed during the PA but no specific requirements have been published. Future monitoring during the repository development and operational phases may provide data which leads to the conclusion that long-term monitoring will not be relevant or identify new parameters that must be monitored. Future developments in the regulations may modify monitoring requirements.

The monitoring techniques specified in this report can be used to meet the requirements in the current regulations governing the facility and monitor performance of the facility. This concept provides for a reliable database against which future monitoring results can be compared.

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APPENDIX A

LONG-TERM MONITORING TECHNICAL STUDY

APPENDIX A

LONG-TERM MONITORING TECHNICAL STUDY

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APPENDIX A

LONG-TERM MONITORING TECHNICAL STUDY

A. Introduction

Geophysical Survey/Monitoring Technology Description

Each of the technologies listed below are discussed, defining the monitoring technology and describing the past, current, and future work using this technology related to performance monitoring. Also defined are the advantages, disadvantages, and proposed uses of the technologies in long-term monitoring of the repository.

Subsidence
Seismic Reflection/Refraction
Gravitational
Electromagnetic
Resistivity
Direct Repository Monitoring

A.1 Subsidence

A.1.1 Description of Subsidence Monitoring

Subsidence is defined as vertical movement of the land surface anywhere in the subsidence basin. Subsidence monitoring is defined as the measurement of relative vertical movement of the land surface. This movement can be up (uplift) or down (subsidence) and is relative to a fixed reference. This reference is assumed fixed, even though it is subjected to the same factors that cause the surface movement and is moving also. Subsidence monitoring is used to determine the measurable vertical movement of a land mass. The techniques used to monitor subsidence measure the vertical height difference between two or more markers placed on the surface a known distance away from each other and is done with a leveling survey. Usually, one reference benchmark is used as the standard and the relative movement of other stations or benchmarks are measured to detect vertical movement over time. All subsidence measurements are relative because the reference is not fixed.

The error of the survey is determined by the equipment and distances between the stations. A first order survey has an error of 1 part in 100,000 and a second order survey has an error of 1 part in 20,000. With current technology, several thousandths of an inch vertical movement can be measured.

Subsidence can be caused by a variety of factors. Mining, hydrocarbon extraction, water injection/extraction, geological tilt, and dissolutioning are major subsidence causing factors all

of which may be applicable to the WIPP over the long term.

A.1.2 Advantages of Subsidence Monitoring

Subsidence monitoring is advantageous because it is a passive monitoring technique that is relatively simple to perform and uses well established technologies. The cost of the survey is low compared to other technologies. This technique requires little system maintenance or monitoring and has no power requirement. The benchmarks are not affected by weather and can last for hundreds of years. Benchmarks can be replaced if required and the data can be offset to account for the change without affecting data quality.

A.1.3 Disadvantages of Subsidence Monitoring

The disadvantages associated with subsidence monitoring is in the benchmark placement. The benchmark should be left undisturbed. Existing benchmarks may be destroyed or moved if new construction occurs over the benchmarks. The permanent markers design may call for large earthen berms around the facility after closure. The placement of the berm may cover up existing benchmarks and may preclude line of sight measurements between existing benchmarks because the berm may be 30 feet high. The benchmarks are not protected, and may be destroyed during land use by ranchers, drillers, or developers.

A.1.4 Past Subsidence Work

During the initial site selection process, 314 km of first order, Class 1 leveling survey was performed in 1977 by the National Geodetic Survey (NGS). Later, new survey lines were established that connected the previous first order benchmarks through Carlsbad to second order survey lines through Eunice and Hobbs. Benchmarks were placed over the Nash draw from the north end to the Remuda Basin, over potash mines, the WIPP site, and the San Simon Sink.[A14] Independent of the NGS benchmarks, an additional 52 benchmarks were installed over the WIPP site and surrounding area.

The NGS network was resurveyed in 1981 and the relative movement between Carlsbad and the WIPP site was measured to be about 2 cm. Relative motion across the network was down to the east and up to the west.[A14] The movement across the site can be seen in Figure A-1 and the positions of the benchmarks are shown in Figure A-2. The relationships between subsidence and potash mining in the WIPP vicinity are discussed in [A14]. From data in this report, potash mining was shown to have caused significant subsidence at mines close to the WIPP. Two benchmarks over the Mississippi Chemical Corporation mine measured relative to Carlsbad show

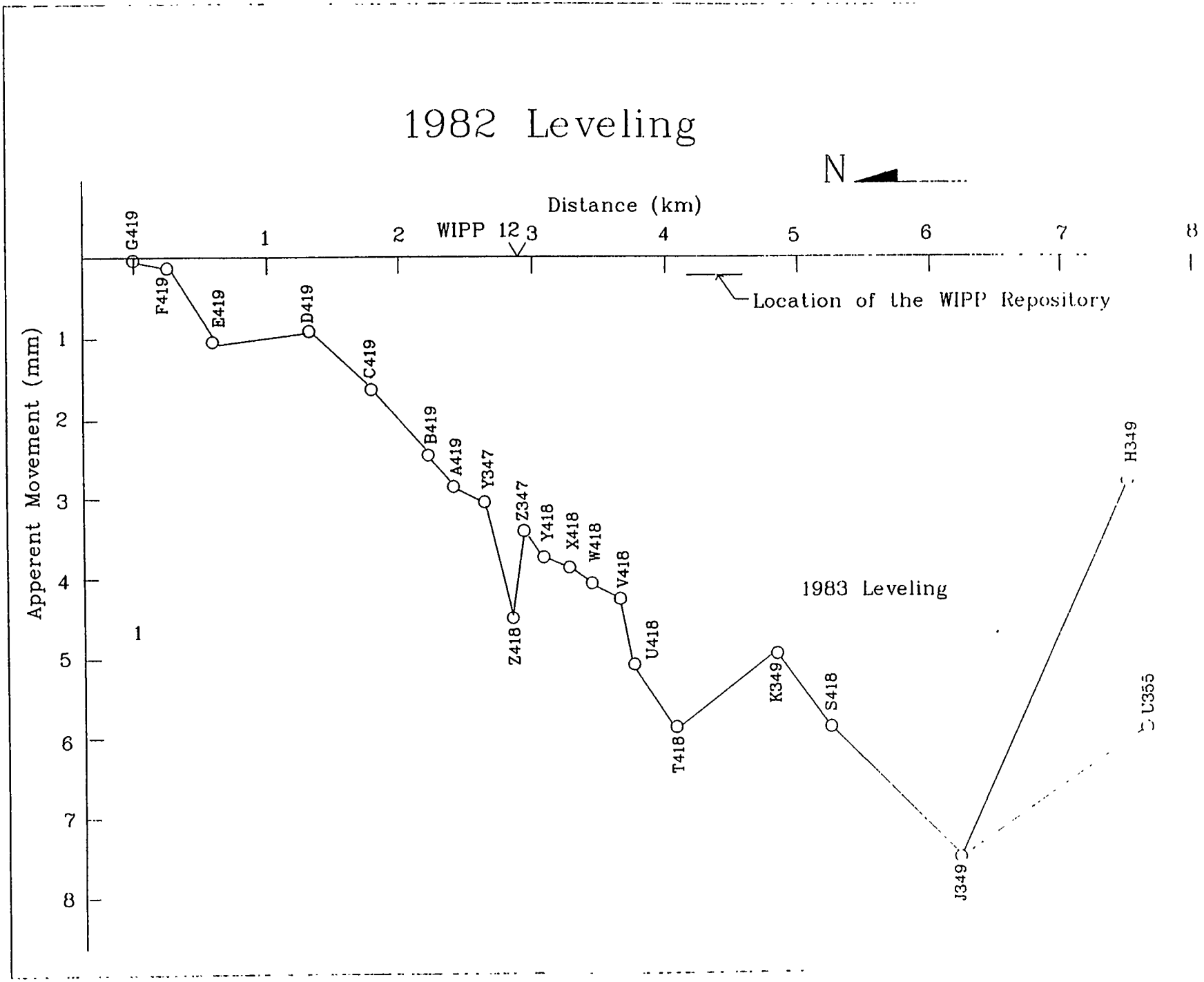


Figure A-1
Measured Subsidence Across WIPP Site

NGS Benchmarks

Subsidence Benchmark Locations

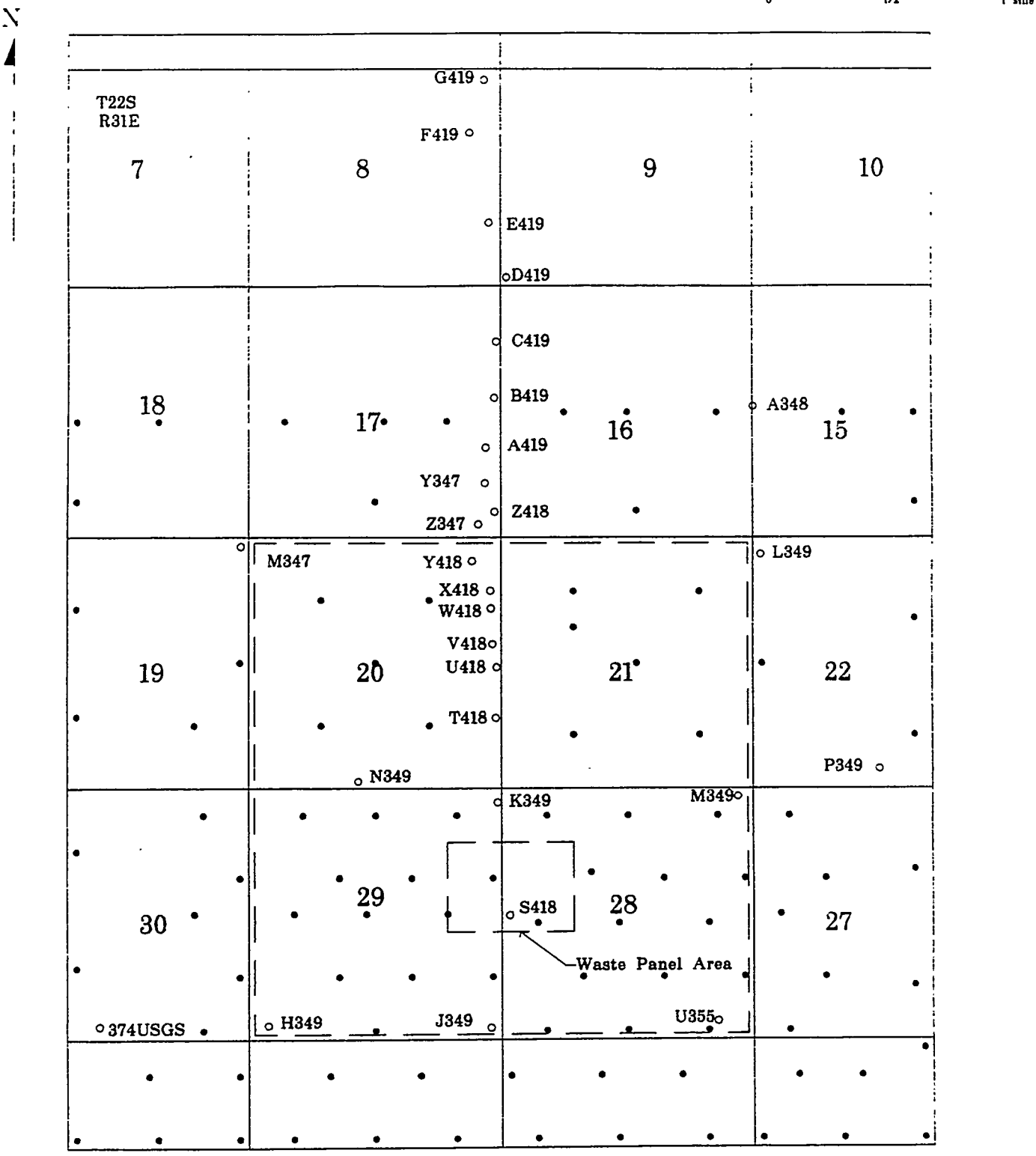


Figure A-2

show 25.4 cm and 102.7 cm movement downward from 1977 to 1981. Powers (1993) also discusses mining effects on surface subsidence at other mines and correlated a relationship between mining and the surface area effects. This effect is of importance to WIPP monitoring in that estimations of area mining and WIPP mining can be calculated into the subsidence predictions.

"In May, 1982, the NGS placed and leveled 15 additional high-quality benchmarks along a north-south line across the position of WIPP 12 (1 mi north of WIPP surface facilities) and the underlying brine reservoirs in the Castile Formation".[A14] After testing and fluid production of approximately 27,058 barrels of brine from the brine reservoir, the NGS resurveyed these benchmarks in January, 1983. "The major difference in elevation across these 15 benchmarks from May, 1982 to January, 1983, is about 6-7 mm between the north end of the line and the approximate position of the WIPP".[A14] Powers stated that he knows of no known mechanical or numerical simulation that can determine if this deformation is consistent with brine production.

A.1.5 Subsidence Predictions

Subsidence predictions due to mining can also be calculated empirically. Techniques such as Mass Conservation, National Coal Board (NCB), and Profile and Influence functions can be used to calculate subsidence caused by mining. The Influence function technique can estimate subsidence from room and pillar type mining, which is the type of mining used at the WIPP.[A1] Four studies have been performed that have calculated subsidence predictions, the results are found in the Final Environmental Impact Statement (FEIS) [A15], the Final Safety Analysis Report (FSAR) [A16], SNL's 1991 comparison with 40 CFR §191 [A17] and the Backfill Engineering Analysis Report (BEAR) [A18]. The following details each report's maximum subsidence predictions:

MAXIMUM SUBSIDENCE PREDICTIONS

FEIS

70% Backfill density	0.3 meter Subsidence
50% Backfill density	0.5 meter Subsidence
No Backfill	1.0 meter Subsidence

FSAR

Shaft pillar area (backfill type and amount not specified)	0.3 to 0.38 meter Subsidence

SNL

35° angle	0.09 meters Subsidence
25° angle	0.13 meters Subsidence

BEAR	
No Backfill (BF)	0.40 to 0.60 meter Subsidence
Highly Compacted BF	0.30 to 0.52 meter Subsidence

A.1.6 Current Work in Subsidence Monitoring

Current subsidence work includes annual monitoring, a proposed NGS survey, and a satellite positioning survey.
The WIPP currently monitors the benchmarks listed in drawing E-2700-1, on an annual basis (drawing by John West Engineering Co., 1-11-93). This survey is performed by Waste Isolation Division WID Personnel.

A.1.7 Future Work on Subsidence Monitoring

A NGS survey has been proposed for fiscal 1996. The current plan is to resurvey about every 10 years. The last NGS survey was performed in 1982.

A.1.8 Define Use of Subsidence Surveys for LTM

This report assumes that substantial work will be performed during the operational phase to gather subsidence information and data. This data will be used to relate expected subsidence over time for various scenarios of repository performance. The effects of petroleum production, mining, and geological subsidence must be accounted for in these scenarios. These estimates would be compared to actual measurements.

During the operational phase, the current benchmarks and new benchmark network will be used to gather baseline data. After the operational phase however, decommissioning of the surface facilities and erection of active and passive controls will eliminate some of this network. For this reason, during the decommissioning, damaged or lost stations should be replaced. Additional stations may be necessary to take into account the placement of the proposed passive permanent markers. It is expected that analysis may have determined subsidence estimates at specific locations; these locations should be included in the benchmark network.

After decommissioning and renovation of the benchmark network, a Class 1 leveling survey should be performed to determine baseline data. The network should be monitored after closure and until monitoring is determined to no longer be necessary. The monitoring frequency is to be determined, however the preliminary plan is every third year for the first 15 years. During this time, the data should be compared to the previous trends and if no anomalies are found, the monitoring frequencies should be adjusted to 10 year intervals.

A.2 Seismic Reflection/Refraction Surveys

A.2.1 Description of Seismic Reflection/Refraction Surveys

Seismic Reflection/Refraction surveys are used to determine the depth, thickness, composition, and physical properties of geologic layers. Data from the survey can locate specific horizons such as water tables, clay layers, and bedrock. This technology can be used to map the geological structures of large areas at great depths. Survey results are often used by geologists to locate specific geologies that may contain hydrocarbon reserves.

This method uses seismic wave transmissions to determine geologic structure depth and composition. Seismic waves travel at different velocities depending on the soil and rock type. Hard and dense rock have higher wave velocities than soft and less dense rock. Seismic waves can travel through, reflect or refract off of geological structures. Some of the wave energy will travel along the layers. This phenomena is used to determine depth and composition of the strata by measuring the return time of an induced wave generated at the surface and reflected and refracted back from the underlying strata.

This technique measures wave travel times through a sensor array called geophones placed over the area of interest. A seismic wave is generated by dropping a weight, (anything from a hand sledge to truck mounted ram) or by using high explosives. A seismograph is used to amplify and record the data. By using various seismic wave input energies, sensor array spacings and numbers, specific depths can be mapped.[A9] The map corresponds to a geological profile along the line surveyed. Figure A-3 details the basic seismic surveying technique.

A.2.2 Advantages of Seismic Reflection/Refraction Surveys

One advantage of this technique is the abundance of existing data. Numerous Petroleum companies have performed seismic surveys in the area and several other surveys were performed during site selection [A2,A5]. This data can be used as a reference to detect changes by comparison with new data. The quality of the data is good for lower structures but are not as useful above the 3,000 foot level.[A5]

Seismic surveys are non-intrusive and require no permanent devices to be installed at the site. Seismic surveys are relatively inexpensive.

A.2.3 Disadvantages of Seismic Reflection/Refraction Surveys

Basic disadvantages of this technique include data quality and interpretation. This technique is sensitive to noise and equipment set-up. The data must be electronically processed, conditioned, and interpreted by an experienced geologist. Interpretation is an art form and no two interpretations are the same.[A4] This can create repeatability errors if the surveys are repeated on the same geology. The results are usually compared to core samples to verify the interpretation and validate the results.

Seismic surveys use equipment that allows for many variations in how data is collected. For comparison reasons, surveys must be performed using similar equipment set-ups (i.e. array spacings, line locations, data conditioning, etc.). Any variations in the technique and equipment must be accounted for in the interpretation of the data to ensure that changes caused when different equipment is used for repeated surveys are not interpreted as geological changes.

Relatively thin strata and layers of similar densities cannot be distinguished. Since the technique is based on wave velocities, layers of material that may have different chemical and geological characteristics but similar velocity components cannot be differentiated.

A.2.4 Past Seismic Reflection/Refraction Survey Work

During the siting process for the WIPP, several geophysical techniques were used to gather geological data that would identify a suitable site location.

From 1976 to 1978, SNL conducted three surveys totaling 79 line miles of data, of which 72 line miles were over or near the WIPP site.[A6] The first survey consisted of three lines totaling 24.98 line miles of conventional petroleum style data and was collected from petroleum companies. The other two surveys were conducted using short geophone spacing and high signal frequency for better shallow field resolution above 4,000 feet.[A5] One of these surveys totaled 47.04 line miles involving 13 lines. The third survey included seven and a half line miles of profiling run along crossing lines through the site.[A3,A6]

Approximately 189 line miles of older (1950's-1960's) seismic surveys performed by Shell Oil Co. were purchased from a brokerage firm.[A19] Exxon allowed 196 line miles of their data to be viewed at their office, Amoco allowed 513 line miles of data to be

Seismic Reflection/Refraction Survey Concept

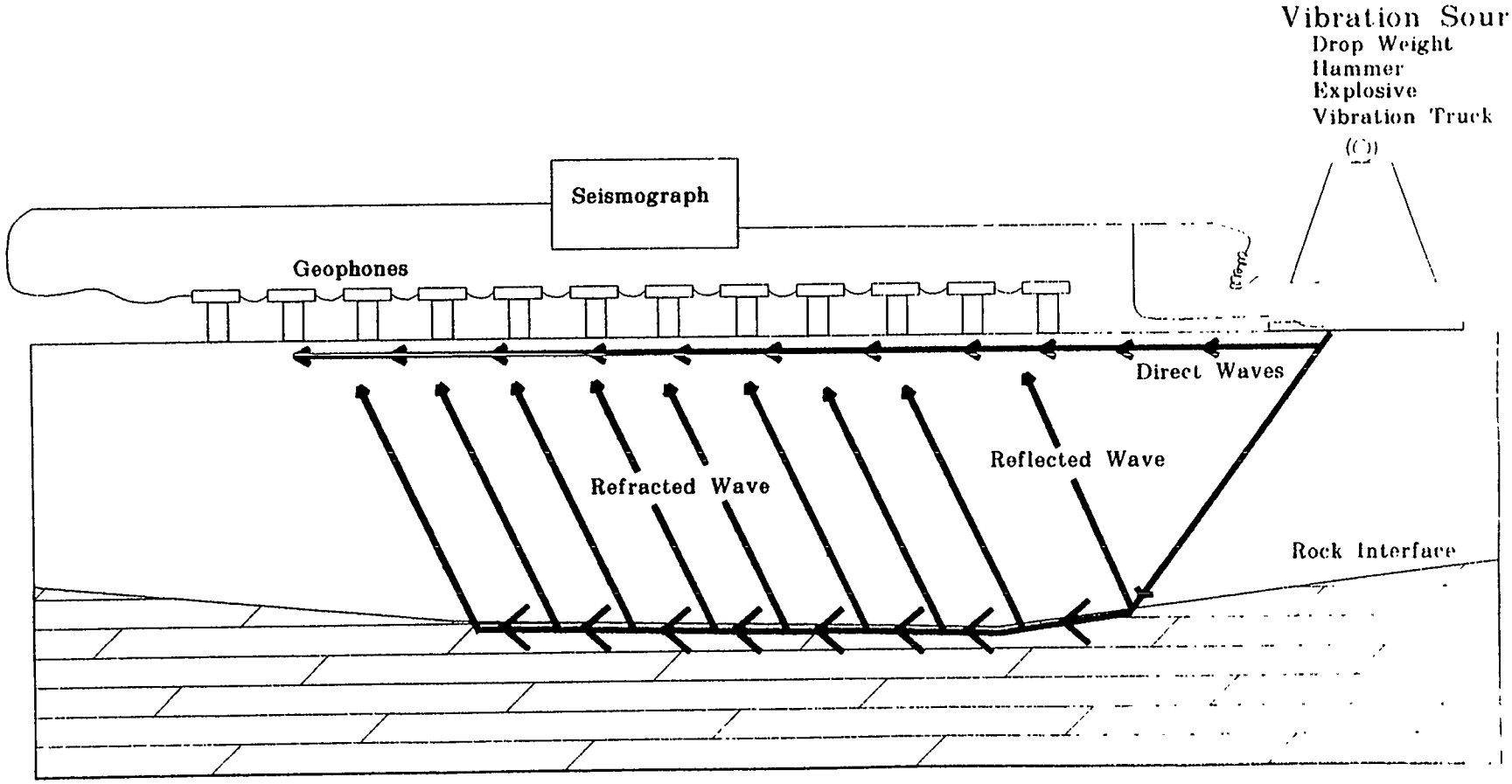


Figure A-3

viewed.[A19] This data was considered proprietary and could not be distributed to other sources. All of the listed data was gathered and interpreted during 1976.[A3] Results of the data were used to map the geological layers around the WIPP site. These maps are found in WP 02-9, FSAR Section 2.7.

In 1976, attempts were made to perform a high resolution shallow survey using weight drop techniques. This survey produced data that was not interpretable when compared to known geological information.[A6]

In 1979, an extensive seismic survey was performed that profiled lines directly over the WIPP site boundaries in north-south and east-west patterns. The north-south lines were spaced at one-fourth mile intervals and the east-west lines were spaced one-half mile apart in Zone 2. In the areas between Zones 2 and 3, the lines were spaced further apart. The north-south lines were separated by one-half mile and the east-west lines were spaced at one mile. This survey used the same basic parameters as the original SNL survey with closer line spacing. The intent was to improve the accuracy of the data above the Salado formation.

A.2.5 Current Seismic Reflection/Refraction Work

No seismic surveys are being performed.

A.2.6 Future Reflection/Refraction Work

No seismic surveying is planned.

A.2.7 Define Uses for Seismic Reflection/Refraction Surveys in LTM

The seismic method determines the difference in geology by measuring the velocity of a wave through the rock. Any physical change in the rock is accompanied by a corresponding change in its velocity. Seismic surveys can be used to map the repository at various times. The specific depths and densities of various formations can be mapped and compared to data generated in the future to evaluate the repository performance. Changes in the strata, such as changes in aquifer depth and strata density changes, can be determined.

After the repository is sealed and the facility is decommissioned, a Seismic survey should be performed over the repository and surrounding area. This survey should be performed to provide good resolution above and below the repository. The survey results and raw data should be well documented and all interpretations of the data should be well defined. The results and data should be archived so baseline data can be used for comparison to future

seismic data if the need arises. The baseline data will help identify changes in the geology surrounding the facility which could help determine if the repository performance is acceptable. The survey would only be performed after closure and would not be resurveyed unless new data was required.

The following are requirements for Seismic monitoring uses in LTM.

- Archive data in at least two permanent formats
- Line surveys should be referenced to benchmarks in the subsidence network
- All data reduction programs should be included in the archive data
- The exact location for the survey should be in accordance with the recommendation of an experienced geologist
- Research methods to improve repeatability in geophone placement

A.3 Gravitational Surveys

A.3.1 Description of Gravitational Surveys

The gravity survey method maps small variations in the earth's gravitational field. These variations result from mass and density difference in the subsurface lithography of the earth's crust. Interpretation of the data from a gravity survey can detect structural displacement in the strata.[A7] The survey is performed by using a gravimeter. The instrument measures the gravity intensity at a point. The data is expressed in milligal, where a gal is an acceleration of 1 cm/sec^2. Standard equipment is accurate to within a tenth of a milligal.

A.3.2 Advantages of Gravitational Surveys

This technology is helpful in determining the depth and area of various geological anomalies. In itself, gravity surveys are not concise, but aid the researcher in determining areas (anomalies) that should be explored using other geophysical techniques to determine the specifics of the anomaly.

The gravity survey is non-intrusive and relatively inexpensive when compared to other geophysical monitoring techniques.

A.3.3 Disadvantages of Gravitational Surveys

Gravity surveys do not provide the type of information that allows a geologist to determine the exact geological description and location of the strata surveyed.

This technique is very dependent on placement of the gravimeter. Placement errors can cause variability in results if the survey is repeated. For repeatability, exact placement of the gravimeter must be recorded and verified. This variation is not as pronounced when the results are mapped over a large area.

The data from the gravimeter is sensitive to surface structure, elevation, geographic latitude, solar and lunar tides.[A7] Corrections must be made for the terrain and usually cause an error of ± 0.3 mgal.[A11] Surveying data point position and altitude is half the effort of the gravity survey. This method is prone to human error since manual recording is used. The data is often "edited" by reviewing the data and deleting any suspected transcription errors.

A.3.4 Past Gravitational Survey Work

During the siting phase a regional gravity control was purchased in 1976, from a geophysical company.[A3,A8] Over 3,000 miles of gravity data was collected in the area as part of various hydrocarbon exploration surveys [FSAR 2.7-27] Also, two gravity surveys, the Main Site and the Reconnaissance Profiles, were conducted by SNL. Three smaller areas within the Main Site survey were resurveyed in greater detail to provide information on suspected anomalies.

The Main Site survey covered approximately eight and one half square miles. The lines were spaced one sixth miles apart and ran north-south with the stations spaced at one eighteen mile intervals.[A7] During this survey, an anomaly was discovered and a bore hole was drilled in that area. This area was surveyed in greater detail and covered an area 1,164 feet by 679 feet. The stations were spaced in a grid 97 feet apart. Two other smaller areas were resurveyed to provide enhanced detail.

This data was used to detect anomalies in the strata and develop an interpretation of the disturbed zone (DZ). However, the DZ data was inconclusive.[A7] Areas surveyed detected some karst development. A gravity contour map of the WIPP site areas surveyed is found in SNL document SAND82-2992.

A.3.5 Current Gravitational Survey Work

No known gravitational survey work is currently being performed.

A.3.6 Future Gravitational Survey Work

No known gravitational surveying is planned.

A.3.7 Define Uses of Gravitational Surveys for LTM

Gravity survey data should be included in the baseline database. All past surveys should be included along with extensive documentation defining the equipment, procedures, and data collection and processing techniques used. Surveys should be performed over the repository after closure and decommissioning, to provide baseline data for the repository. The original gravity survey data will not include the influence of over six million cubic feet of waste so a new survey is required to provide a baseline after closure.

A.4 Electromagnetic Conductivity Surveys

A.4.1 Description of Electromagnetic Conductivity Surveys

The term Electromagnetic Conductivity is used by many geological companies to describe various geophysical equipment. For this report, the term is defined as a method that measures subsurface conductivity by low-frequency electromagnetic induction. This method uses a coil placed on the surface that transmits electromagnetic pulses which induce eddy current loops in the layered strata below the transmitting loop. The induced loop currents are theoretically directly proportional to the resistance of the strata. The induced current produces a secondary field current that can be sensed by a receiving coil placed a fixed distance from the transmitting coil. The reading is a bulk measurement of conductivity of the strata directly below the transmitting loop to the effective depth of the instrument. The instruments effective depth is related to the distance between the transmitting and receiving coils. The electromagnetic system usually measures conductivity of the materials in millimhos per meter and is easily converted to resistivity. Conductivity is the reciprocal of resistivity.

The EM system determines the conductivity of the strata which is related to the soil/rock geophysical and geochemical properties. Properties such as porosity, permeability, concentrations of colloids and dissolved electrolytes in the pores and conductive minerals all influence conductivity but the most influential factor is water content. Since water is the main factor, aquifers and brine pockets can be detected. Pipes, waste containers, metallic debris, and wire lines can also be detected.[A9]

Electromagnetic systems can be used to profile and map strata. Both stationary and mobile systems are available. Mobile systems are capable of taking continuous readings. A diagram of the basic system configuration is shown in Figure A-4.

Electromagmetic Survey Technique

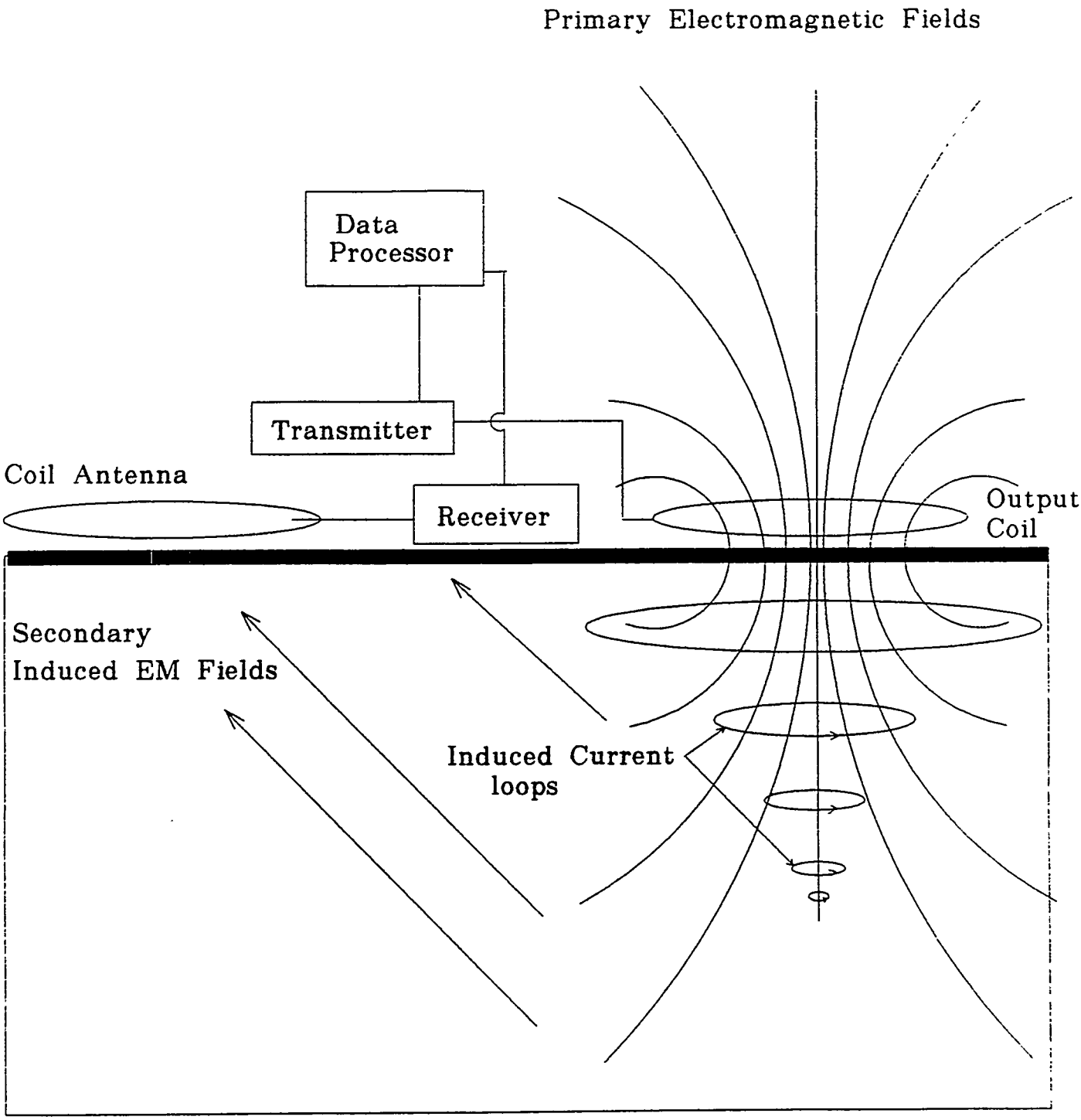


Figure A-4

A.4.2 Advantages of Electromagnetic Conductivity Surveys

The electromagnetic method is non-intrusive and can detect brine occurrences, strata layers with differing physical properties, and aquifers. Mapping of an area can be compared to subsequently acquired data to determine changes such as brine movements. The depth and area of brine pockets can be determined which can then be used to estimate the volumes of the pockets. Electromagnetic surveys may be used to locate waste after placement.

The electromagnetic method does not require ground contact and the measurements can be taken continuously. Methods of this nature have good repeatability. Measurements can be made at ground level or from aerial surveys.

A.4.3 Disadvantages of Electromagnetic Conductivity Surveys

Electromagnetic technology falls short in data interpretation when a highly resistive layer is sandwiched between two highly conductive layers. Strata can have the same relative conductivity but be entirely different geologically. This method is not concise enough to be a stand alone method but can be used along with other geophysical techniques to interpret the strata.

The results can vary with ground moisture content. Results after substantial rains are different than those performed after prolonged droughts. Interpretation of the data must account for these variations.

A.4.4 Past Electromagnetic Conductivity Survey Work

Several electromagnetic type surveys were performed by SNL. One survey was initiated to map brine occurrences in the strata above and below the repository. The survey measured 36 locations in a one and one half by one kilometer grid directly over the repository. Two other measurements were made, one at WIPP-12 borehole and the other at DOE-1 borehole. A calibration measurement was made at ERDA-9. The final interpretation of the survey data details brine occurrences. These results correlated well with the depths of the brine occurrences found at WIPP-12 and ERDA-9.[A20]

When comparing the results of EM survey data with bore hole logs, the accuracy of determining the depth to brine is better than 75 meters at depths between 1,000 to 1,500 meters.

Aeromagnetic survey maps are available from the U.S. Geological Survey (Map GP-861, Carlsbad/West Texas) and Aero Service Library

(No. 43-6, Carlsbad/West Texas). [A10]

A.4.5 Current Electromagnetic Conductivity Survey Work

No EM work is currently being performed.

A.4.6 Future Electromagnetic Conductivity Survey Work

No EM work is planned.

A.4.7 Define Uses of Electromagnetic Conductivity Surveys for LTM

Electromagnetic surveying has the capability of detecting water or brine occurrences, and can differentiate layers with varying physical properties. This technique could be used to monitor the facility after closure to determine if brine has migrated into the shafts, bore holes and/or repository.

The performance of the shaft, and bore hole seals, and bore holes could be monitored to determine if they are maintaining the isolation between the aquifers in the Rustler Formation. The repository could be mapped directly after the repository is sealed and included in the baseline data to be used for comparison at a later date.

A.5 Resistivity Surveys

A.5.1 Description of Resistivity Surveys

The Resistivity method is similar in nature to the EM method. Resistivity measures the resistance of the rock and EM measures the conductance. Resistance is the reciprocal of conductance. The resistivity of the rock and soil is influenced by the same factors listed in the previous section for conductivity. By varying the electrode spacing geometries and currents, different parameters can be measured. Two specific methods used during WIPP siting are called Schlumberger sounding and Gradient array profiling.

The resistivity method uses four sets of electrodes on the surface, spaced in a specific geometry. Two electrodes are energized to create a current through the strata between the electrodes. The second pair of electrodes measures the potential produced from the first pair. The strata's resistivity can be calculated from the potential and electrode geometry/spacing.

As with the other types of geophysical monitoring methods,

resistivity measurements can be used to perform sounding and profiling. Profiling maps the changes in the subsurface resistivity horizontally. Sounding can detect vertical changes in subsurface resistivity. The interpretation of the results can be used to determine the depth and thickness of geologic layers of different resistivity. This method can detect soil thickness and depth to aquifers or brine layers.[A9] A diagram describing the basic system configuration is shown in Figure A-5.

A.5.2 Advantages of Resistivity Surveys

The Gradient array method is a relatively simple method. The electrodes are separated at large distances which enables economical mapping of large areas.

The advantages of this method are identical to the electromagnetic method.

A.5.3 Disadvantages of Resistivity Surveys

Variations in placement will give differing results if the survey is repeated in the same area. The Resistivity surveys require direct ground contact and cannot be performed continuously. The condition of the surface layer can effect the results because variation in the soils moisture content can be detected. Measurements performed shortly after rains will be different than measurements taken after prolonged droughts. This can be accounted for in the interpretation of the results. Resistivity also has the same disadvantages as the EM method.

A.5.4 Past Resistivity Survey Work

Extensive Resistivity surveys were conducted during the siting of the WIPP from 1976 to 1978. Areas around suspected breccia pipes and sinks (off-site) were surveyed to determine if resistivity surveys could be used to detect these structures within the WIPP site. All zones of the WIPP site were surveyed. Mining Geophysical Surveys, Inc. performed 53 Schlumberger array soundings and approximately 391 line miles of gradient array profiling (9,880 measurements).[A12]

A.5.5 Current Resistivity Survey Work

No Resistivity work is currently being performed.

A.5.6 Future Resistivity Survey Work

No Resistivity work is planned.

Resistivity Survey Concept

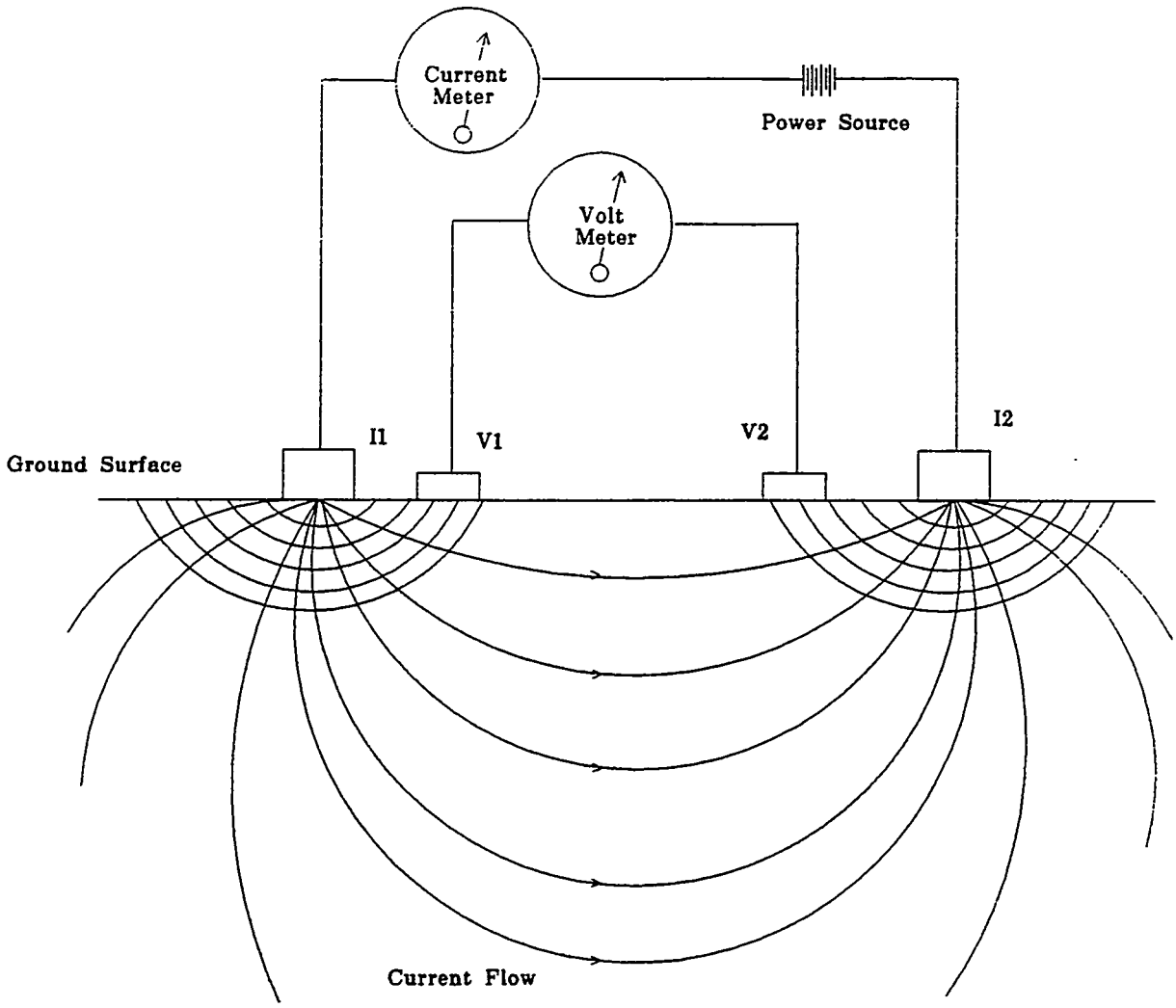


Figure A-5

A.5.7 Define Uses of Resistivity Surveys for LTM

This technology can be used along with EM techniques to gather data immediately after the repository is sealed. Both profiling and sounding should be performed to produce geological maps of the strata's resistivity.

When the surveys are made, the exact locations and methods used should be carefully documented. If possible, research may be required to develop a system for electrode placement to ensure good repeatability in the surveys. This data should be documented in the baseline database for future comparison.

A.6 Environmental Monitoring

A.6.1 Discussion

Environmental monitoring of the WIPP repository will be performed during the operational and decontamination and decommissioning periods. Regulations require some form of surface, air, and water radiological monitoring during the operation of the repository, however, the use of these systems after closure in detecting timely deviations in the repository's long-term performance is impractical because detection would only serve to assess the severity of the release, not to predict its occurrence. The Agreement of Consultation and Cooperation between the State of New Mexico and the DOE requires radiological environmental monitoring for at least five years past closure. This agreement specifies that the environmental monitoring program in place during the operational phase must be continued after closure and decommissioning for at least two years, and that an abbreviated program with a limited number of radiological air, soil, water, and background samples be taken for the following two years.

The post-closure environmental monitoring program is required to include the following:[A22]

- Radiological Environmental Monitoring (first two years after D&D)
  - External Radiation
    Continuous Exposure Rate Measurements
  - Airborne Particulate
    Lo-Vol Sampling, eight stations
  - Vegetation
    Four sites
  - Beef
    Annual muscle samples if available
  - Game Animals
    Annual muscle samples of rabbits and quail.

- Soil Samples
  Annual, multiple samples at multiple depths at six locations.
- Surface/drinking Water
  Annual surface water samples from 12 major bodies of surface water in the vicinity of the site (drinking water will not exist after D&D)
- Groundwater
  Annually, one sample from eight of the wells within the 16 sections boundary taken from the Culebra Dolomite.
- Aquatic Foodstuffs
  Samples of catfish taken from the Pecos River and Brantley Lake and analysis annually.
- Sediment Sampling
  Annual samples taken from the Hill and Indian tank and the Pecos River near Artesia and Malaga, NM.

• Abbreviated Radiological Environmental Monitoring (years three, four, and five after D&D).
  - Airborne Particulate
    Intermittent operation of the state-operated high volume air sampling stations.
  - Soil
    Four annual soil surface samples.
  - Water
    Four annual well water samples.

Only the radiological environmental monitoring techniques that apply after closure are included. Items such as effluent monitoring at the exhaust shaft were not included because they do not apply after closure.

A.6.2 Past Environmental Monitoring Work

Environmental Monitoring has been an ongoing program since the WIPP's inception. Baseline environmental data was gathered and reported in annual reports and Environmental Monitoring Plan (EMP) was created. This information is too vast to be included in this report. The current operational EMP is detailed in the "Environmental Monitoring Plan", WIPP/DOE 94-024 and the "Site Environmental Report for the Calendar Year 1993", DOE/WIPP 94-2033. The reference section of these reports list most of the previous environmental monitoring work reports.

A.7 Direct Repository Monitoring (DRM)

A.7.1 Discussion

From earlier discussions, no proposed long-term monitoring techniques include technologies to directly monitor the repository. This is due to the inherent difficulties imposed by the non-invasive requirement. No wiring or bore holes can be used to connect monitoring equipment in the repository to the surface.

The U.S Bureau of Mines and commercial companies throughout the world are currently researching techniques to communicate through the strata to mine working areas using very-low frequency (VLF) and ultra-low frequency (ULF) electromagnetic radiation. Several companies have developed mine paging systems that use VLF to warn workers within the mine using a system placed on the surface. One system can transmit messages with up to 32 characters to mobile mine pagers. This technology shows promise in remote instrumentation communication that could directly monitor the repository. It has been demonstrated in other salt mines that communication from the surface to the depth of the WIPP repository is possible.

Recently, researchers have started to investigate methods to remotely monitor the sealed rooms and panels. This work uses VLF technology to link sensors and equipment in sealed rooms to the data recorder without a hardwired link. Current work is focused on communication from where the link between the transmitter and receiver is only three to ten meters.

The VLF could be used to transmit data from the surface to equipment located in the repository but the problem lies in communicating the sensor data to the surface. The power required to transmit between the surface and the underground using the current technology is related to the strata conductivity, the output power at the transmitter, and the antenna design. Tests performed in actual mines used large loop antennas on the surface to transmit the signal. Tests have shown that loop diameter is more important in transmission efficiency than output power. Antennas ranging from 30 to over 100 meters in diameter have been used.[A13]

There are many problems that must be overcome to directly monitor the repository after closure. Some of these problems are listed below.

- Sensor/transducer calibration
- Sensor longevity in the repository environment.
- Data collection and transmission power requirements.
- Antenna locations and sizes.

A.7.2 Sensor Calibration

Over time, most sensors such as pressure, gas analyzer, and extensometer sensor/transducer experience some change in resolution or drift. Any type of sensor/transducer used would need to operate for 100 years without re-calibration. To overcome this problem, redundant sensors, sensor drift calculations, and accessible sensors as standards could be used to limit the induced errors. However, this would not ensure accuracy over the required time frame.

A.7.3 Sensor Longevity

The sensors used for long-term monitoring would be required to operate in a salt/brine environment for over 100 years. This imposes the biggest obstacle in direct repository monitoring. Corrosion, oxidation, and various chemical reactions within the electrical components limit the life span to less than 50 years. Extreme condition research would be required to design a system that could operate for that period of time.

A.7.4 Data Collection and Transmission Power Requirements

A power source that could operate for the time required is not currently available. Battery systems have limited shelf lives and capacities. Lithium type batteries have the longest shelf life of the common battery types. Standard shelf lives of 5-10 years at their rated capacity is standard with some manufactures claiming 80% capacity after 15 years. Since the capacity requirements are dependent on the equipment load, the highest current requirement would occur during data transmittal. From experimental work, an estimate of at least 350 watts may be required to transmit to the surface. This can be accomplished with standard power sources for the short- term, but other methods of power generation would be required for the long-term.

One method is power transmission and retention. Power could be transmitted from the surface using ULF energy and an antenna would intercept this energy and store it in capacitors or a special battery. Since the system could be charged for long periods of time between data transmissions, only a small amount of surface transmitted power is required. The problem with this approach is power storage.

The chemical nature of rechargeable batteries limits their life span. The effects of oxidation, outgassing, and heat damage will cause a battery to fail. The life span of most common rechargeable (lead acid, gel, and NiCad) batteries is dependent on the number of recharge cycles, the rate of discharge, and charge rates. Under

favorable conditions, most rechargeable batteries can last up to 10 years.

The capacitor is a device that stores energy on two plates separated by an insulator. Capacitors can be designed for this application that would last the required time frame. The problem associated with capacitors is related to power storage capability and size. In comparison, a capacitor and a battery with the same approximate volume do not have the same energy storage capacity. For example, a one uf capacitor charged to 1,000 V has one-half Joule of energy storage, a 500 mAh NiCad (1.2 Volt) of similar volume has 2,160 Joules of energy storage. A capacitor that has this energy storage potential would be extremely large (4,320 times larger).

Satellite power sources use nuclear energy to generate power. These systems would require extensive regulatory groundwork before it could be used. The systems are not considered off the shelf technology. However, work is progressing on a Nuclear Heat Power Source using (almost) off the shelf technology. One experimental study calls this type of power source a Powerstick.[A21] This theoretical device would use a nuclear heat source and a thermopile to generate an electrical potential. The heat source is a common satellite product used to heat instrumentation. The power source is capable of producing 42 milliwatts at 15 volts initially and would degrade to 37 milliwatts at 14 volts in 10 years. These power sources could be used to slowly charge batteries and/or capacitors that would then be used for a short duration, high demand data transmission cycle or in parallel for a higher current source.

The regulatory issues associated with nuclear power sources have not been researched. If the remote handled (RH) waste could be used as the heat source and WIPP receives RH waste, the regulatory issues may be overcome.

The nuclear/thermopile power source technology has not been proven and there is no prototype as yet. Advances in battery design and the development of this nuclear power source could eventually allow this technology to power a direct repository monitor.

A.7.5 Antenna Location and Size

The size of the antenna may pose a problem in the mine setting. If the antenna is placed inside a room, diameters are limited to a maximum of approximately 10 meters. If the antenna can be wrapped around a pillar, the antenna would have a radius of approximately 50 meters but diameters between 10 and 100 would require special provisions. Also, the effects of the metal in the room will increase the power requirement. These problems can be overcome and

experimentation would be needed to verify the effectiveness of the antenna design.

From current technology no known system is currently available that could be used to directly transmit data to the surface without a hardwired link. Extensive research and development is needed to develop such a system, however the systems longevity will be suspect since actual long-term testing could not be accomplished and new technologies are rarely foolproof. For this reason, DRM is not recommended at this time for LTM.

A.8 Conclusion

There is no single geophysical technical exploratory technique that can determine the condition of the surveyed strata. Several techniques are used to gather data to assess the geological structure that is being examined because interpretation of one technique often uses data from another. For this reason, no one technique should be used to fully assess the repository's condition. One technique can be used as an identifier to alert that a condition may exist and other techniques can be used in unison to assess and validate the condition.

From the review of geophysical survey techniques, the best current monitoring technology that can be used for a LTM identifier is Subsidence. This method is the most practical because it is a simple, repeatable, low cost, low maintenance, low technology approach to monitoring the repository. This method should be used as a primary monitor technique for determining that a possible repository performance problem exists. Other techniques can then be utilized to determine the cause of the problem.

A combination of seismic, electromagnetic, resistivity, and gravitational surveys can be used to assess repository performance. However, it is not practical to perform these on a regular basis, especially if there is good confidence that a performance related event will not occur. For this reason, an initial collection of surveys could be compiled and used as a standard to assess future data and perform subsidence monitoring to forewarn of changing conditions that may affect repository performance.

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APPENDIX NUTS

NUTS is multidimensional, multicomponent transport, single-porosity (SP), dual-porosity (DP), and dual-permeability (DPM) five-point finite-difference simulator. The model simulates first order radioactive chain decay during radionuclide transport. However, the simulator is not limited to radioactive material transport and any non-radioactive material can be included. Also three types of sorption isotherms are considered to represent ion exchange between the waste and the surrounding formation: linear, Freundlich, and Langmuir equilibrium isotherms. Furthermore, hydrodynamic dispersion is modeled with the assumption that the dispersivity corresponds to an isotropic porous medium. Solubility limit of the waste components and their precipitation during migration are included. The precipitate is allowed to undergo decay and to redissolve in the brine if the concentration drops below the solubility limit. Multi-radioactive-site representation is also possible. In this case, the contribution from each site to the component concentration and precipitation, if any, in each computational node can be found. A similar technique has been used to handle a daughter generated from the decay of different parents. The system of partial differential equations is solved implicitly and sequentially to determine the contribution from parent radionuclide decay to the immediate daughter. In the sequential method, the solution proceed progressively from the top of each radioactive chain. Therefore, the contribution to any daughter from parent decay will be available. This has been done to avoid inverting a huge very sparse matrix in which the bands are not well structured.

Transport in Liquid Phase

Transport Mass Balance Equation. In a standard dual-permeability techniques, the partial differential equations that represent the transport in a fractured porous medium consist of fracture and matrix equations coupled by a transfer function between the two media (Kazemi et a1, 1976; Hill and Thomas, 1985; Litvak, 1985; Coats, 1989). The multidimensional difference form of the equations governing the transport of radionuclides in the liquid phase in the dual-permeability formulation (Bear, 1993; Shinta and Kazemi, 1993) are as follows:

Fracture:

$$\Delta_x\left[\phi_f S_{wf} K_{wf} \Delta_x C_{nwf}\right] + \Delta_x\left[T_{wf} C^{\cdot}_{nwf}(\Delta_x P_{wf} - \gamma_{wf}\Delta_x D_f)\right] + C^*_{nwf} Q_{wf} - \tau_{wm|f} C_{nwm|f} -$$
$$\phi_m S_{wm} K_{wm|f}(C_{nwf} - C_{nwm}) = \frac{V_R}{\Delta t}\Delta_t\left[\phi_f S_{wf} C_{nwf} + (1 - \phi_t)\rho_s C_{nsf}\right] + \quad (1)$$
$$V_R\left[\phi_f S_{wf} C_{nwf} + (1 - \phi_t)\rho_s C_{nsf}\right]\lambda_n - V_R\sum_{j=1}^{J}\left\{\left\{\phi_f S_{wf} C_{nwfpj} + (1 - \phi_t)\rho_s C_{nsfpj}\right\}\lambda_{npj}\right\}$$
$$n = 1,2,.....,N$$

Appendix NUTS

1 Matrix:

$$\Delta_x[\phi_m S_{wm} K_{wm} \Delta_x C_{nwm}] + \Delta_x[T_{wm} C_{nwm} (\Delta_x P_{wm} - \gamma_{wm} \Delta_x D_m)] + C^*_{nwm} Q_{wm} + \tau_{wm/f} C_{nwm/f} +$$
$$\phi_m S_{wm} K_{wm/f} (C_{nwf} - C_{nwm}) = \frac{V_R}{\Delta t} \Delta_t [\phi_m S_{wm} C_{nwm} + (1 - \phi_t) \rho_s C_{nsm}] + \quad (2)$$
$$V_R[\phi_m S_{wm} C_{nwm} + (1 - \phi_t) \rho_s C_{nsm}] \lambda_n - V_R \sum_{j=1}^{J} \{\{\phi_m S_{wm} C_{nwmpj} + (1 - \phi_t) \rho_s C_{nsmpj}\} \lambda_{npj}\}$$
$$n = 1,2,.....,N$$

2 where

3

4	C_{nw}	solute concentration of component n [kg/m^3]
5	C^*_{nw}	injected or produced solute concentration of component n [kg/m^3],
6	C_{ns}	sorbate concentration of component n [kg/m^3],
7	D	depth [m],
8	K	dispersion coefficient [m^3/s],
9	N	total number of nuclides,
10	P	pressure [Pa],
11	Q	injection/production rate [m^3/s],
12	S	saturation, fraction,
13	t	time [s],
14	T	transmissibility [m^3/Pa-s],
15	V_R	grid block volume [m^3],
16	Δ_t	value at time n+1 - value at time n,
17	Δ_x	finite difference operator in x-direction,
18	γ	static pressure gradient [Pa/m],
19	λ	decay constant [s^{-1}],
20	ϕ	porosity,
21	ρ	density [kg/m^3],
22	τ	matrix /fracture transfer function [m^3/s],

23

24 Subscripts:

25

26	f	fracture
27	m	matrix
28	m/f	matrix/fracture
29	n	component number
30	pj	parent number
31	s	solid phase (rock)
32	t	total (fracture + matrix)
33	w	water phase

34

For compactness purposes in the above formulations, only Δ_x which represents a central finite difference operator in x-direction is written. Similar operators can be included for y- and z-direction. The number of continua in the above formulae is limited to two, i.e.: matrix and fracture. Therefore, it is possible to perform single-porosity, dual-porosity, and dual-permeability simulations. In the single-porosity, the calculations can be run either in the fracture or in the matrix continuum. Depending on the flow flux field and whether matrix-matrix flow is assumed, NUTS behaves as dual-porosity when the fracture is the main path for the transport (continuous continuum) and the matrix is dispersed in the fracture as a sink/source term, and a dual-permeability model when appreciable transport can be attributed to the matrix flow. In both dual-porosity and dual-permeability models, matrix/fracture transfer is the coupling transport term between the two continua.

Convective Transport. The second and fourth terms in Equations 1 and 2 are the contribution from the convective transport. In the NUTS conceptualization, mass transfer across grid block interfaces is governed by a Darcian transient flow of the liquid phase consistent with BRAGFLO. However, the transfer at the fracture/matrix interface is dominated by a semi steady-state Darcian flow represented by $\tau_{wm/f}$. The magnitude of these flow terms and their idealization are provided by BRAGFLO as volumetric rates.

The x-component of fracture and matrix transmissibilities of the liquid phase (water) T_{wfx} and T_{wmx} are defined as follows:

$$T_{wfx} = \frac{\Delta y \Delta z}{\Delta x} (k\phi)_{fx} \left(\frac{k_r}{\mu}\right)_{wf} \quad (3)$$

and

$$T_{wmx} = \frac{\Delta y\, \Delta z}{\Delta x} k_{mx} \left(\frac{k_r}{\mu}\right)_{wm} . \quad (4)$$

The fracture /matrix transfer function τ for the water is given by:

$$\tau_w = \sigma V_R k_m \left(\frac{k_r}{\mu}\right)_{wm/f} [P_{wf} - P_{wm} - \gamma_{wm/f}(D_f - D_m)] , \quad (5)$$

where

D	depth [m],
k	permeability [m^2],
k_r	relative permeability [dimensionless],
P	pressure [Pa],
V_R	grid block volume [m^3],
γ	static pressure gradient [Pa/m],
Δx	grid block dimension in x-direction [m],
Δy	grid block dimension in y-direction [m],
Δz	grid block dimension in z-direction [m],
μ	viscosity [Pa/s],
σ	shape factor [m^{-2}].

Dispersive Transport. When a contaminant is transported in porous media, the front spreadout beyond an abrupt interface is expected only from the convective part of the flow. Among the processes that lead to a smear (S-shape) front are sorption-desorption process and mixing or dispersion. Dispersion phenomena (Bear 1988) is classified into:

1. Mechanical dispersion, which results from the variation of velocity distribution along the tortuous path of the pore spaces. Heterogeneity introduced by local variation of permeability can also contribute to this kind of dispersion.

2. Molecular diffusion caused by differential tracer concentration. The difference in concentration could be a consequence of any chemical process capable of changing the concentration of the transported nuclide, such as deposition, sorption, solution ion exchange, chemical reaction, and radioactive decay.

In practical application of solute transport, it is customary to include hydrodynamic dispersion (both molecular and mechanical dispersion). Fick's second law of dispersion is utilized in NUTS to describe the dispersion contribution to mass transfer in both fracture and matrix (term 1 in Equations 1 and 2). Dispersion here is treated as a tensor with the assumption that the dispersivity corresponds to an isotropic porous media. Bear (1988) has shown that this assumption allows representation of the dispersivity tensor, in terms of six components, by the following matrix,

$$K = \begin{vmatrix} K_{xx} & K_{xy} & K_{xz} \\ K_{yx} & K_{yy} & K_{yz} \\ K_{zx} & K_{zy} & K_{zz} \end{vmatrix} . \qquad (6)$$

The above tensor is symmetric and has the property of $K_{xy} = K_{yx}$, $K_{xz} = K_{zx}$, and $K_{yz} = K_{zy}$. If the coordinate system coincides with the principal axes of dispersion (the medium

is assumed to be isotropic with regards to dispersivity), off-diagonal values will be zero in the tensor matrix. Therefore, the dispersion coefficients for the x-direction in the fracture and the matrix (Bear, 1993) are:

$$K_{fx} = \frac{\Delta y \Delta z}{\Delta x}\left\{\frac{D^*_m}{\tau^*_f} + \frac{1}{\phi_f S_{wf}|\vec{v}_{wf}|}\left[\alpha_{Lf} v^2_{wfx} + \alpha_{Tf}\left(v^2_{wfy} + v^2_{wfz}\right)\right]\right\} \quad (7)$$

and

$$K_{mx} = \frac{\Delta y\, \Delta z}{\Delta x}\left\{\frac{D^*_m}{\tau^*_m} + \frac{1}{\phi_m S_{wm}|\vec{v}_{wm}|}\left[\alpha_{Lm} v^2_{wmx} + \alpha_{Tm}\left(v^2_{wmy} + v^2_{wmz}\right)\right]\right\} \quad (8)$$

where the terms between brackets are the x-component of the dispersivity tensor and,

D^*_m molecular diffusion coefficient [m^2/s],
τ^* tortuosity [dimensionless],
α_L longitudinal dispersivity [m],
α_T transverse dispersivity [m],

and the velocity vector v– is given by:

$$|\vec{v}| = \sqrt{v^2_x + v^2_y + v^2_z}\,. \quad (9)$$

where v_x, v_y, v_z are the velocities [m/s] in x, y, z directions, respectively. Similar formulations can be written for y and z components of the dispersion tensor.

Dispersion in the fracture and matrix is generally small and can be neglected if the convective part of the transport is dominant. However, for transport in the repository, dispersion could be the major transport term, particularly away from the radioactive source. Nevertheless, dispersion can be a significant means of mass transfer between fracture and matrix (term 5 in Equations 1 and 2). The dispersion coefficient for fracture/matrix flow (Bear, 1993) is given by

$$K_{wmlf} = \sigma V_R\left\{\frac{D^*_m}{\tau^*_m} + \alpha_m \frac{|v_{wmlf}|}{\phi_m S_{wmlf}}\right\}, \quad (10)$$

where

$v_{wm/f}$ velocity of liquid transfer [m/s],
$S_{wm/f}$ upstream weighted fracture or matrix saturation [dimensionless].

The shape factor σ above is defined in general form as

$$\sigma = \sum \frac{A_m}{V_m d}, \tag{11}$$

where

A_m the surface area of the face subjected to flow [m^2],
V_m the volume of the matrix block [m^3],
d the distance between the face and the center of the matrix block [m].

For a cubical matrix block, the shape factor (Kazemi et al, 1976) is therefore,

$$\sigma = 4\left(\frac{1}{L_x} + \frac{1}{L_y} + \frac{1}{L_z}\right), \tag{12}$$

where L_x, L_y, and L_z are the block dimension in x, y, and z coordinates.

Sorption. Many chemicals might undergo sorption to the solid surface of the matrix rock. This surface phenomena takes place because of the mass transfer between the solute and the solid surface and is controlled by the chemical properties of both the solid and the solute. Sorption as a retarding factor in the transport front propagation is expressed in NUTS through the variables C_{sm} and C_{sf}, which represent the sorbed concentration of the radionuclide per unit rock weight. It is conventional to relate C_{sm} and C_{sf} to the solute concentration by some sort of empirical relations called isotherms. As the name implies, these isotherms are no more than the sorbate concentration versus the solute concentration at a constant temperature. Three equilibrium isotherms are considered in NUTS, They are

1. Linear Adsorption isotherm in which the adsorbate concentration is related to the solute concentration by:

$$C_s^{n+1} = k_d\, C_w^{n+1} \tag{13}$$

where

n+1 implicitness of the concentration (current time step),

k_d partition equilibrium constant.

2. Freundlich isotherm is expressed by:

$$C_s^{n+1} = x_1 C_w^{\left(\frac{1}{x_2}\right)^{n+1}} = x_1 C_w^{\left(\frac{1-x_2}{x_2}\right)^{n}} C_w^{n+1} = \chi C_w^{n+1} \qquad (14)$$

where n refers to the old time step and

$$\chi = x_1 \left(C_w^{\frac{1-x_2}{x_2}} \right)^n \qquad (15)$$

x_1 and x_2 are Freundlich distribution coefficient and Freundlich coefficient, respectively.

3. Langmuir isotherm which is the most common isotherm used in the literature besides the linear one and is defined by:

$$C_s^{n+1} = \chi_1 C_w^{n+1} \quad \textit{where } \chi_1 = x_1 \left(1 - \frac{x_2 C_w^n}{1 + x_2 C_w^n} \right) \qquad (16)$$

The empirical parameters x_1 and x_2 are Langmuir distribution coefficient and Langmuir coefficient, respectively.

Obviously, NUTS considers the adsorption in the fracture and the matrix. However, it has the ability to bypass any continuum adsorption. Also, it is possible to assign any specified nuclide as adsorbable or not.

Decay. Radionuclides decay by first-order chains to other radionuclides. Therefore, the description of their migration is much more complex compared to stable contaminants. This complexity arises from the fact that each nuclide has different sorption and decay rates.

NUTS simulates the migration of radionuclide decay chains of the form A→B→C→....→N. Since the properties of the modeled nuclides are considered in the input and the differential form of the decay is used (as oppose to the Bateman's equations), there is no limitation on the number of members in each simulated chain. The second and the third terms of the right-hand side of Equations 1 and 2 are the disappearance of radionuclide n by decay and appearance of n from decay of the preceding chain member, respectively. Examination of these terms shows that both sorbed and dissolved radionuclides contribute to the decay terms. Because of the implicit treatment of the parent contribution into the immediate daughter, the partial differential equations are solved sequentially from the top of each chain. Therefore, it is essential in NUTS input file to provide sequentially the names of the parent and the daughter for each chain.

Solubility Limit and Precipitation. When ground water comes in contact with released waste, dissolution of the radionuclides begins and continues until equilibrium concentrations are attained or all radionuclides are consumed. The capacity of the ground water to dissolve radionuclides is controlled by temperature, pressure and chemical composition. Consequently, there is a solubility limit for each element in the waste. NUTS requires the solubility limit of the elements and allocates the solubility limit for the isotopes according to their mole fractions. The amount of radionuclides in excess of their solubility limit precipitates in the grid block. Precipitate in NUTS undergoes decay and precipitation is treated as a reversible process. Once the solute concentration drops below the solubility limit, ground water is allowed to redissolve from the precipitate a mass equivalent of the solubility limit (or lower) of that solute, depending on the abundance of the precipitate.

Multi-Site Representation. Multi-radioactive-sites are possible in NUTS. In this case, the contribution from each site to the radionuclide concentration (dissolved and adsorbed) and precipitation, if any, in the computational nodes can be found. In order to track the migration of any radionuclide, this kind of treatment requires that similar radionuclides from different sites be handled as different components except in the precipitation and dissolution. The contribution of multi-site radionuclide to the precipitate and dissolution is assumed to be linear (weighted by the mole fraction). Similar technique has been used in NUTS to evaluate the same daughter generated from different parents.

Source/Sink Terms. NUTS has many options to include the source/sink terms, they are

1. Unlimited number of injection/production wells can be incorporated within or outside the waste region. It is also possible to attach a history to each well.

2. Specified inventory placement of any number of nuclides at different radioactive sites.

3. NUTS has the ability to interface with other computer code to pick up an actinide source instead of waste emplacement mentioned in item 2.

4. A constant strength source (Dirichlet type boundary conditions) placed anywhere in the simulated domain.

Temperature Dependency. It is optional in NUTS to implement the temperature dependency of certain parameters. Solubility limit can either be considered as a constant or evaluated from certain correlations to account for its thermal dependency in thermal processes.

The molecular diffusion changes with temperature and the following formula is derived to evaluate its dependency,
where

$$D^*_m(T) = D^*_{mref} \frac{T}{T_{ref}} \frac{\mu_{ref}}{\mu(T)} \qquad (17)$$

D^*_{mref} molecular diffusion evaluated at the reference temperature (T_{ref})
$D^*_m(T)$ molecular diffusion at temperature T
μ_{ref} reference viscosity at T_{ref}
$\mu(T)$ solvent viscosity at temperature T.
T_{ref} reference temperature

Adsorption is another temperature dependent parameter. The following is a preliminary formulation derived for the temperature dependency of k_d which can also be applied to Freundlich and Langmuir coefficients with fair accuracy.

$$K_{d2} = K_{d1} \exp\left[\frac{\xi(T_2 - T_1)}{T_2 T_1}\right], \quad where \ \xi = \frac{\Delta H^o}{R}. \qquad (18)$$

In Equation 18, K_{d1}, and K_{d2} are partition equilibrium constants at temperatures T_1 and T_2, respectively, ΔH^o is the enthalpy of sorption at reference temperature T_{ref}, and R is the gas constant.

Transport in the Gas Phase. It is essential in gas transport to consider the chemical interaction between the gas and the porous media (and its content) in which it flows. This interaction or phase equilibrium can be classified as gas-solid phase equilibrium described by sorption-desorption process and gas-liquid phase equilibrium.

The description of multiphase equilibrium in porous media is complex and requires a compositional simulator that strongly couples the transport with flow equations. This kind of treatment arises because some mixtures like VOC+H_2O, can be observed under certain

conditions of pressure, temperature and composition, as single phase, liquid or vapor, two phase (vapor-liquid or liquid-liquid), or three-phase (vapor-liquid-liquid). To appropriately describe such a system and predict the number of phases in equilibrium, transport in the liquid and gas phases should be conducted simultaneously. In this case, the solute will be partitioned according to its equilibrium constant between the phases in equilibrium.

However, this compositionally equilibrated system requires not only a detailed description of the pressure, temperature and initial composition fields in the computational domain, but also is very demanding with regard to computation time and resources. Thus, because of data limitations, NUTS considers the porous media and its fluid content as a retardation factor for the constituents transported by the gas phase (Doctor et al., 1992). The following phenomena are included in NUTS:

1. Solid-gas phase equilibrium is considered by the same linear equilibrium sorption isotherm described above.

2. Liquid-gas equilibrium is modeled through gas solubility in the water as a function of temperature. The equation that describes this equilibrium is

$$K_{LG} = \frac{C_L}{C_G} , \tag{19}$$

where C_L and C_G are the concentration of the solute in the liquid and gas phases, respectively. The value of the ratio at the right-hand side is represented by a linear relationship as a function of temperature

$$\frac{C_L}{C_G} = A - B\,T , \tag{20}$$

where A and B are the intercept and the slope, respectively. This linear representation is valid only for a limited range of temperature and at low pressure where composition dependency is usually weak.

Because the migration rate in the liquid phase is much slower compared to the gas phase, and because the gas and the liquid phases transport are decoupled in NUTS, liquid transport of the constituent abundantly transported by the gas phase will not be tracked. With the above mentioned assumptions, the transport in the gas phase of a dual-permeability system can be described by the following equations:

1 **Fracture:**

$$\Delta_x[\phi_f S_{Gf} K_{Gf} \Delta_x C_{nGf}] + \Delta_x[T_{Gf} C_{nGf}(\Delta_x P_{Gf} - \gamma_{Gf} \Delta_x D_f)] + C^*_{nGf} Q_{Gf} - \tau_{Gm|f} C_{nGm|f} -$$
$$\phi_m S_{Gm} K_{Gm|f}(C_{nGf} - C_{nGm}) = \frac{V_R}{\Delta t} \Delta_t[\phi_f S_{Gf} C_{nGf} + (1 - \phi_t)\rho_s C_{nsf}$$
$$+ \phi_f(1 - S_{Gf}) K_{LG} C_{nGf}] + V_R[\phi_f S_{Gf} C_{nGf} + (1 - \phi_t)\rho_s C_{nsf} + \phi_f(1 - S_{Gf}) K_{LG} C_{nGf}]\lambda \quad (21)$$
$$- V_R \sum_{j=1}^{J} \{\{\phi_f S_{Gf} C_{nGfpj} + (1 - \phi_t)\rho_s C_{nsfpj} + \phi_f(1 - S_{Gf}) K_{LG} C_{nGfpj}\} \lambda_{npj}\} \; n = 1,2,.,.,.,.,N$$

2 **Matrix:**

$$\Delta_x[\phi_m S_{Gm} K_{Gm} \Delta_x C_{nGm}] + \Delta_x[T_{Gm} C_{nGm}(\Delta_x P_{Gm} - \gamma_{Gm} \Delta_x D_m)] + C^*_{nGm} Q_{Gm} + \tau_{Gm|f} C_{nGm|f} +$$
$$\phi_m S_{Gm} K_{Gm|f}(C_{nGf} - C_{nGm}) = \frac{V_R}{\Delta t} \Delta_t[\phi_m S_{Gm} C_{nGm} + (1 - \phi_t).\rho_s C_{nsm} \quad (22)$$
$$+ \phi_m(1 - S_{Gm}) K_{LG} C_{nGm}] + V_R[\phi_m S_{Gm} C_{nGm} + (1 - \phi_t)\rho_s C_{nsm} + \phi_m(1 - S_{Gm}) K_{LG} C_{nGm}]\lambda_n$$
$$- V_R \sum_{j=1}^{J} \{\{\phi_m S_{Gm} C_{nGmpj} + (1 - \phi_t)\rho_s C_{nsmpj} + \phi_m(1 - S_{Gm}) K_{LG} C_{nGmpj}\} \lambda_{npj}\} \; n = 1,2,.,.,.,.,N$$

3 where subscript G refers to the gas phase, and K_{LG} is the gas-liquid equilibrium constant.
4 The rest of the nomenclatures are defined in Equations 1 and 2.
5
6 **Assumption and Limitations.** Assumptions and limitations for NUTS are as follows:
7
8 1. Decoupling of flow and transport equations is permitted by dilute solute concentration
9 (does not affect fluid density, viscosity, etc.).
10
11 2. Local equilibrium exists between interacted phases.
12
13 3. If modeling liquid phase, the radionuclides transported by this model are
14 thermodynamically stable within their solubility limit. No gas phase or radionuclides-
15 rich liquid phase is allowed. However, precipitation is possible beyond the solubility
16 limit.
17
18 4. Radionuclides are in equilibrium with the precipitate. The precipitation is a reversible
19 process controlled by the solubility limit as an upper bound.
20
21 5. Sorption obeys only equilibrium isotherms.
?

6. Dispersion is assumed to obey Fick's second law with dispersivities corresponding to an isotropic porous medium so that it can be represented by two constants in the principal directions of flow.

7. Solubility of each isotope is evaluated as:

$$(\text{Solubility})_{\text{isotope}} = (\text{Mole Fraction})_{\text{isotope}} \times (\text{Solubility})_{\text{element}}$$

8. If modeling the gas phase, gas-liquid equilibrium follows a linear relationship represented by Equation 19.

9. If modeling the gas phase, gas travels much faster than the liquid and, therefore, liquid phase is acting as a retarding agent to the constituents transported by the gas phase.

The Numerical Approach. The transport equations (Equations 1 and 2) have NxG unknowns for single porosity and Nx2G unknowns for dual-porosity and dual-permeability formulations, where G is the number of grid blocks in the simulated spatial domain. The system of the partial differential equations is strongly coupled due to the contribution of the parent decay to the immediate daughter (the last terms in Equations 1 and 2). The sequential method is used to solve the system implicitly. In the sequential method, the solution proceeds progressively from the top of each radioactive chain. Therefore, the contribution to any daughter from parent decay will be available. This method was chosen to avoid inverting a big (for large number of radionuclides) and very sparse matrix in which the bands are not well structured.

Standard Gaussian elimination has been used to invert the numerical matrix. Two techniques are applied to reduce the size of the numerical matrix to a more manageable size. In the first technique, an optimum dimension (in standard ordering) is chosen to define the connectivity of the grid blocks. The guideline of this choice is the minimum number of grid blocks. Hence, for a two dimension problem in x and y, the numbering will start from min(x,y) and proceed to the next dimension. The second technique is included by straightening the numerical matrix diagonals and limiting the calculation in the entries between the uppermost and the lowermost diagonals. Therefore, for a single-porosity system in two dimension, a pentagonal matrix of IBWxG is inverted instead of GxG matrix, where IBW is the band width.

Input/Output:

NUTS requires two types of input: a flow field input, and radionuclides input. The first input is taken directly from the output of BRAGFLO. The second one is a user-generated file which provides component properties as well as dispersion and adsorption required data, such as molecular dispersion, dispersivities, rock densities, adsorption coefficients, etc. The model has the ability to read the BRAGFLO output file from CAMCON database and from a binary file whereas the second input can be read from an

ASCII file. Moreover, NUTS is capable of bypassing BRAGFLO input to a user supplied ASCII file. The last property is valuable in testing the model against analytical solutions and to make runs independent of BRAGFLO.

Output from NUTS is also flexible and can be binary, ASCII, or CAMCON depending on user specifications. In each output file, up to fourteen options are accessible to represent the concentration in each continuum on a different basis i.e.: volumetric, soil, masses, curies, individual, and total nuclei basis or a combination of them. Furthermore, an optional ASCII scratch type file can be activated for debugging purposes. A specific spatial range ASCII output for any of the designated output variable is also available.

REFERENCES:

Bear, J., "Dynamic of Fluids in Porous Media", Dover Publications, Inc., NY (1988).

Bear, J., "Flow and Contaminant Transport in Fractured Rock", Academic Press, Inc., (1993).

Coats, K.H., "Implicit Compositional Simulation of Single-Porosity and Dual-Porosity Reservoirs", Paper SPE 18427 presented at the 10th SPE Symposium on Reservoir Simulation, Houston, TX, Feb. 6-8, 1989.

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Kazemi, H., L.S. Merrill, K.L. Porterfield and P.R. Zeman, "Numerical Simulation of Water-Oil Flow in Naturally Fractured Reservoirs", SPEJ 317-326 (1976).

Litvak, B.L., "Simulation and Characterization of Naturally Fractured Reservoirs", Proc. Res. Characterization Technical Conf., Dallas Academic Press, NY (1985).

Shinta, A.A. and H. Kazemi, "Tracer Transport in Characterization of Dual-Porosity Reservoirs", Paper SPE 26636 presented at the 1993 SPE Annual Tech. Conf. and Exh., Houston, TX, 3-6 Oct.

Hill, A.C. and G.W. Thomas, "A New Approach for Simulating Complex Fractured Reservoirs", Paper SPE 13537 presented at the 1985 Res. Sim. Sys., Dallas, TX, 10-13 Feb.

Parameter Sheets
Parameter Name: Salado Anhydrite Permeability and Porosity

Parameter Description:

Permeability of undisturbed anhydrite layers within the Salado Formation. Log permeability values given (dimensionless); permeability has units of square meters.

Regulatory Driver(s):

40 CFR Part 191

191.13(a) Disposal systems . . . shall be designed to provide reasonable expectation, based on performance assessments, that the cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall . . .

40 CFR 191.15[a] Disposal systems for waste and any associated radioactive material shall be designed to provide a reasonable expectation that, for 10,000 years after disposal, undisturbed performance of the disposal system shall not cause the annual committed effective dose, received through all potential pathways from the disposal system, to any member of the public in the accessible environment, to exceed 15 millirems (150 microsieverts).

(a) The standards were formulated . . . because the properties of the geologic media around a mined repository are expected to provide much of the disposal system's capability to isolate these wastes over these long time periods. (Preamble, 50 FR 30871b)

(b) When predicting disposal system performance, the agency assumes that reasonable projections of the protection expected from all of the engineered and natural barriers of a disposal system will be considered. (Appendix C)

Computational Code(s):

Parameter Name: MBPERM (Permeability), MBPOR (Porosity)
Code: BRAGFLO

Model Input Data Values:		
Median:	**Range:**	**Units:**
Constructed Distribution used for both Parameters	10^{-15} to 10^{-21} (Permeability) 0.1 to 8 (Porosity)	log permeability (m^2) % (Porosity)

Parameter Sensitivity:

Not Determined

Data:

Raw Data

Beauheim et al (1991), Beauheim et al (1993), Domski (1994) [attached], Howarth (1994) [attached], Jensen et al (1993), Saulnier et al (1991), and Stensrud et al (1992).

Parameter Sheets
Parameter Name: Salado Anhydrite Permeability and Porosity

Data: continued

Point Data:

Fourteen hydraulic tests have been performed in anhydrite and are included in Table 1. Interpreted permeabilities using a Darcy-flow model range from 2×10^{-20} to $7 \times 10^{-18} m^2$ for anhydrite intervals. Interpreted formation pore pressures range from atmospheric to 12.5 MPa for anhydrite intervals. Lower values are caused by depressurization near the excavation.

The properties of anhydrite interbeds have also been investigated in the laboratory. Tests were performed on three groups of core samples from Marker Bed 139 as part of the Salado Two-Phase Flow Laboratory Program. The laboratory experiments provided porosity, intrinsic permeability, a capillary pressure data. Preliminary analysis of capillary pressure test results indicate a threshold pressure of less than 1 MPa. The laboratory-measured effective porosity and intrinsic permeability data are shown in Howarth (1994) [attached].

Table 1. Summary of Test-Interpretation Results from In Situ Permeability and Pore Pressure Tests. [attached]

Model Input Data:

Table 2. Anhydrite Interbed Parameter Values. [attached]

Discussion:

Performance assessment uses three distinct anhydrite interbeds in the BRAGFLO model, representing Marker Bed 138, anhydrites "a" and "b", and Marker Bed 139. The three interbeds have the same model parameter set assigned to them, and the parameters are spatially constant: the only difference between the interbeds is their position and thickness. Model parameters describing the interbeds are shown in Table 6-10.

Repository pressures are not expected to be greater than lithostatic because such pressures would result in negative effective stress in rock near the repository and cause dilation of fracturing. This will allow gas floout of the repository, which reduces pressure. Field tests and laboratory tests in anhydrite interbeds support the use of a pressure-dependent permeability and porosity, and indicate that such alteration may take place below lithostatic pressure.

The model used in performance assessment to represent interbed fracture aassigns a fracture initiation pressure such that when this pressure is reached, local fracturing takes place. Below the fracture initiation pressure, an interbed has a constant permeability and compressibility, and the porosity is determined using the standard integral equation. Above the fracture initiation pressure, the local compressibility of the interbed is assumed to increase linearly with pressure, which dramatically affects how rapidly porosity increases with increasing pore pressure. Additionally, permeability increases by the magnitude of porosity increase raised to a power. The compressibility, porosity, and permeability continue to increase until the full fracture pressure is reached, above which these values cease to change. Table 3 illustrates fracture model parameters.

Parameter Sheets
Parameter Name: Salado Anhydrite Permeability and Porosity

References:

Beauheim, R.L., G.J. Saulnier, Jr., and J.D. Avis. 1991. *Interpretation of Brine-Permeability Tests of the Salado Formation at the Waste Isolation Pilot Plant Site: First Interim Report.* SAND90-0083. Albuquerque, NM: Sandia National Laboratories.

Beauheim, R.L., R.M. Roberts, T.F. Dale, M.D. Port, and W.A. Stensrud. 1993. *Hydraulic Testing of Salado Formation Evaporites at eh Waste Isolation Pilot Plant Site: Second Interpretive Report.* SAND92-0533. Albuquerque, NM: Sandia National Laboratories.

Domski (1994) [attached]

Howarth (1994) [attached]

Jensen, A.L., C.I., Howard, R.L. Jones, and T.P. Peterson. 1993. *Room Q Data Report: Test Borehole Data from April 1989 through November 1991.* SAND92-1172. Albuquerque, NM: Sandia National Laboratories.

Saulnier, Jr., G.J., P.S. Domski, J.B. Palmer, R.M. Roberts, and W.A. Stensrud. 1991. *WIPP Salado Hydrology Program Data Report #1.* SAND90-7000. Albuquerque, NM: Sandia National Laboratories.

Stensrud, W.A., T.P. Dale, P.S. Domski, J.B. Palmer, R.M. Roberts, M.D. Port, and G.J. Saulnier, Jr. 1992. *Waste Isolation Pilot Plant Salado Hydrology Program Data Report #2.* SAND92-7072. Albuquerque, NM: Sandia National Laboratories.

Table 1. Summary of Test-Interpretations Results from In Situ Permeability and Pore Pressure Tests

TEST INTERNAL (METERS FROM EXCAVATION)	HOLE	ZONE	MAP UNIT	TEST	ANALYSIS METHOD	AVERAGE PERMEAB-ILITY K (m^2)	FOR-MATION PORE PRESS-URE Pr (MPa)	DATA REF.	INTERPRE-TATION REFERENCE
8.63-10.06	L4P51-B	test	anhydrite "c"	PB	Interpret/2	5.1×10^{-20}	5.17	a	b
				all	GTFM	6.4×10^{-20}	5.21	a	b
6.75-7.79		guard	H-2	SI	-	-	>3.25	a	b
4.14-5.56	L4P52-A	test	anhydrite "a"	PB	Interpret/2	6.4×10^{-20}	6.50	a	b
				all	GTFM	6.0×10^{-20}	6.75	a	b
2.27-3.32		guard	anhydrite "b"	SI	-	-	>3.25	a	b
8.70-10.15	S1P71-B	test	anhydrite "c"	all	GTFM	8.0×10^{-20}	5.12	a	b
6.82-7.87		guard	H-2	SI	-	-	>4.2	a	b
2.15-3.18	S1P72-A	guard	0, PH-4	all	GTFM	1.8×10^{-21}	4.08	a	b
3.38-4.80	S1P73-A	test	anhydrite "a"	SI	-	-	0	a	b
0.85-2.49		guard	anhydrite "b"	SI	-	-	0	a	b
9.92-11.32	S1P73-B	test	MB138	PW2	type curve	4.9×10^{-20}	-	a	b
				CPW	type curve	1.8×10^{-20}	-	a	b
				PB	Interpret/2	4.9×10^{-20}	4.29	a	b
				all	GTFM	4.9×10^{-20}	4.37	a	b
8.04-9.09		guard	AH-1	SI	Horner	-	2.55	a	b
10.68-15.39	SCP01-A	test	MB139	CPW2	type curve	5.8×10^{-20}	-	a	b
				PB2	Interpret/2	5.1×10^{-20}	12.40	a	b
				all	GTFM	7.1×10^{-20}	12.55	a	b
2.09-5.58	C2H01-A	test	0-5	all	GTFM	9.1×10^{-19}	0.54	c	d
		test	4-5	all	GTFM	3.5×10^{-18}	0.56	c	d
4.50-5.58	C2H01-B	test	0	all	GTFM	6.9×10^{-21}	3.22	c	d
2.92-4.02		guard	0-4		GTFM	2.5×10^{-21}	4.17	c	d
6.63-8.97	C2H01-C	test	MB139	all	GTFM	1.2×10^{-18}	8.16	c	d
9.47-10.86	C2H02	test	MB139	all	GTFM	1.0×10^{-19}	9.43	c	d
7.76-9.14	C2H03	test	9	all	GTFM	$<10^{-21}$	?	c	d
3.33-4.75	L4P51-A	test	PH-3, clay D	all	GTFM	7.9×10^{-21}	2.81	c	d
3.74-5.17	SOP01	test	PH-3, clay D	all	GTFM	1.1×10^{-20}	4.52	c	d
1.86-2.91		guard	MB139	all	GTFM	7.4×10^{-18}	0.56	c	d
3.12-4.56	S1P71-A	test	PH-3, clay D	all	GTFM	7.0×10^{-20}	3.01	c	d
24.49-26.37 (12.3)***	QPPO1	test	MB138	all	GTFM	$8.4\times10^{-20**}$	10.4**	e	f
23.20-24.05 (6.2)	QPPO2	test	12-13	all	-	?	?	e	f
22.45-23.35	QPPO3	test	anhydrite "b"	all	GTFM	$7.8\times10^{-20*}$	12.4*	e	f
(2.9)		test	anhydrite "b"	all	GTFM	$7.8\times10^{-20**}$	6.9**	e	f

23.69-24.54 (1.9)	QPPO4	test	6-7	all	-	?	?	e	f
22.08-22.98	QPPO5	test	6	all	GTFM	$3.6\times10^{-23*}$	6.5*	e	f
(0.8)		test	6	all	GTFM	$4.1\times10^{-20**}$	0.3**	e	f
25.29-26.64	QPP11	test	H1	all	GTFM	$5.3\times10^{-22*}$	5.5*	e	f
(12.3)		test	H1	-	-	-	7.4**	e	f
23.35-24.20	QPP12	test	H3	all	GTFM	$2.7\times10^{-22*}$	9.6*	e	f
(6.2)		test	H3	all	GTFM	$2.7\times10^{-22*}$	9.6**	e	f
22.54-23.44 (3.3)	QPP13	test	MB139	all	GTFM	$7.3\times10^{-20**}$	8.1**	e	f
22.35-23.20	QPP14	test	MB139	all	GTFM	$2.1\times10^{-23*}$	8.0*	e	f
(2.1)		test	MB139	all	GTFM	$2.0\times10^{-23**}$	8.0**	e	f
22.14-23.04	QPP15	test	O-PH4	all	GTFM	$1.1\times10^{-23*}$	7.5*	e	f
(1.0)		test	O-PH4	all	GTFM	$3.1\times10^{-22**}$	3.1**	e	f
23.18-24.54 (12.0)	QPP21	test	2-3	all	GTFM	$8.8\times10^{-23*}$	3.9*	e	f
		test	2-3	all	GTFM	$1.5\times10^{-21**}$	5.0**	e	f
22.25-23.10 (5.9)	QPP22	test	3	all	GTFM	$1.3\times10^{-21**}$	3.2**	e	f
21.99-22.89 (3.0)	QPP23	test	3	all	GTFM	$1.2\times10^{-20**}$	3.5**	e	f
22.01-22.86 (1.6)	QPP24	test	1-2	-	-	?	?	e	f
21.96-22.86 (1.0)	QPP25	test	2-3	all	GTFM	$7.0\times10^{-21**}$	2.2**	e	f

Key: PB = Pressure-buildup test
SI = shut-in pressure buildup
PW = pulse-withdrawal test
CPW = constant-pressure withdrawal test
* = before mining of Room Q
** = after mining of Room Q

a = Stensrud, W.A., T.F. Dale, P.S. Domski, J.B. Palmer, R.M. Roberts, M.D. Fort, G.J. Saulnier, Jr., and A.L. Jensen. 1992. *Waste Isolation Pilot Plant Salado Hydrology Program Data Report #2.* SAND92-7072. Albuquerque, NM: Sandia National Laboratories.

b = Beauheim, R.L., R.M. Roberts, T.F. Dale, M.D. Fort, and W.A. Stensrud. 1993. *Hydraulic Testing of Salado Formation Evaporites at the Waste Isolation Pilot Plant Site: Second Interpretive Report.* SAND92-0533. Albuquerque, NM; Sandia National Laboratories.

c = Saulnier, G.J., Jr., P.S. Domski, J.B. Palmer, R.M. Roberts, W.A. Stensrud, and A.L. Jensen. 1991. *WIPP Salado Hydrology Program Data Report #1.* SAND90-7000. Albuquerque, NM: Sandia National Laboratories.

d = Beauheim, R.L., G.J. Saulnier, Jr., and J.D. Avis. 1991. *Interpretation of Brine-Permeability Tests of the Salado Formation at the Watste Isolation Pilot Plant Site: First Interim Report.* SAND90-0083. Albuquerque, NM: Sandia National Laboratories.

e = Jensen, A.L., C.L. Howard, R.L. Jones. and T.P. Peterson. 1993. *Room Q Data Report: Test Borehole Data from April 1989 through November 1991.* SAND92-1172. Albuquerque, NM: Sandia National Laboratories.

f = Domski, June 29, 1994. Memo

*** = Approximate post-mining distance from Room Q to test interval.

Table 2. Anhydrite Interbed Parameter Values

Parameter	Maximum	Minimum	Median or Constant***
permeability, (m^2)	10^{-15}	10^{-21}	--*
porosity, (%)	8	0.1	--*
specific storage (1/m)	10^{-5}	10^{-7}	10^{-6}
two-phase** Brooks/Corey	--	--	2/3
P_t (Pa)	$5.6xk^{-0.346}$	$5.6x10^{-4}xk^{-0.346}$	--*
S_{br}	0.6	0	--*
S_{gr}	0.4	0	--*
λ	10.0	0.2	5.1
van Genuchten/ Parker	--	--	1/3
S_{br}	0.6	0	--*
S_{gr}	0.4	0	--*
m	0.91	0.17	0.836

* A constructed distribution between the maximum and minimum values was used.
** Relative permeability model chosen was identical to that sampled for halite.
*** Parameters with no maximum and minimum values are treated as constants in PA.

Table 3. Interbed fracture parameter values

Parameter, units	Maximum	Minimum	Median or Constant*
Initiation Pressure, (Pa)	14.8×10^6	13.8×10^6	14.3×10^6
Full Fracture Pressure (Pa)	17.3×10^6	16.3×10^6	16.8×10^6
Maximum Porosity	--	--	Initial + 1%
Max. Permeability (m^2)	--	--	10^{-9}

* Parameters with no maximum and minimum values are treated as constants in the PA.

Sandia National Laboratories

Albuquerque, New Mexico 87185

to: R. Beauheim, 6115

from: S. Howarth, 6115

date: September 9, 1994

subject: Laboratory-measured Values for Porosity and Permeability from Preliminary Laboratory Tests Performed on Marker Bed 139 Cores

Preliminary tests were performed on three groups of core samples from Marker Bed 139 of the Salado Formation during FY93 to provide data to support the development of the numerical models used to predict the long-term hydrological and structural response of the WIPP to waste-generated gas as part of the Salado Two-Phase Flow Laboratory Program. These preliminary laboratory experiments: 1) generated WIPP-specific porosity, single-phase permeability, and capillary pressure data, 2) provided information needed to design and implement planned tests to measure threshold pressure, capillary pressure, and relative permeability, and 3) will be used to evaluate the suitability of using tight gas sands correlations as a Salado analog for assessment of the long-term performance of the WIPP. Total and effective porosity and gas and liquid steady-state single-phase permeability were measured as the test specimens were subjected to three different levels of hydrostatic confining stress while the pore pressure remained constant. Darcy flow was maintained during the permeability tests (i.e., the graph of flow rate versus pressure drop across the core was linear). Vertical and horizontal permeability were measured on adjacent cores.

Table 1 contains a summary of the porosity and permeability data results received from two (TerraTek and RE/SPEC) of the three laboratories that performed preliminary tests on Marker Bed 139 samples. Preliminary results from the third laboratory (Core Laboratories) are within the same ranges as the results contained in Table 1. Once QA of the Core Laboratories data is complete, Table 1 will be updated to incorporate all porosity and permeability data from the Preliminary Tests.

The laboratory-measured effective porosity values range from 0.4 to 2.7% with a mean of 1.25% (see Table 1). These values compare well with the range and mean values for porosity used in the 1992 PA; 0.1 to 3.0% and 1.25%, respectively. The laboratory-measured single-phase permeability values ranged from 8.4×10^{-16} to 5.5×10^{-20} m^2, depending on the stress conditions during the test (see Table 1). The mean was approximately 3.5×10^{-18} m^2 at 6 MPa. These values are an order of magnitude higher on the low end of the permeability distribution curve than those used in the 1992 PA. Likewise, the mean laboratory-measured single-phase permeability was an order of magnitude higher than the mean used in the 1992 PA.

Liquid single-phase permeability data are also reported in Table 1 for three samples for which gas permeability was also measured. As expected, these data compare well with the Klinkenberg-corrected gas single-phase data at all confining stress levels. It should be noted that the liquid permeability test specimens were chosen using high gas permeability as the primary selection criterion. Single-phase permeability, whether gas or non-reactive-liquid, is considered to be an intrinsic property of the rock. Therefore, one should not draw the conclusion that liquid permeability of the Salado is more uniform or, on average, higher than the gas permeability. Thus, for single-phase permeability of the Salado anhydrite, the range and mean values detailed in the preceding paragraph should be used.

Results indicate that the both porosity and single-phase permeability were reduced as increasing levels of confining stress were applied to the test specimen. Typically, permeability was reduced by less than an order of magnitude with an increase in confining stress from 2 to 10 MPa. Porosity reduction was less dramatic over the same pressure range; porosity was reduced by less than half a percent with an increase in confining stress from 2 to 10 MPa. These experimental results illustrate the stress dependence of porosity and permeability for Marker Bed 139 anhydrite.

Copy to:

6115 Davies, P.
6115 Webb, S.
SWCF-A:WBS1141;HYD/TPF

Table 1. Porosity and Permeability Data from Preliminary Laboratory Tests on Marker Bed 139 Cores

Lab	Sample Number	Sample Bulk Volume (cc)	Total Porosity (%)	Effective Porosity (%)	Klinkenberg- Corrected Gas Permeability (m^2) Under Net Hydrostatic Confining Stress (MPa)	Liquid Permeability (m^2) Under Net Hydrostatic Confining Stress (MPa)
R/S	P3X11-5-2-SP1T	12.62	2.8		3.2×10^{-18} (2 Mpa) 1.7×10^{-18} (6 Mpa) 1.4×10^{-18} (10 Mpa)	
R/S	P3X11-5-3-SP3T	14.97	2.2		1.6×10^{-17} (2 Mpa) 8.9×10^{-18} (6 Mpa) 5.1×10^{-18} (10Mpa)	
R/S	P3X10-6-SP2T	14.59				
TT	E1X08-A	822.24		1.87	8.4×10^{-18} (2 Mpa) 5.8×10^{-18} (6 Mpa) 5.1×10^{-18} (10Mpa)	6.8×10^{-18} (2 Mpa) 5.8×10^{-18} (6 Mpa) 5.4×10^{-18} (10Mpa)
TT	E1X08-B	776.83		0.49	1.3×10^{-17} (2 Mpa) 7.5×10^{-18} (6 Mpa) 4.7×10^{-18} (10Mpa)	
TT	E1X08-C	819.62		1.01	4.6×10^{-18} (2 Mpa) 2.6×10^{-18} (6 Mpa) 2.0×10^{-18} (10Mpa)	3.7×10^{-18} (2 Mpa) 2.4×10^{-18} (6 Mpa) 1.8×10^{-18} (10Mpa)
TT	E1X08-EP1	83.47	1.4	1.29		
TT	E1X08-EP2	84.39	0.6	0.75		
TT	E1X08-EP3	83.54	0.4	0.42		
TT	E1X08-EP4	83.35	1.6	1.60		
TT	E1X07-D	803.84		0.73	1.5×10^{-19} (2 Mpa) 6.0×10^{-20} (6 Mpa) 5.5×10^{-20} (10Mpa)	
TT	E1X07-E	843.08		1.55	8.4×10^{-16} (2 Mpa) 3.1×10^{-16} (6 Mpa) 1.6×10^{-16} (10Mpa)	

Lab	Sample Number	Sample Bulk Volume (cc)	Total Porosity (%)	Effective Porosity (%)	Gas Permeability (m^2) Under Net Hydrostatic Confining Stress (Klinkenberg Corrected)	Liquid Permeability (m^2) Under Net Hydrostatic Confining Stress
TT	E1X07-F	815.25		1.00	1.1×10^{-18} (2 Mpa) 7.0×10^{-19} (6 Mpa) 5.8×10^{-19} (10Mpa)	1.1×10^{-18} (2 Mpa) 6.2×10^{-19} (6 Mpa) 5.2×10^{-19} (10Mpa)
TT	E1X07-EP5	84.85		1.92		
TT	E1X07-EP6	84.04		2.73		
TT	E1X07-EP7	83.73		0.55		
TT	E1X07-EP8	84.52		1.57		
Total Number of Data Points			6	14	8 at each Confining Stress	3 at each Confining Stress
Range of Data			0.4 to 2.8%	0.42 to 2.73%	2 MPa: 1.5×10^{-19} - 8.4×10^{-16} 6 MPa: 6.0×10^{-20} - 3.1×10^{-16} 10MPa: 5.5×10^{-20} - 1.6×10^{-16}	2 MPa: 1.1×10^{-18} - 6.8×10^{-18} 6 MPa: 6.2×10^{-19} - 5.8×10^{-18} 10MPa: 5.2×10^{-19} - 5.4×10^{-18}
Mean			1.5%	1.25%	6.6×10^{-18} (2 Mpa) 3.5×10^{-18} (6 Mpa) 2.5×10^{-18} (10Mpa)	3.0×10^{-18} (2 Mpa) 2.0×10^{-18} (6 Mpa) 1.7×10^{-18} (10Mpa)

R/S = RE/SPEC laboratory, Rapid City, South Dakota
TT = TerraTek laboratory, Salt Lake City, Utah

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: June 29, 1994

to: Rick Beauheim/SNL

from: Paul S. Domski/INTERA Inc. PSD

subject: Room Q Pore Pressure Borehole Formation Parameter Estimates

Attached are two tables which contain the final formation parameter estimates based on data collected from 1989 to 1992 in the Room Q pore pressure boreholes. I've included parameter estimates from the period before mining (Table 1), as well as for the period following mining (Table 2). The test-zone geology for QPP12 - QPP15 was based on video log information provided to me by Fred Holzmer of INTERA Inc., the geology of the other boreholes was based on a cross section provided to me by Bob Jones of Tech Reps on 16 February 1994. Call me if you have any questions.

Table 1

ESTIMATED FORMATION PARAMETERS FOR THE PORE PRESSURE BOREHOLES SURROUNDING ROOM Q
FOR THE PERIOD BEFORE MINING

Borehole	Geology	Contributing Thickness (m)	PRE-MINING T(m2/s)	kh(m3)	K(m/s)	k(m2)	Ss(1/m)	S(-)	Pi(MPa)
QPP01	MB138,AH2,H6	0.19	NA	NA	NA	NA	NA	NA	NA
QPP02	MU 12 & 13		NA	NA	NA	NA	NA	NA	NA
QPP03	ANHY B, MU9	0.06	2.7E-14	4.7E-21	4.5E-13	7.8E-20	1.0E-06	6.0E-08	12.4
QPP04	MU 6 & 7		NA	NA	NA	NA	NA	NA	NA
QPP05	MU 6	0.90	1.8E-16	3.2E-23	2.0E-16	3.6E-23	4.0E-07	3.6E-07	6.5
QPP11	H1	0.70	2.1E-15	3.7E-22	3.0E-15	5.3E-22	3.9E-06	2.7E-06	5.5
QPP12	H3	0.85	1.3E-15	2.3E-22	1.5E-15	2.7E-22	2.5E-06	2.1E-06	9.6
QPP13	MB139, Clay E, H4	0.15	NA	NA	NA	NA	NA	NA	NA
QPP14	PH4, MB139	0.85	1.0E-16	1.8E-23	1.2E-16	2.1E-23	1.0E-06	8.5E-07	8.0
QPP15	MU 0, PH4	0.90	5.4E-17	9.5E-24	6.0E-17	1.1E-23	2.8E-08	2.5E-08	7.5
QPP21	MU 2 & 3	1.36	6.8E-16	1.2E-22	5.0E-16	8.8E-23	2.0E-06	2.7E-06	3.9
QPP22	MU 3	0.85	NA	NA	NA	NA	NA	NA	NA
QPP23	MU 3	0.90	NA	NA	NA	NA	NA	NA	NA
QPP24	MU 1 & 2		NA	NA	NA	NA	NA	NA	NA
QPP25	MU 2 & 3	0.90	NA	NA	NA	NA	NA	NA	NA

Table 2

ESTIMATED FORMATION PARAMETERS FOR THE PORE PRESSURE BOREHOLES SURROUNDING ROOM Q
FOR THE PERIOD FOLLOWING MINING

Borehole	Geology	Contributing Thickness (m)	POST-MINING T(m2/s)	kh(m3)	K(m/s)	k(m2)	Ss(1/m)	S(-)	Pi(MPa)
QPP01	MB138,AH2,H6	0.19	1.1E-13	1.6E-20	5.8E-13	8.4E-20	4.0E-06	7.6E-07	10.4
QPP02	MU 12 & 13		NA	NA	NA	NA	NA	NA	NA
QPP03	ANHY B, MU9	0.06	2.7E-14	4.7E-21	4.5E-13	7.8E-20	1.0E-06	6.0E-08	6.9
QPP04	MU 6 & 7		NA	NA	NA	NA	NA	NA	NA
QPP05	MU 6	0.90	2.7E-13	3.7E-20	3.0E-13	4.1E-20	8.0E-06	7.2E-06	0.3
QPP11	H1	0.70	NA	NA	NA	NA	NA	NA	7.4
QPP12	H3	0.85	1.3E-15	2.3E-22	1.5E-15	2.7E-22	2.5E-06	2.1E-06	9.6
QPP13	MB139, Clay E, H4	0.15	6.4E-14	1.1E-20	4.3E-13	7.3E-20	4.0E-07	6.0E-08	8.1
QPP14	PH4, MB139	0.85	9.4E-17	1.7E-23	1.1E-16	2.0E-23	1.3E-06	1.1E-06	8.0
QPP15	MU 0, PH4	0.90	1.6E-15	2.8E-22	1.8E-15	3.1E-22	2.8E-08	2.5E-08	3.1
QPP21	MU 2 & 3	1.36	1.2E-14	2.1E-21	8.8E-15	1.5E-21	1.0E-06	1.4E-06	5.0
QPP22	MU 3	0.85	6.4E-15	1.1E-21	7.5E-15	1.3E-21	3.1E-06	2.6E-06	3.2
QPP23	MU 3	0.90	6.3E-14	1.1E-20	7.0E-14	1.2E-20	1.0E-08	9.0E-09	3.5
QPP24	MU 1 & 2		NA	NA	NA	NA	NA	NA	NA
QPP25	MU 2 & 3	0.90	3.6E-14	6.3E-21	4.0E-14	7.0E-21	1.0E-06	9.0E-07	2.2

Parameter Sheets
Parameter Name: Salado Halite Permeability

Parameter Description:

Permeability of halite and polyhalite within the Salado Formation. Log permeability values given (dimensionless): permeability has units of square meters.

Regulatory Driver(s):

40 CFR Part 191

191.13(a) Disposal systems . . . shall be designed to provide reasonable expectation, based on performance assessments, that the cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall . . .

40 CFR 191.15[a] Disposal systems for waste and any associated radioactive material shall be designed to provide a reasonable expectation that, for 10,000 years after disposal, undisturbed performance of the disosal system shall not cause the annual committed effective dose, received through all potential pathways from the disposal system, to any member of the public in the accessible environment, to exceed 15 millirems (150 microsieverts).

(a) The standards were formulated . . . because the properties of the geologic media around a mined repository are expected to provide much of the disposal system's capability to isolate these wastes over these long time periods. (Preamble, 50 FR 30871b)

(b) When predicting disposal system performance, the agency assumes that reasonable projections of the protection expected from all of the engineered and natural barriers of a disposal system will be considered. (Appendix C)

Computational Code(s):

Parameter Name: SALPERM
Code: BRAGFLO

Model Input Data Values:		
Median:	**Range:**	**Units:**
Log Uniform Distribution Used	10^{-24} to 10^{-20}	log permeability (m^2)

Parameter Sensitivity: Not Determined

Data:
Raw Data

Beauheim et al (1993), Domski (1994) [attached], Jensen et al (1993), Saulnier et al (1991), and Stensrud et al (1992).

Point Data:

Hydraulic testing in the Salado halite-rich sections provided quantitative estimates of the hydraulic properties controlling brine flow through the Salado Formation. The tests are interpreted using models based on potentiometric flow (Beauheim et al., 1991; 1993). Thetest influence rock as far as 10 meters distant from the test zone and are not thought to significantly alter the pre-test conditions of the rock. The stratigraphic intervals tested include both pure and impure halite. Because tests close to the repository are within the DRZ, it is reasonable to use the results of the tests farthest from the repository as most representative of undisturbed conditions.

Parameter Sheets
Parameter Name: Salado Halite Permeability

Point Data: continued

Twenty-two hydraulic tests have been performed in impure halite, and two in pure halite. Interpreted permeabilities using a Darcy-flow model range from 1×10^{-23} to 4×10^{-18} m^2 for impure halite intervals. IInterpreted formation pore pressures range from 0.3 to 9.7 MPa for impure halite. Tests in pure halite show no observable response, indicating either extremely low permeability ($<10^{-23}$ m^2), or not flow whatsoever, even though appreciable pressures are applied to the test interval. Table 1 contains a summary of the results of field permeability tests to date.

Table 1. Summary of Test-Interpretation Results from In Situ Permeability and Pore Pressure Tests. [attached]

Model Input Data:

Table 2. Salado Halite Parameter Value. [attached]

Discussion:

A single porous media with spatially-constant properties is used in performance assessment to represent the various intact, halite-rich layers present in the Salado Formation, and anhydrite interbeds contained within those layers that are not explicitly represented. A comparison has been made between the simplified stratigraphy used in performance assessment and a more detailed stratigraphy amenable in a more complex model; this comparison confirmed that the performance assessment stratigraphic representation is reasonable. This comparison will be available for the final application. The two phase properties of the halite have not been measured. A wide range of possible two-phase properties is incorporated by sampling between two sets of multiphase equations, and by sampling on parameters within the different equations. Due to small pore size, the halite-rich units are expected to ıve threshold pressure high enough that waste-generated gas will not penetrate, and halite threshold pressure has accordingly been set arbitrarily high to prevent gas penetration. This assumption eenhances gas migration in anhydrite interbeds.

References:

Beauheim, R.L., G.J. Saulnier, Jr., and J.D. Avis. 1991. *Interpretation of Brine-Permeability Tests of the Salado Formation at the Waste Isolation Pilot Plant Site: First Interim Report.* SAND90-0083. Albuquerque, NM: Sandia National Laboratories.

Beauheim, R.L., R.M. Roberts, T.F. Dale, M.D. Port, and W.A. Stensrud. 1993. *Hydraulic Testing of Salado Formation Evaporites at eh Waste Isolation Pilot Plant Site: Second Interpretive Report.* SAND92-0533. Albuquerque, NM: Sandia National Laboratories.

Domski (1994) (attached)

Jensen, A.L., C.I., Howard, R.L. Jones, and T.P. Peterson. 1993. *Room Q Data Report: Test Borehole Data from April 1989 through November 1991.* SAND92-1172. Albuquerque, NM: Sandia National Laboratories.

Saulnier, Jr., G.J., P.S. Domski, J.B. Palmer, R.M. Roberts, and W.A. Stensrud. 1991. *WIPP Salado Hydrology Program Data Report #1.* SAND90-7000. Albuquerque, NM: Sandia National Laboratories.

Stensrud, W.A., T.P. Dale, P.S. Domski, J.B. Palmer, R.M. Roberts, M.D. Port, and G.J. Saulnier, Jr. 1992. *Waste Isolation Pilot Plant Salado Hydrology Program Data Report #2.* SAND92-7072. Albuquerque, NM: ndia National Laboratories.

Table 1. Summary of Test-Interpretations Results from In Situ Permeability and Pore Pressure Tests

TEST INTERNAL (METERS FROM EXCAVATION)	HOLE	ZONE	MAP UNIT	TEST	ANALYSIS METHOD	AVERAGE PERMEAB-ILITY K (m^2)	FOR-MATION PORE PRESS-URE Pr (MPa)	DATA REF.	INTERPRE-TATION REFERENCE
8.63-10.06	L4P51-B	test	anhydrite "c"	PB	Interpret/2	5.1×10^{-20}	5.17	a	b
				all	GTFM	6.4×10^{-20}	5.21	a	b
6.75-7.79		guard	H-2	SI	-	-	>3.25	a	b
4.14-5.56	L4P52-A	test	anhydrite "a"	PB	Interpret/2	6.4×10^{-20}	6.50	a	b
				all	GTFM	6.0×10^{-20}	6.75	a	b
2.27-3.32		guard	anhydrite "b"	SI	-	-	>3.25	a	b
8.70-10.15	S1P71-B	test	anhydrite "c"	all	GTFM	8.0×10^{-20}	5.12	a	b
6.82-7.87		guard	H-2	SI	-	-	>4.2	a	b
2.15-3.18	S1P72-A	guard	0, PH-4	all	GTFM	1.8×10^{-21}	4.08	a	b
3.38-4.80	S1P73-A	test	anhydrite "a"	SI	-	-	0	a	b
0.85-2.49		guard	anhydrite "b"	SI	-	-	0	a	b
9.92-11.32	S1P73-B	test	MB138	PW2	type curve	4.9×10^{-20}	-	a	b
				CPW	type curve	1.8×10^{-20}	-	a	b
				PB	Interpret/2	4.9×10^{-20}	4.29	a	b
				all	GTFM	4.9×10^{-20}	4.37	a	b
8.04-9.09		guard	AH-1	SI	Horner	-	2.55	a	b
10.68-15.39	SCP01-A	test	MB139	CPW2	type curve	5.8×10^{-20}	-	a	b
				PB2	Interpret/2	5.1×10^{-20}	12.40	a	b
				all	GTFM	7.1×10^{-20}	12.55	a	b
2.09-5.58	C2H01-A	test	0-5	all	GTFM	9.1×10^{-19}	0.54	c	d
		test	4-5	all	GTFM	3.5×10^{-18}	0.56	c	d
4.50-5.58	C2H01-B	test	0	all	GTFM	6.9×10^{-21}	3.22	c	d
2.92-4.02		guard	0-4		GTFM	2.5×10^{-21}	4.17	c	d
6.63-8.97	C2H01-C	test	MB139	all	GTFM	1.2×10^{-18}	8.16	c	d
9.47-10.86	C2H02	test	MB139	all	GTFM	1.0×10^{-19}	9.43	c	d
7.76-9.14	C2H03	test	9	all	GTFM	$<10^{-21}$	?	c	d
3.33-4.75	L4P51-A	test	PH-3, clay D	all	GTFM	7.9×10^{-21}	2.81	c	d
3.74-5.17	SOP01	test	PH-3, clay D	all	GTFM	1.1×10^{-20}	4.52	c	d
1.86-2.91		guard	MB139	all	GTFM	7.4×10^{-18}	0.56	c	d
3.12-4.56	S1P71-A	test	PH-3, clay D	all	GTFM	7.0×10^{-20}	3.01	c	d
24.49-26.37 (12.3)***	QPPO1	test	MB138	all	GTFM	$8.4\times10^{-20**}$	10.4**	e	f
23.20-24.05 (6.2)	QPPO2	test	12-13	all	-	?	?	e	f
22.45-23.35	QPPO3	test	anhydrite "b"	all	GTFM	$7.8\times10^{-20*}$	12.4*	e	f
(2.9)		test	anhydrite "b"	all	GTFM	$7.8\times10^{-20**}$	6.9**	e	f

23.69-24.54 (1.9)	QPPO4	test	6-7	all	-	?	?	e	f
22.08-22.98	QPPO5	test	6	all	GTFM	$3.6x10^{-23*}$	6.5*	e	f
(0.8)		test	6	all	GTFM	$4.1x10^{-20**}$	0.3**	e	f
25.29-26.64	QPP11	test	H1	all	GTFM	$5.3x10^{-22*}$	5.5*	e	f
(12.3)		test	H1	-	-	-	7.4**	e	f
23.35-24.20	QPP12	test	H3	all	GTFM	$2.7x10^{-22*}$	9.6*	e	f
(6.2)		test	H3	all	GTFM	$2.7x10^{-22*}$	9.6**	e	f
22.54-23.44 (3.3)	QPP13	test	MB139	all	GTFM	$7.3x10^{-20**}$	8.1**	e	f
22.35-23.20	QPP14	test	MB139	all	GTFM	$2.1x10^{-23*}$	8.0*	e	f
(2.1)		test	MB139	all	GTFM	$2.0x10^{-23**}$	8.0**	e	f
22.14-23.04	QPP15	test	O-PH4	all	GTFM	$1.1x10^{-23*}$	7.5*	e	f
(1.0)		test	O-PH4	all	GTFM	$3.1x10^{-22**}$	3.1**	e	f
23.18-24.54 (12.0)	QPP21	test	2-3	all	GTFM	$8.8x10^{-23*}$	3.9*	e	f
		test	2-3	all	GTFM	$1.5x10^{-21**}$	5.0**	e	f
22.25-23.10 (5.9)	QPP22	test	3	all	GTFM	$1.3x10^{-21**}$	3.2**	e	f
21.99-22.89 (3.0)	QPP23	test	3	all	GTFM	$1.2x10^{-20**}$	3.5**	e	f
22.01-22.86 (1.6)	QPP24	test	1-2	-	-	?	?	e	f
21.96-22.86 (1.0)	QPP25	test	2-3	all	GTFM	$7.0x10^{-21**}$	2.2**	e	f

Key: PB = Pressure-buildup test
SI = shut-in pressure buildup
PW = pulse-withdrawal test
CPW = constant-pressure withdrawal test
* = before mining of Room Q
** = after mining of Room Q
a = Stensrud, W.A., T.F. Dale, P.S. Domski, J.B. Palmer, R.M. Roberts, M.D. Fort, G.J. Saulnier, Jr., and A.L. Jensen. 1992. *Waste Isolation Pilot Plant Salado Hydrology Program Data Report #2.* SAND92-7072. Albuquerque, NM: Sandia National Laboratories.
b = Beauheim, R.L., R.M. Roberts, T.F. Dale, M.D. Fort, and W.A. Stensrud. 1993. *Hydraulic Testing of Salado Formation Evaporites at the Waste Isolation Pilot Plant Site: Second Interpretive Report.* SAND92-0533. Albuquerque, NM; Sandia National Laboratories.
c = Saulnier, G.J., Jr., P.S. Domski, J.B. Palmer, R.M. Roberts, W.A. Stensrud, and A.L. Jensen. 1991. *WIPP Salado Hydrology Program Data Report #1.* SAND90-7000. Albuquerque, NM: Sandia National Laboratories.
d = Beauheim, R.L., G.J. Saulnier, Jr., and J.D. Avis. 1991. *Interpretation of Brine-Permeability Tests of the Salado Formation at the Watste Isolation Pilot Plant Site: First Interim Report.* SAND90-0083. Albuquerque, NM: Sandia National Laboratories.
e = Jensen, A.L., C.L. Howard, R.L. Jones. and T.P. Peterson. 1993. *Room Q Data Report: Test Borehole Data from April 1989 through November 1991.* SAND92-1172. Albuquerque, NM: Sandia National Laboratories.
f = Domski, June 29, 1994. Memo
*** = Approximate post-mining distance from Room Q to test interval.

Table 2. Salado Halite Parameter Values

Parameter	Maximum	Minimum	Median or Constant*
permeability, (m^2)	10^{-20}	10^{-24}	--**
porosity, (%)	3	0.1	1.5
specific storage (1/m)	10^{-5}	10^{-7}	10^{-6}
two-phase			
Brooks/Corey	—	—	2/3
P_t			50 MPa
S_{br}			0.3
S_{gr}	0.6	0	0.2
λ	0.4	0	5.1
van	10.0	0.2	1/3
Genuchten/Parker	—	—	
S_{br}			0.3
S_{gr}	0.6	0	0.2
m	0.4	0	0.836
	0.91	0.17	

* Parameters with no maximum and minimum values are treated as constants in the PA.

** A log uniform distribution between the maximum and minimum values was used.

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: June 29, 1994

to: Rick Beauheim/SNL

from: Paul S. Domski/INTERA Inc. PSD

subject: Room Q Pore Pressure Borehole Formation Parameter Estimates

Attached are two tables which contain the final formation parameter estimates based on data collected from 1989 to 1992 in the Room Q pore pressure boreholes. I've included parameter estimates from the period before mining (Table 1), as well as for the period following mining (Table 2). The test-zone geology for QPP12 - QPP15 was based on video log information provided to me by Fred Holzmer of INTERA Inc., the geology of the other boreholes was based on a cross section provided to me by Bob Jones of Tech Reps on 16 February 1994. Call me if you have any questions.

Table 1

ESTIMATED FORMATION PARAMETERS FOR THE PORE PRESSURE BOREHOLES SURROUNDING ROOM Q
FOR THE PERIOD BEFORE MINING

Borehole	Geology	Contributing Thickness (m)	PRE-MINING T(m2/s)	kh(m3)	K(m/s)	k(m2)	Ss(1/m)	S(-)	Pi(MPa)
QPP01	MB138,AH2,H6	0.19	NA	NA	NA	NA	NA	NA	NA
QPP02	MU 12 & 13		NA	NA	NA	NA	NA	NA	NA
QPP03	ANHY B, MU9	0.06	2.7E-14	4.7E-21	4.5E-13	7.8E-20	1.0E-06	6.0E-08	12.4
QPP04	MU 6 & 7		NA	NA	NA	NA	NA	NA	NA
QPP05	MU 6	0.90	1.8E-16	3.2E-23	2.0E-16	3.6E-23	4.0E-07	3.6E-07	6.5
QPP11	H1	0.70	2.1E-15	3.7E-22	3.0E-15	5.3E-22	3.9E-06	2.7E-06	5.5
QPP12	H3	0.85	1.3E-15	2.3E-22	1.5E-15	2.7E-22	2.5E-06	2.1E-06	9.6
QPP13	MB139, Clay E, H4	0.15	NA	NA	NA	NA	NA	NA	NA
QPP14	PH4, MB139	0.85	1.0E-16	1.8E-23	1.2E-16	2.1E-23	1.0E-06	8.5E-07	8.0
QPP15	MU 0, PH4	0.90	5.4E-17	9.5E-24	6.0E-17	1.1E-23	2.8E-08	2.5E-08	7.5
QPP21	MU 2 & 3	1.36	6.8E-16	1.2E-22	5.0E-16	8.8E-23	2.0E-06	2.7E-06	3.9
QPP22	MU 3	0.85	NA	NA	NA	NA	NA	NA	NA
QPP23	MU 3	0.90	NA	NA	NA	NA	NA	NA	NA
QPP24	MU 1 & 2		NA	NA	NA	NA	NA	NA	NA
QPP25	MU 2 & 3	0.90	NA	NA	NA	NA	NA	NA	NA

Table 2

ESTIMATED FORMATION PARAMETERS FOR THE PORE PRESSURE BOREHOLES SURROUNDING ROOM Q
FOR THE PERIOD FOLLOWING MINING

Borehole	Geology	Contributing Thickness (m)	POST-MINING T(m2/s)	kh(m3)	K(m/s)	k(m2)	Ss(1/m)	S(-)	Pi(MPa)
QPP01	MB138,AH2,H6	0.19	1.1E-13	1.6E-20	5.8E-13	8.4E-20	4.0E-06	7.6E-07	10.4
QPP02	MU 12 & 13		NA	NA	NA	NA	NA	NA	NA
QPP03	ANHY B, MU9	0.06	2.7E-14	4.7E-21	4.5E-13	7.8E-20	1.0E-06	6.0E-08	6.9
QPP04	MU 6 & 7		NA	NA	NA	NA	NA	NA	NA
QPP05	MU 6	0.90	2.7E-13	3.7E-20	3.0E-13	4.1E-20	8.0E-06	7.2E-06	0.3
QPP11	H1	0.70	NA	NA	NA	NA	NA	NA	7.4
QPP12	H3	0.85	1.3E-15	2.3E-22	1.5E-15	2.7E-22	2.5E-06	2.1E-06	9.6
QPP13	MB139, Clay E, H4	0.15	6.4E-14	1.1E-20	4.3E-13	7.3E-20	4.0E-07	6.0E-08	8.1
QPP14	PH4, MB139	0.85	9.4E-17	1.7E-23	1.1E-16	2.0E-23	1.3E-06	1.1E-06	8.0
QPP15	MU 0, PH4	0.90	1.6E-15	2.8E-22	1.8E-15	3.1E-22	2.8E-08	2.5E-08	3.1
QPP21	MU 2 & 3	1.36	1.2E-14	2.1E-21	8.8E-15	1.5E-21	1.0E-06	1.4E-06	5.0
QPP22	MU 3	0.85	6.4E-15	1.1E-21	7.5E-15	1.3E-21	3.1E-06	2.6E-06	3.2
QPP23	MU 3	0.90	6.3E-14	1.1E-20	7.0E-14	1.2E-20	1.0E-08	9.0E-09	3.5
QPP24	MU 1 & 2		NA	NA	NA	NA	NA	NA	NA
QPP25	MU 2 & 3	0.90	3.6E-14	6.3E-21	4.0E-14	7.0E-21	1.0E-06	9.0E-07	2.2

Parameter Sheets
Parameter Name: Magenta Permeability

Parameter Description:

Magenta Permeability

Regulatory Driver(s):

40 CFR Part 191

191.13(a) Disposal systems . . . shall be designed to provide reasonable expectation, based on performance assessments, that the cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall . . .

(a) The standards were formulated . . . because the properties of the geologic media around a mined repository are expected to provide much of the disposal system's capability to isolate these wastes over these long time periods. (Preamble, 50 FR 30871b)

(b) When predicting disposal system performance, the agency assumes that reasonable projections of the protection expected from all of the engineered and natural barriers of a disposal system will be considered. (Appendix C)

Computational Code(s):

Parameter Name:
Code:

Model Input Data Values:		
Median:	**Range:**	**Units:**
1.1×10^{-16}	Constant	m^2

Parameter Sensitivity:

Not Determined

Data:

Raw Data

Beauheim (1986), Beauheim (1987), Beauheim et al (1991), Mercer (1983)

Point Data

Hydraulic tests have been performed on the Magenta at 16 locations and are reported in Mercer, (1983), Beauheim (1987a), and Beauheim et al. (1991). The transmissivity values obtained from these tests are shown in Table 1. Hydraulic head measurements are in Table 2. Most of the transmissivity values are less than or equal to 0.1 ft^2/day. Higher values of transmissivity, 0.3 and 1.0 ft^2/day, found at H-6a and H-9a, respectively. No halite is present in the Rustler at either of these two locations. The two highest values of Magenta transmissivity, 375 and 53 ft^2/day, are found in Nash Draw at WIPP-25 and WIPP-27, respectively, where dissolution of the upper Salado has caused collapse and fracturing of the overlying Rustler. Mercer (1983) noted that the transmissivity of the Magenta at WIPP-25 may have been overestimated because of possible leakage from the Culebra along fractures during hydraulic testing.

Parameter Sheets
Parameter Name: Magenta Permeability

Point Data: continued

Table 1. Summary of Transmissivity Data for the Magenta Dolomite Member of the Rustler Formation. [attached]

Table 2. Hydraulic-Head Information for the Magenta Dolomite Member of the Rustler Formation. [attached]

Model Input; Data:

Table 3. Model parameter values for the Magenta Member of the Rustler [attached]

Discussion:

The Magenta of the Rustler is a fine-grained dolomite that ranges in thickness from 4 to 8 meters (from 13 to 26 feet) and is about 6 meters (19 feet) thick at the WIPP. The Magenta is saturated except near outcrops along Nash Draw, and hydraulic data are available from 15 wells. According to Mercer, transmissivity ranges over five orders of magnitude from $1x10^{-9}$ to $4x10^{-4}$ square meters per second ($1.3x10^{-6}$ square feet per day).

The hydraulic transmissivities of the Magenta, based on sparse data, shows a decrease in conductivity from west to east, with slight indentations of the contours north to south of the WIPP that correspond to the topographic expression of Nash Draw. In most locations, the hydraulic conductivity of the Magenta is one to two orders of magnitude less than that of the Culebra.

No porosity measurements have been made on the Magenta. Beauheim (1987, pp. 111, 115) assumed a porosity representative of dolomite of 0.20 for the interpretations of well tests. The hydrologic gradient across the site varies from 16 to 20 feet per mile (3 to 4 meters per kilometer) on the eastern side, steepening to about 32 feet per mile (6 meters per kilometer) along the western side near Nash Draw.

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Richey, S.F. 1987. *Water-Level Data from Wells in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico.* United States Geological Survey Open-File Report 87-120. Albuquerque, NM: United States Geological Survey

Table 1. Summary of Transmissivity Data for the Magenta Dolomite Member of the Rustler Formation.

WELL	MAGENTA DEPTH INTERVAL (ft)[a]	TRANSMISSIVITY (ft^2/day)[a]	COMMENTS
DOE-2	699-722[b]	$1x10^{-3}$[c]	
H-1	563-589	$5x10^{-2}$	
H-2a	515-543	$1x10^{-2}$	
H-2b1	515-540[d]	$2.4x10^{-3}$[d]	
H-3b1	559-584	1x10-1 $1.6x10^{-1}$[d]	
H-4a	375-400	$6x10^{-2}$	
H-5a	783-810	$1x10^{-1}$	
H-6a	492-511	$3x10^{-1}$	
H-8a	466-488	$6x10^{-3}$	
H-9a	523-554	$1x10^{0}$	
H-10a	1256-1280	$1x10^{-2}$	
H-14	424-448[e]	$6x10^{-3}$[e]	
H-16	590-616[e]	$3x10^{-2}$[e]	
WIPP-25	302-328	$3.75x10^{2}$	
WIPP-27	176-194	$5.3x10^{1}$	
WIPP-28	285-310	Low	Testing Unsuccessful
WIPP-30	513-537	$4x10^{-3}$	

[a]Data from Mercer (1983) except as noted
[b]Data from Mercer et al. (1987)
[c]Data from Beauheim (1986)
[d]Data from Beauheim et al. (1991)
[e]Data from Beauheim (1987a)

Table 2. Hydraulic-Head Information for the Magenta Dolomite Member of the Rustler Formation.

WELL	GROUND-SURFACE ELEVATION (ft amsl)[a]	STABILIZED DEPTH TO WATER (ft)[b]	DATE OF WATER-LEVEL MEASUREMENT	DEPTH TO MIDDLE OF MAGENTA (ft)[c]	BOREHOLE-FLUID DENSITY (g/cm^3) ($\pm$0.01)[c]	FRESHWATER-HEAD ELEVATION (with measured variation) (ft amsl)	MIDDLE OF MAGENTA PRESSURE (with measured variation) (psi)
DOE-2	3418	>>310[d]	10/84	711[e]	1.18[e,f]	<<3180$\pm$8	<<205.0$\pm$3.5
H-1	3398	247	2-3/79	576	1.021	3158$\pm$3	145.6$\pm$1.4
H-2a	3378	229	7-9/1	529	1.012	3152$\pm$3	131.6$\pm$1.3
H-3b1	3389	240	'78-'79	572	1.01	3153$\pm$3	145.3$\pm$1.4
H-4a	3333	189	'79-'80	388	1.017	3147$\pm$2	87.7$\pm$0.9
H-5a	3506	344	'78-'80	797	1.008	3164$\pm$5	197.9$\pm$2.0
H-6a	3347	291	'78-'80	502	1.007	3058$\pm$2	82.1$\pm$0.9
H-8a	3433	405	'80-'84	477	2.008[g]	3029$\pm$1	31.4$\pm$0.3
H-9a	3406	282	'80-'83	539	1.008[g]	3125$\pm$3	112.0$\pm$1.1
H-10a	3687	587	'80-'82	1268	1.171[f,g]	3216$\pm$14	345.6$\pm$5.9
H-14	3346	>221[h]	10/86	436[i]	1.2[i]	<3168$\pm$4	<111.8$\pm$1.9
H-16	3410	<344[j,k]	11/87	603[i]	1.2[i]	>3117$\pm$1[j]	>134.5$\pm$0.6
WIPP-25	3212	158	'80-'84	315	1.01	3056$\pm$2	68.7$\pm$0.7
WIPP-27	3177	103	'81-'82	185	1.095[f]	3082$\pm$2	38.9$\pm$0.7
WIPP-28	3347	202	'81-'82	298	1.048[f]	3149$\pm$2	43.6$\pm$0.8
WIPP-30	3428	303	'82-'83	525	1.01[l]	3127$\pm$2	97.2$\pm$1.0

[a] Data from Gonzales (1989)
[b] Data from Richey (1987b; OFR 87-120) except as noted
[c] Data from Mercer (1983) except as noted
[d] Converted from pressure data presented in Beauheim (1985)
[e] Data from Beauheim (1986)
[f] Uncertainty = $\pm$0.02
[g] Data from Richey (1986)
[h] Converted from pressure data presented in Beauheim (1987a)
[i] Data from Beauheim (1987a)
[j] Lowered by drainage into WIPP shafts
[k] Converted from pressure data presented in Stensrud et al. (1988)
[l] Data from Lambert and Robinson (1984)

Table 3. Model Parameter Values for the Magenta Member of the Rustler

Parameter	Maximum	Minimum	Constant*
permeability (m^2)	--	--	1.1×10^{-16}
porosity (%)	--	--	9
pore compressibility (1/Pa)	--	--	2.2×10^{-9}
two phase flow Brooks/Corey P_t, Pa S_{br} S_{gr} λ	--	--	 1.0 1.86×10^5 0.2 0.2 0.7
thickness (m)	--	--	8.5
initial pressure (Pa)	--	--	9×10^5

* Parameters without maximum and minimum values are treated as constants in PA.

Parameter Sheets
Parameter Name: Index for Culebra Transmissivity Fields

Parameter Description:

The index for the transmissivity fields is a random variable between 0 and 1 that is mapped onto the generated transmissivity fields to select the realization to be used in the PA calculations.

Regulatory Driver(s):

40 CFR Part 191

191.13(a) Disposal systems . . . shall be designed to provide reasonable expectation, based on performance assessments, that the cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall . . .

(a) The standards were formulated . . . because the properties of the geologic media around a mined repository are expected to provide much of the disposal system's capability to isolate these wastes over these long time periods. (Preamble, 50 FR 30871b)

(b) When predicting disposal system performance, the agency assumes that reasonable projections of the protection expected from all of the engineered and natural barriers of a disposal system will be considered. (Appendix C)

Computational Code(s):

Parameter Name: CULTRFLD
Code: SECO2D

Model Input Data Values:		
Median:	**Range:**	**Units:**
An unconditional simulation generates a random Culebra transmissivity field that has the same spatial correlation structure as measured transmissivities, but does not necessarily match measured transmissivities at the location of their measurements.	An unconditional simulation generates a random Culebra transmissivity field that has the same spatial correlation structure as measured transmissivities, but does not necessarily match measured transmissivities at the location of their measurements.	Dimensionless

Parameter Sensitivity: Not Determined

Parameter Sheets
Parameter Name: Index for Culebra Transmissivity Fields

Data:
Raw Data

Mercer (1983) reported values for Culebra transmissivity at 20 locations. Beauheim (1987a) provided values for Culebra transmissivity at 15 new locations, and new estimates at seven locations for which values had previously been reported. Combined with testing performed for Project Gnome and other recent work performed at DOE-2 , H-3, H-11, WIPP-13, AEC-7, and D-268, the Culebra has been tested at 41 locations in the vicinity of the WIPP (Table 4-4). Figure 4-4 shows these 41 locations and the most-recent transmissivity values at each provided by the reports referenced above, as well as the distribution of halite within the Rustler over the same area. In general, the highest Culebra transmissivities (tens to thousands of ft^2/day) are found in areas where no halite is present in the Rustler, and the lowest transmissivity ($\leq$ 0.004 ft^2/day) is found at P-18 where halite is present in all three non-dolomite Rustler members. At the two wells (H-12 and H-17) where halite is absent from the Forty-niner but present in the Tamarisk and unnamed member, the transmissivity of the Culebra is about 0.2 ft^2/day. Where halite is present only in the unnamed lower member, Culebra transmissivity ranges from 0.07 to 89 ft^2/day.

Parameter Sheets
Parameter Name: Index for Culebra Transmissivity Fields

Raw Data: continued

Culebra transmissivities of about 1 ft^2/day or greater appear to be related to fracturing. Where the transmissivity of the Culebra is less than 1 ft^2/day, few or no open fractures have been observed in core and the Culebra's hydraulic behavior during pumping or slug tests is that of a single-porosity medium. Where transmissivities are between 1 and at least 100 ft^2/day, numerous open fractures are observed in core and the hydraulic behavior of the Culebra during pumping tests is that of a double-porosity medium. Where the transmissivity of the Culebra is greater than approximately 100 ft^2/day, Culebra core is heavily fractured to the point of brecciation. Double-porosity hydraulic behavior is less apparent in these highly transmissive areas, perhaps because matrix-block size decreases as fracture frequency increases, decreasing the time lag observed between the hydraulic response of the fractures and that of the matrix.

In most of the wells completed to the Culebra, water levels have been measured on a regular basis since the wells were constructed. Culebra water levels at and around the WIPP site have been affected by continuous drainage into WIPP shafts since the construction of the Exploratory Shaft in late 1981, as well as by numerous pumping tests and water-quality sampling exercises conducted since 1980.

Cauffman et al. (1990) performed a thorough review of Culebra water-level data, borehole- and formation-fluid-density data, and WIPP-related hydraulic stresses, and derived estimates of the undisturbed freshwater heads at 35 wells. These estimates are presented in Table 2. The freshwater-head contours indicate a southwesterly flow direction down Nash Draw, a southerly flow direction across the WIPP site, and an area of low gradients with apparent westerly flow south of the WIPP site. Davies (1989) reports that flow directions in this southern area of low hydraulic gradients are difficult to determine because of the effects of variation in water density, and suggested that flow in this area may have a larger easterly, down-dip component than is predicted considering only equivalent freshwater heads.

Point Data:

Table 1. Summary of Transmissivity Data for the Culebra Dolomite Member of the Rustler Formation. [attached]

Table 2 Hydraulic-Head Information for the Culebra Dolomite Member of the Rustler Formation. [attached]

Model Input; Data:

Table 3. Culebra parameter values for the BRAGFLO model. [attached]

Discussion:

The 1990 WIPP Performance Assessment used a simple zonal approach for including uncertainty in the transmissivity (T) field within the Culebra Dolomite Member of the Rustler Formation. The zonal method divides the regional and local computational domains into geographic regions; 8, 13, and 15 regions have been used for different analyses reported in Marietta et al. (1989) and Bertram-Howery et al. (1990). In each region, a distribution was constructed using transmissivity measurements from available wells (Tables 1 and 2). This empirical distribution was sampled and one constant value used for the transmissivity in each zone. Each zone was sampled independently, so a single simulation used 8 (or 13 or 15) transmissivity values to represent the regional T field. Some simulations used distributions constructed from pilot point values (LaVenue et al., 1990) at locations assigned during calibration in addition to actual measurements at well locations.

`iscussion: continued

The early (1990) approach was improved in 1991 in two ways:

- The reason for varying transmissivity over geographic zones is to include spatial variability in the *T* field. Correlations exist in the *T* field over distances greater than five kilometers; thus, assuming that the 8 (or 13 or 15) zones are independent during sampling is only a first approximation. Spatial dependence has been included over the whole model domain.

- The *T* fields generated by the simple zonal approach directly used transmissivity measurements whereas other information was included only indirectly through pilot point values. Many other data are available, and it has been possible to incorporate some of these data directly, e.g., hydraulic head measurements (Table 3) and geologic information.

Transmissivities display a variability in space that can be characterized using measured data, e.g., pump tests, by geostatistical analyses. This spatial variability was found to be stationary in the mean (LaVenue et al., 1990), but intrinsic in the second moment (IRF = 0) with a linear variogram without nugget effect (i.e., locally described by a constant with radom perturbations that increase in variance with distance). Several techniques are available to generate random fields having this spatial structure: turning bands, inversion of the full covariance matrix, and spectral methods. Many such realizations uld be generated and each realization could be used as one input for a system simulation. Each ıealization would then have the correct spatial structure of the true field, and would satisfy the first objective above.

However, these realizations would not be fully coherent with the actual measurements, and would overestimate the uncertainty in the *T* field. Making realizations of random fields coherent with measured information is called "conditioning." For WIPP PA, conditioning can be performed on at least four types of information:

- Measured *T* values at the wells.

- Measured or estimated head values at the wells in pre-excavation steady-state conditions.

- Measured head valued during various transient hydraulic tests (e.g., long-term pump tests, shaft excavation).

- Indirect geologic data that can be correlated with transmissivity (such as overburden thickness, or presence of evaporites in the Culebra or Rustler).

Discussion: continued

Of the half-dozen methods available for conditioning on head data, two have been used to date in WIPP PA work. In 1991, random fields conditioned on *T* measurements at well locations and on values assigned during manual calibration were assigned to pilot point locations where no measurements were available (LaVenue et al., 1990). Forty-one measured-*T* and 41 pilot point values are available. The pilot point values were assigned to insure coherence of the calibrated *T* fields with the measured head data (both steady-state and transient conditions) so conditioning on head data is indirectly included. An advantage of this method is that it does not require any assumption on the acceptable range of variability of *T* (Var(*T*)). Many methods require that the Var (In*T*)>1, and in the Culebra the Var(In*T*) is about 3.5. This first method also allows using a variable-density fluid-flow model which may be important in the Culebra (Davies, 1989). Other methods are linear, but can only accommodate constant-density fluid-flow models. A second advantage is computational efficiency because the Cholesky decomposition only needs to be performed once regardless of the number of simulations.

The approach in 1992 was an extension of the pilot point approach used for the calibration of the Culebra *T* field. This method generates random fields conditioned on *T* measurements, steady-state, and transient head data without restriction on the Var(In*T*) and with variable-density fluid-flow models.

In this method, random *T* fields conditioned only on the measured *T* values are first generated. These fields are further conditioned on the head data by calibrating them with the pilot point approach both on steady-state and transient data. The procedure has been automated to generate a large number of calibrated random fields. Order of pilot point selection and the uniqueness of the resulting *T* field we issues to be examined during operational tests and sensitivity analyses.

References:

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Mercer, J.W. 1983. *Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medanos Area, Southeastern New Mexico.* Water-Resources Investigations Report 83-4016. Albuquerque, NM: U.S. Geological Survey.

Table 1: Summary of Transmissivity Data for the Culebra Dolomite Member of the Rustler Formation

WELL	CULEBRA DEPTH INTERVAL (ft)	TRANSMISSIVITY (ft^2/day)	REFERENCE
AEC-7	870-896	1.8×10^{-1}	Beauheim et al. (1991)
Cabin Baby-1	503-529	2.8×10^{-1}	Beauheim (1987a)
D-268	370-392	2.2×10^{0}	Beauheim et al. (1991)
DOE-1	821-843	1.1×10^{1}	Beauheim (1987a)
DOE-2	824-846	8.9×10^{1}	Beauheim (1986)
Engle	659-681	4.3×10^{1}	Beauheim (1987a)
ERDA-9	704-727	4.6×10^{-1}	Beauheim (1987a)
H-1	676-699	8.7×10^{-1}	Beauheim (1987a)
H-2	623-645	4×10^{-1}	Mercer (1983)
H-3	672-694	2.3×10^{0}	Beauheim (1987b)
H-4c	490-516	6.5×10^{-1}	Beauheim (1987a)
H-5	897-920	2×10^{-1}	Mercer (1983)
H-6	492-511	7.3×10^{1}	Mercer (1983)
H-7	237-283	$>1 \times 10^{3}$	Mercer (1983)
H-8b	588-614	8.2×10^{0}	Beauheim (1987a)
H-9	647-677	2.3×10^{2}	Mercer (1983)
H-10b	1360-1391	7×10^{-2}	Mercer (1983)
H-11	730-756	2.7×10^{1}	Saulnier (1987)
H-12	823-850	1.8×10^{-1}	Beauheim (1987a)
H-14	545-571	3.0×10^{-1}	Beauheim (1987a)
H-15	861-883	1.3×10^{-1}	Beauheim (1987a)
H-16	702-724	8.0×10^{-1}	Beauheim (1987a)
H-17	706-731	2.2×10^{-1}	Beauheim (1987a)
H-18	689-713	2.0×10^{0}	Beauheim (1987a)
P-14	573-595	1.4×10^{2}	Mercer (1983)
P-15	413-435	9.1×10^{-2}	Beauheim (1987a)
P-17	558-583	1.0×10^{0}	Beauheim (1987a)
P-18	909-938	$<4 \times 10^{-3}$	Beauheim (1987a)
USGS-1	517-549	4.7×10^{2}	Cooper and Glanzman (1971)
WIPP-12	810-835	1×10^{-1}	Beauheim (1987a)
WIPP-13	703-726	6.9×10^{1}	Beauheim (1987c)
WIPP-18	787-808	3.0×10^{-1}	Beauheim (1987a)
WIPP-19	756-779	6.0×10^{-1}	Beauheim (1987a)
WIPP-21	729-753	2.5×10^{-1}	Beauheim (1987a)
WIPP-22	742-764	3.7×10^{-1}	Beauheim (1987a)
WIPP-25	447-472	2.7×10^{2}	Mercer (1983)
WIPP-26	186-209	1.25×10^{3}	Mercer (1983)
WIPP-27	292-318	6.5×10^{2}	Mercer (1983)
WIPP-28	420-446	1.8×10^{1}	Mercer (1983)
WIPP-29	12-42	1×10^{3}	Mercer (1983)
WIPP-30	631-653	1.8×10^{-1}	Beauheim (1987a)

Table 2: Hydraulic-Head Information for the Culebra Dolomite Member of the Rustler Formation.

WELL	GROUND-SURFACE ELEVATION (ft amsl)[a]	FRESHWATER-HEAD ELEVATION (with measured variation) (ft amsl)	DEPTH TO MIDDLE OF CULEBRA (ft)[c]	MIDDLE OF CULEBRA PRESSURE (with measured variation) (psi)	CULEBRA FLUID DENSITY (g/cm^3)[b]
AEC-7	3657	3058±3	883	123.1±1.3	?
Cabin Baby-1	3327	2989±2	516	77.1±0.9	?
D-268	3279	3002±1	381[d]	45.1±0.4	?
DOE-1	3465	2998+9, -7	832[e]	158.2+3.8, -3.0	1.088
DOE-2	3416	3069±5	835[f]	210.6±2.2	1.041
H-1	3398	3029±7	688	138.2±3.0	1.022
H-2c	3378	3029+6	634	123.5+2.6	1.006
H-3b1	3389	3009+6	683	131.3+2.6	1.035
H-4b	3333	2995±4	510	74.5±1.7	1.014
H-5b	3505	3064±5	909	202.8±2.2	1.102
H-6b	3348	3060±3	616	142.1±1.3	1.038
H-7b	3164	2994±2	260	39.0±0.9	0.999
H-8b	3434	2992+2	601	68.9+0.9	1.000
H-9b	3406	2978+4	662	101.4+1.7	1.000
H-10b	3687	3023±7	1376	308.5±3.0	1.047
H-11b2	3412	2994+5, -3	743[g]	140.8+2.2, -1.3	1.078
H-12	3426	2998±4	837[h]	177.2±1.7	1.095
H-14	3345	3003+2	558[h]	93.6+0.9	1.010
H-15	3480	2999+9	872[h]	169.4+3.9	1.154
H-16	3410	>3006±1[i]	713[h]	>134.0±0.6	1.037[j]
H-17	3384	2989±3	719[h]	140.4±1.3	1.100
H-18	3413	3057+5, -4	701[h]	149.5+2.2, -1.7	1.017
P-14	3360	3041±3	584	114.8±1.3	1.018
P-15	3310	3008±3	424	52.9±1.3	1.015
P-17	3336	2991±2	571	97.9±0.9	1.061
USGS-1	3426	2985+1	533[k]	39.9+0.4	1.000
USGS-4	3413	2985	489[k]	26.4	1.000
USGS-8	3410	2989	477[k]	24.3	1.000
WIPP-12	3471	3059±4	823	178.1±1.7	?
WIPP-13	3405	3064±4	713	161.2±1.7	1.046
WIPP-18	3456	3051±4	798	170.3±1.7	?
WIPP-25	3212	3047±3	460	127.8±1.3	1.009
WIPP-26	3152	3016±1	195	25.9±0.4	1.009
WIPP-27	3177	3078±2	305	89.3±0.9	1.093
WIPP-28	3347	3075+3, -4	433	69.8+1.3, -1.7	1.032
WIPP-29	2977	2970±1	27	8.7±0.4	?
WIPP-30	3427	3069+6, -7	642	123.1+2.6, -3.0	1.018

[a]Data from Gonzales (1989)
[b]Data from Cauffman et al. (1990) except as noted
[c]Data from Mercer (1983) except as noted
[d]Data from Beauheim et al. (1991)
[e]Data from Freeland (1982)
[f]Data from Mercer et al. (1987)
[g]Data from Mercer (1990)
[h]Data from Beauheim (1987a)
[i]Lowered by drainage into WIPP shafts; converted from pressure data presented in Stansrud et al. (1988a)
[j]Specific-gravity value from Culebra in Air-Intake Shaft (Lyon, 1989)
[k]Data from Cooper and Glantman (1971)

TABLE 3: Culebra parameter values for the BRAGFLO model.

Parameter	Maximum	Minimum	Constant*
permeability (m^2)	--	--	2.65×10^{-13} m^2
porosity (%)	--	--	14.6
pore compressibility (1/Pa)	--	--	1.42×10^{-9}
two phase flow Brooks/Corey P_t, Pa S_{br} S_{gr} λ	--	--	 1.0 1.25×10^4 0.2 0.2 0.7
thickness (m)	--	--	7.7
initial pressure (Pa)	--	--	8.52×10^5

* Parameters without maximum and minimum values are treated as constants in the PA.

PERMANENT MARKER CONCEPTUAL DESIGN REPORT

DRAFT

MARCH 1995

PERMANENT MARKER CONCEPTUAL DESIGN REPORT
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PERMANENT MARKER CONCEPTUAL DESIGN REPORT

I. INTRODUCTION

A. Purpose

This conceptual design report describes a concept for permanently marking the Waste Isolation Pilot Plant (WIPP) as required by Title 40 CFR 191.14(c) which states that:

> Disposal sites shall be designated by the most permanent markers, records, and other passive institutional controls practicable to indicate the dangers of the wastes and their location.

Although erection of the permanent marker system will not be initiated until after closure of the WIPP, design information is necessary to evaluate the efficacy of the marker system, which in turn can be used in the demonstration of compliance. This conceptual design will be used as part of the 40 CFR 191 Compliance Certification Application and the No-Migration Variance Petition (NMVP) for disposal submitted to the Environmental Protection Agency (EPA).

B. Scope

This report describes a design concept for a permanent marker system comprised of various messages, surface monument markers, small sub-surface warning markers, on-site rooms for long term storage of messages, archival storage of WIPP information off-site, and large earthen structures marking the WIPP repository footprint on the surface. It should be noted that the illustrations used to support this conceptual design report are not intended to represent the final configurations or even the most current concepts. Rather they are for the purpose of representing the type of illustrations which are intended to be used in the final design.

Three separate concepts of the configuration of the earthen structures, arrangement of the monument markers, and placement of the archival storage rooms within the perimeter of the repository footprint are described. The first concept consists of a large earthworks configured in the shape of a trefoil centered above the repository surface footprint center. An Information Center is also placed at the center with large monoliths arranged along the footprint's perimeter and outside the trefoil. Two Storage Rooms are located east

and west of the trefoil center. Each of these rooms are buried approximately 6M (20 feet) below the footprint surface.

A second configuration consists of a large earthworks configured as an earthen berm enclosing the footprint's perimeter. The large monoliths are arranged just inside the berm along the footprint perimeter. The locations of the Information Center and the Storage Rooms are geographically similar to the trefoil concept with small warning markers buried throughout the footprint surface.

The third concept includes several large earthen berm-like structures arranged in a pattern intended to convey a "menacing" appearance. The structures "radiate" out from the footprint perimeter as outlined by the monoliths. The four corner sections are significantly larger than the other sections. Within each corner section is buried a Storage Room. The Information Center is located at the footprint center. Again, the small warning markers are buried throughout the footprint surface area.

The second configuration described previously is the concept recommended at this point in time for consideration of a preliminary design effort. When initiated, the preliminary design should include detailed planning for the testing of various materials and configurations over a period of several decades of WIPP operation and active control after closure.

All three earthwork configurations are constructed in a similar manner as described later in this report. The testing effort is for the purpose of better understanding the long term chemical stability and weathering resistance characteristics of various materials and message configurations. The resulting information will then be used for the final design of the permanent marker system prior to its construction after closure of the facility.

C. Background

Title 40 of the Code of Federal Regulations (CFR), Part 191 prescribes that disposal systems be designed and built such that they provide a reasonable expectation that for 10,000 years: 1) the undisturbed performance of the system will not result in an annual committed effective dose to any member of the public in excess of 15 millirem; 2) the levels of radioactivity in groundwater will not exceed limits specified by the standard in 40 CFR §191.24; and 3) the probability of releases from all significant processes and events acting on the disposal system will not exceed the specifications in 40

CFR §191.13(a). Appendix C to Title 40 CFR Part 191 states that inadvertent and intermittent intrusion by exploratory drilling for resources can be the most severe intrusion scenario assumed by the DOE. This represents the greatest potential risk to release of the stored transuranic (TRU) mixed waste into the environment. The primary goal of the permanent marker system is to minimize the likelihood of inadvertent human intrusion.

Sandia National Laboratories (SNL) in its capacity as the scientific advisor to the DOE for the WIPP Project established two groups of experts to examine the issues involved with selecting, designing, and implementing an effective system of permanent markers. These groups assumed a period of 10,000 years as the time frame of interest. 40 CFR §191.13 also specifies 10,000 years as the period of applicability of the containment requirements. Hora et al., **Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant**, SAND90-3063, December 1991 is the report by the Futures Panel (FP) discussing the "underlying physical and societal factors that would influence society and the likely modes of human-intrusion at the WIPP."

The FP members also developed probabilities of various alternative futures, of inadvertent human intrusion, and in some cases, of particular modes of intrusion. The report was an important reference and source of information for the follow-on group of experts when developing Trauth et. al., **Expert Judgment on Markers to Deter Inadvertent Human Intrusion into the Waste Isolation Pilot Plant**, SAND92-1382, November 1993. Trauth, 1993 reports the results of two teams of experts, the Markers Panel (MP), who considered various concepts of marking the site and conveying to future generations information regarding the presence of dangerous waste material and the potential consequence of intrusion into the waste repository. The conceptual designs described in this report are expansions of the ideas developed by the MP.

The testing described in Section IX will include the development of data regarding the long term durability of construction materials intended to be used in the Permanent Marker System. It is anticipated that this testing program will initiate during the disposal phase and continue on beyond decommissioning into the Active Controls phase. During the Active Controls phase periodic evaluation of test structures will be conducted. Actual construction of the Permanent Marker System will be delayed for some decades after decommissioning to provide sufficient time to effectively evaluate the long term durability of the various construction

materials and the effects of weathering on monument markers and a section of berm.

II. SITE DESCRIPTION

The WIPP facility has been constructed 26 miles east of Carlsbad, New Mexico in southeastern New Mexico's Eddy County. The site, occupying 10,240 acres (16 sections), was withdrawn from the public domain in October 1992 by the Waste Isolation Pilot Plant Land Withdrawal Act (LWA) (Public Law 102-579). This law places jurisdiction of the land in the hands of the Secretary of Energy. The area surrounding the site is sparsely populated with about 25 people living within 10 miles. The activities in the general area are primarily devoted to livestock grazing, potash mining, and oil and gas development. Figure II-1 shows the general location of the WIPP site.

The surface physiography of the land in immediate WIPP vicinity is that of sand dunes from which the area gets its name, Los Mendanos. The area within the waste disposal area footprint is punctuated with dunes up to approximately 10 feet high. The dunes have been stabilized primarily by Havard Shin Oak which has an extensive root structure to limit the wind effects on the sand dunes. The sand is underlain by a caliche layer. The caliche represents a fairly impermeable barrier to moisture. Within the 10,240 acres, approximately 35 acres are devoted to surface structures and facilities including the four shafts leading to the repository horizon 655M (2150 feet) below the surface. The surface footprint of the repository occupies an area south of the surface structures. Figure II-2 provides a general spatial rendition of the relative locations of the surface facilities, the underground Experimental Area, and the underground Waste Disposal Area.

The surface facilities provide security and safeguards, accommodate routine operations, provide administrative and management facilities, and support on-going scientific studies. These facilities are designed to service full-scale operations and have undergone extensive testing and operational review. The waste handling building is the principal surface structure dedicated to supporting the handling of TRU waste containers and their transport to the underground. The building shelters the facilities for receiving Contact Handled (CH) TRU waste containers within the Nuclear Regulatory Commission certified Transuranic Package Transporter-II (TRUPACT-II), unloading the TRUPACT-II, inspecting the waste containers, and preparing the containers for transfer to the underground repository. The building also shelters facilities for receiving Remote Handled (RH) TRU waste in canisters and shielded casks. The building is divided into two (2) major areas. One area is for receipt and

inspection of CH TRU waste and the other area is dedicated to the receipt and inspection of RH TRU waste. A single waste shaft is designed integral with the waste handling building to transport either CH or RH TRU waste containers to the underground repository. Within the RH TRU waste area is the Hot Cell. The Hot Cell provides a radiation shielded facility for unloading and manipulating containers of radioactive waste with surface radiation dose rates of up to 1000 Rem/hr. The Hot Cell is constructed of concrete walls 4.5 feet thick and extending 60 feet above grade. The Hot Cell basement extends approximately 20 feet below the grade level. It is planned as part of this conceptual design that the concrete Hot Cell will remain as an archeological monument after decommissioning the WIPP site.

External to the waste handling building and the waste shaft are additional buildings and three (3) shafts. The major buildings are the support building, the safety and emergency services facility, the engineering building, the training building, the warehouse/shops building, and the core storage building. A number of temporary buildings and trailers are also used to support various operational, maintenance, technical, and administrative functions.

The salt handling shaft, located north of the support building, is used for transport of personnel to and from the underground, for transporting mined salt from the mine, and as a secondary source of air to the underground. An air intake shaft provides the primary source of air into the underground ventilation system. An exhaust shaft with two normal ventilating fans and three emergency fans provides for the forced ventilation of the entire underground area. The three emergency fans exhaust through a bag house containing particulate filters to mitigate the release of radioactive particulate in the unlikely event that such material is released in the underground storage area.

In the underground, to the north of the surface structures, is the Experimental Area. This 12-acre area is dedicated to conducting scientific investigations and experiments. To the south of the surface structures' footprint is the Waste Disposal Area. Approximately 100 acres is dedicated to the projected eight (8) panels planned for storage of TRU mixed waste. Connecting the Experimental and Waste Disposal Areas are four (4) major interconnecting drifts (tunnels) used for ventilation and traffic. In addition, equipment and maintenance facilities supporting the underground mining and operational activities are constructed along the drifts.

Each of the eight panels (only Panel 1 is currently mined) is planned to be comprised of 7 rooms. The nominal excavated dimensions of the individual rooms are 300′ X 33′ X 13′. The designed storage capacity of the repository is 6,200,000 ft^3. CH TRU waste will be contained in individual Standard Waste Boxes (SWB) or 55 gallon drums arranged in 7-packs. The SWBs and 7-packs will be stacked in the waste disposal rooms. Containers will also be emplaced within the ventilation supply and exhaust drifts within each panel. Individual panels will be closed as they are filled and upon complete filling of the repository, the shafts will be plugged and sealed along their entire lengths up to the surface. Figure II-3 illustrates a shaft plugging and sealing configuration, Nowak 1990.

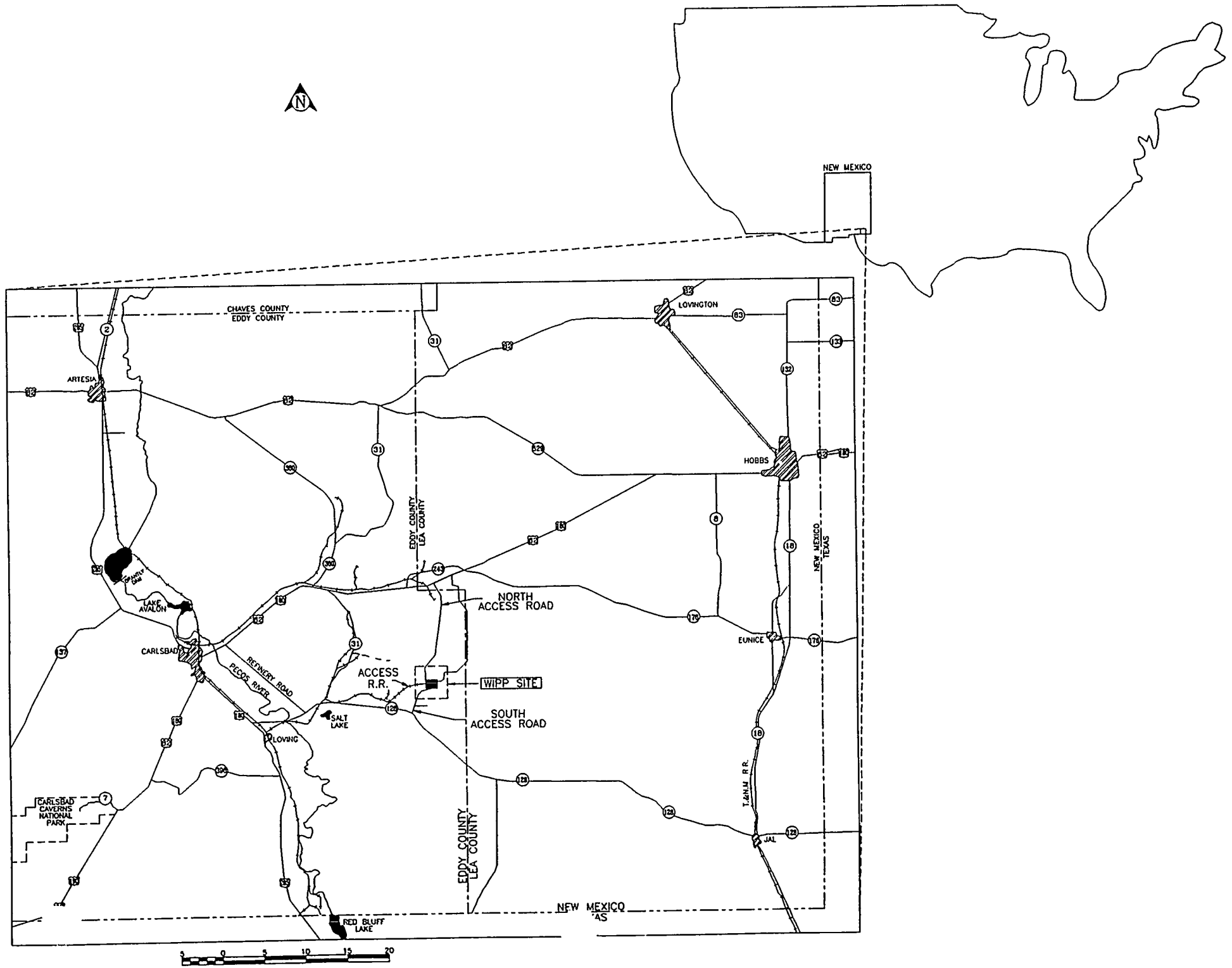
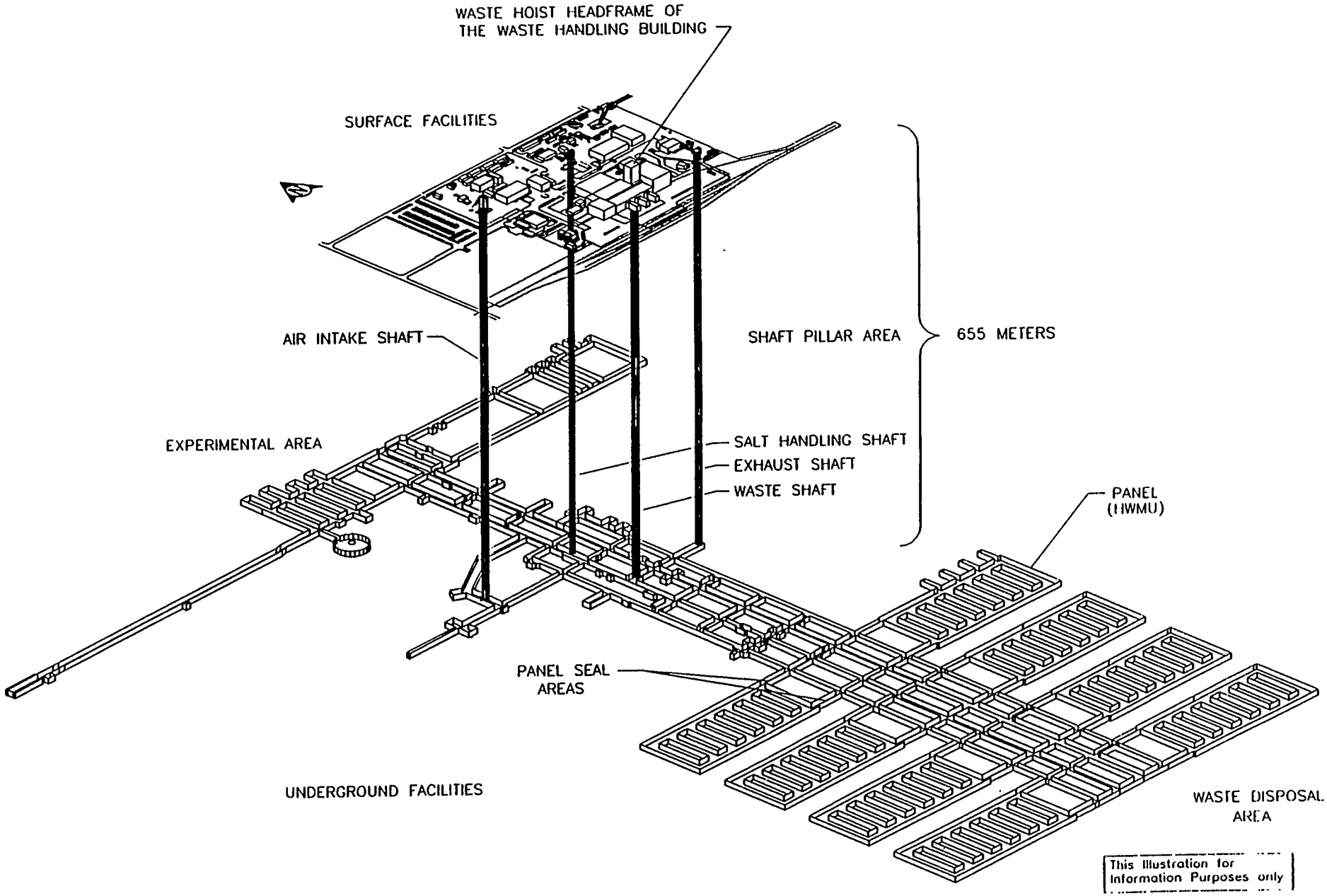

NEW MEXICO
CHAVES COUNTY
EDDY COUNTY
ARTESIA
LOVINGTON
HOBBS
EDDY COUNTY
LEA COUNTY
NEW MEXICO
TEXAS
LAKE AVALON
CARLSBAD
NORTH
ACCESS ROAD
EUNICE
ACCESS
R.R.
WIPP SITE
SOUTH
ACCESS ROAD
REFINERY ROAD
PECOS RIVER
SALT
LAKE
LOVING
T.&N.M. R.R.
CARLSBAD
CAVERNS
NATIONAL
PARK
JAL
EDDY COUNTY
LEA COUNTY
NEW MEXICO
AS
RED BLUFF
LAKE
5 0 5 10 15 20

FIGURE II-1



SPATIAL VIEW OF WIPP SURFACE & UNDERGROUND FACILITIES

FIGURE II-2

PM2

TYPICAL SHAFT SEAL SYSTEM

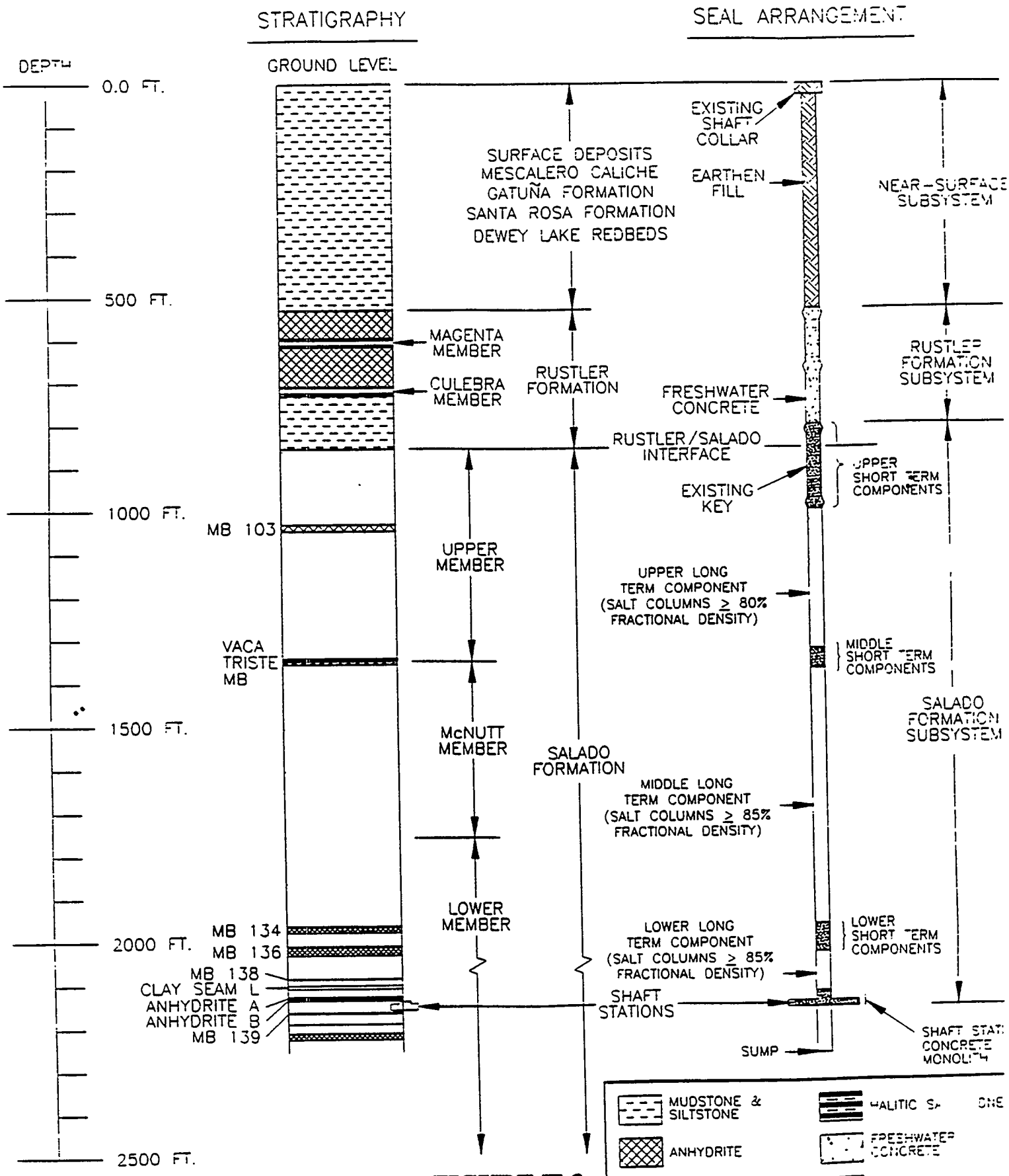


FIGURE II-3

III. DESIGN REQUIREMENTS/CRITERIA

Trauth, 1993 discusses at length the processes used to form the expert panel which developed SAND92-1382. The panel was divided into two teams, Team A and Team B. Each team then developed its philosophy for passing messages on to future generations. Appendix 1 is the table from Trauth, 1993 comparing the Marker System Components developed by each team. As can be seen from a review of the table, some differences existed between the teams. Drawing on information found in the table and a review of the individual team reports documented in Trauth, 1993, the following principles were applied to guiding the conceptual permanent marker design:

- The site is marked
- Message(s) are truthful and informative
- Multiple components exist within a marker system
- Multiple means of communication (e.g., language, pictographs, scientific diagrams) are provided
- Multiple messages with differing levels of complexity between messages are inscribed on individual marker system elements
- Materials with little recycle value are used
- Compliance with international standards of marking locations and contents of nuclear waste repositories

All but the last of these principles are in this document. The last principle, while laudatory is not achievable at this point in time. No international standards exist. If, in the future, standards are developed and adopted by the United States, they will be evaluated for incorporation as appropriate in preparing the final permanent marker design.

The following design requirements were developed from a review of Trauth, 1993 and the applicable regulations. Each of the requirements has been addressed in the development of the design criteria.

- The marking system should provide reasonable assurance that the site will be uniquely marked visually and electronically and such marking will endure and will be recognizable for a period of 10,000 years. It is recognized that experience gained during the first 100 years may result in marker system modifications to improve the endurance capability of the system
  BASIS: Title 40 CFR Part 191 and Trauth, 1993. The period of regulatory interest is 10,000 years.

- The site must be marked in such a manner as to provide

reasonable assurance that the marker's purpose cannot be mistaken or its intended message misinterpreted. The system should include a combination of surface and subsurface markers
BASIS: Trauth, 1993. Expert panel judgement to account for possible removal of surface markers and effects of erosion for uncovering subsurface markers

- The marking system must include the concept of "defense in depth" which implies redundancy by way of its physical design and message delivery concepts
  BASIS: Trauth, 1993. Expert panel judgment and a common design philosophy of the nuclear industry.

- Materials comprising the marking system should have as little intrinsic value as is reasonable to minimize the likelihood of future generations salvaging the material for recycling purposes
  BASIS: Trauth, 1993. Expert panel judgment.

- The marking system on the surface should encompass the grade level equivalent of the entire waste storage footprint (waste filled panels and drifts) but not exceed the footprint by more than 10% in area
  BASIS: Trauth, 1993 and engineering judgment. Expert panel judgment that the marker system extent should be limited to the repository footprint so as not to give false sense of the hazard if deep drilling is conducted outside the footprint with no hazardous material encountered. Engineering judgment to provide a 10% margin.

- The message delivery subsystem should provide a means of communicating with reasonable assurance the what, when, who, why, and how essentials of the WIPP program to future generations and should include an assortment of symbolic, pictographic, linguistic, narrative, diagrammatic, scientific, and astronomic messages
  BASIS: Trauth, 1993. Expert judgment.

- The marker system should be constructible with available technology and its construction should be cost effective
  BASIS: Engineering judgment

Development of the design criteria applicable to the permanent marker system included adherence to the guidelines and design requirements addressed above. Design criteria were established to:

1. Provide a system for marking the disposal area footprint on the surface through use of berms and monoliths:

   - Berm dimensions should be a minimum of 30M (100 feet) at the base and a minimum 10M (31 feet) high.
     BASIS: Trauth, 1993. Expert judgment. Berms should be massive to withstand human and natural forces. Slope needs to accommodate a roadway on the surface to facilitate construction.

   - Berm slope should be at least 1.3 horizontal to 1.0 vertical.
     BASIS: Slope of a natural talus is 1.3 to 1.0. Any steeper slope may significantly impact effects of erosion.

   - Berm should be mechanically packed.
     BASIS: Provides for a more stable structure and reduces slumping with time

   - Berm should provide a dielectric or magnetic anomaly when compared to the local surface characteristics.
     BASIS: Trauth 1993. Expert judgment. Provide a capability for marker detection by electronic means as part of the defense in depth concept.

   - Configuration of the berm marker should provide for observation of the entire marked area from any point on top of the berm adjacent to the marked area.
     BASIS: Trauth 1993. Expert judgment.

   - To the extent practical when considering a projected 10,000 year life, local material should be used for the majority of the berm structure
     BASIS: Trauth 1993. Expert judgment.

   - Monoliths should be at least 7.5M (25 feet) high
     BASIS: Trauth 1993. Expert judgment. Monoliths should be high enough not to be covered by blowing sand.

   - Monoliths should include a minimum 20 tons continuous mass (no bonding materials between components for individual monoliths)
     BASIS: Trauth 1993. Expert judgment. Monoliths should be sufficiently massive to minimize the affects of vandalism or removal. Bonding materials

of different chemical composition than the monolith material may have long term detrimental affects on the monolith material.

- The total number of perimeter marking monoliths should be a power of 2.
  BASIS: Trauth 1993. Expert judgment. Provide a sufficient number of monoliths to permit future societies to reconstruct monolith orientation with several monoliths missing.

- The spacing between monoliths should be such that an average individual standing adjacent to one monolith will be able to see the monoliths on either side.
  BASIS: Trauth 1993. Expert judgment.

- Monolithic material should be relatively unaffected by anticipated environmental and climatic conditions for 10,000 years.
  BASIS: Trauth 1993. Expert judgment. Minimize the risk of adverse environmental affects.

- The monolith messages shall be engraved to a depth of at least 1cm.
  BASIS: Engineering judgment when considering 10,000 year environmental affects.

2. Place subsurface warning markers throughout the disposal area footprint:

   - Warning markers shall be less than 0.6M (2 feet) in the longest dimension.
     BASIS: Engineering judgment. Sufficient size to carry a warning message but not represent individually a major emplacement effort.

   - Marker material should be inert with respect to the local environmental conditions at the depth at which they are buried.
     BASIS: Trauth 1993. Endure a 10,000 year buried period.

   - Burial depth should be greater than deep plowing/tilling or that expected to be dug by amateur archaeologists
     BASIS: Trauth 1993. Minimize loss due to inadvertent uncovering or vandalism.

- The warning message carried by the warning markers shall be engraved in such a manner that slight erosion or fracture of the marker will not render the message completely unintelligible
  BASIS: Engineering judgement.

- The warning message shall be written in Spanish, English, Russian, Chinese, French, Arabic, and Navajo. Distribution of the seven languages should be evenly spread among all the buried warning markers.
  BASIS: Trauth 1993. Expert and engineering judgment.

- Marker spacing should be such that their discovery has a high probability under conditions currently anticipated to be created by drilling crews and professional archaeologists
  BASIS: Engineering judgment.

3. Provide for detailed, complex information storage:

- Structures for the permanent storage of detailed and complex information relating to the repository location, contents, and associated hazards shall be constructed.
  BASIS: Trauth 1993. Expert judgment.

- Buried and surface structures shall be provided.
  BASIS: Trauth 1993. Expert judgment. Provide reasonable assurance that complex information is available during the entire period of regulatory concern.

- The structural material shall be inert and sufficiently durable to provide a high degree of protection for the stored information for a period of 10,000 years.
  BASIS: Trauth 1993 and engineering judgment.

- Stored written records, tables, figures, graphs, maps, and diagrams shall be engraved in stone or man-made materials having the durability to retain the engraved information over the 10,000 year period.
  BASIS: Trauth 1993 and engineering judgment.

- Entry to buried structures shall be designed to preclude removal of the stored information by

curious individuals. Removal should require a concerted effort by a well financed and technically competent organization.
BASIS: Engineering judgment.

- Concrete for construction shall be in accordance with the Building Code requirements for Reinforced Concrete (ACI-318, latest edition) with special emphasis on durability, (ACI-201.2, Guide to Durable Concrete).
BASIS: Engineering judgment.

IV. MESSAGES

Five levels of messages will be used in the Permanent Marker System.

- Message level I conveys the message that the site is manmade. The message itself is in the physical form of the marker system and the effort expended in constructing it

- Message level II conveys the message that something dangerous is buried here and that no digging or drilling should be conducted. This message is carried in seven languages uniformly distributed among the subsurface warning markers. Each marker has the message in a single language. The level II message is also engraved on each monolith in seven languages.

- Message level III conveys basic information that tells what, why, when, where, who, and how. This is the message that is carried by the monolithic markers

- Message level IV conveys complex information in seven languages and is stored in the permanent structure(s) buried underground and the Information Center on the surface

- Message level V is archival and stores a more complete rulemaking record than the messages provided at the WIPP site. This record is not stored at the site but shall be located in various public access facilities at the local, state, federal, and international levels

Figure IV-1 represents the level II and level III messages. Appendix 2 contains the level II, III, and IV message text in English. During the final design phase, the messages will be translated into the other six languages. Testing of the messages' ability to convey their intent to inform the public about the danger of intruding into the repository will be tested among populations indigenous to the language's locale.

The Level I message consists of the surface structures delineating the site boundaries and providing the surfaces upon which to engrave the Level II, III, and IV messages. This includes the earthen berm, the granite monoliths, and the information center. The physical size of these structures should clearly convey the notion that the site is a manmade facility which required a significant amount of effort to construct, Trauth 1993. This should provide the inspiration

for any organization with sufficient resources to dismantle the surface structures to investigate and attempt to understand the purpose of the site prior to initiating activities which are counter to maintaining the site's integrity. Individuals intent on vandalism or artifact collection may cause some superficial damage but it is very doubtful that they could significantly reduce the structures sufficiently to destroy the implication that something manmade occupies the site.

The Level II and III (Figure IV-1) messages are engraved on the granite monoliths. The Level II message is a warning of danger. The graphic symbols from Trauth 1993 accompanying the "DANGER" warning are meant to convey:

-  - Horror and terror

-  - Something nauseating or poisonous

The danger is defined by the description that waste is both poisonous and radioactive. The Trefoil symbol (☢) is used throughout the messages in association with the terms "radioactive" and "radioactivity". Its use in association with these terms should provide the interpretive definition of the symbols significance. This would seem to be more appropriate than attempting to define the symbol narratively. The Biohazard symbol is shown along with the Trefoil on the monoliths and the small subsurface warning markers as indicated in Figure V-1 and Figure V-2. Finally the Level II message admonishes the reader not to dig or drill. Figure IV-1 illustrates the three part Level II message.

The Level III message, also illustrated in Figure IV-1, provides more definition with respect to what is buried, the size of the area in which digging or drilling should be prohibited, and the depth at which the radioactive waste is located. Readers of this message will also be made aware of when the WIPP was closed and the fact that there was an intent to preserve the warning information for 10,000 years. Included in this message is a request that the reader take action to update the message or the marker system to add long lasting materials and/or messages written in languages more current to the times. The design of the monoliths provide sufficient blank surface areas for the addition of messages in

other languages. It is anticipated that over time the languages will change such that they may become incomprehensible to the general public and only scholars will be able to interpret their meaning.

Jensen 1993 provides an example of how quickly (relative to 10,000 years) the english language has changed by providing the following quote from Sir Gawain and the Greene Knight (unknown author written about 1375 AD-less than 650 years ago):

> The stele of a stif staf the sturne hit bi gripte
> That was wounden with iron to the wandes ende,
> And al bigraven with grene in gravios werkes.

In the modern english this quote is written as:

> The grim man gripped it by its great strong handle,
> which was wound with iron all the way to the end,
> and graven in green with graceful designs.

For this reason, the messages are being presented in a variety of languages to improve the likelihood that their meaning will be understood by future generations. A monolith with its messages in 7 different languages is a modern Rosetta stone. However, unlike the Rosetta stone, the size of each monolith is such that it is not likely a monolith will be moved to some remote location in order to be studied and interpreted. Rather the interpreters will need to record the messages for study and even if the study activity does occur elsewhere, the fact that the original messages are not moved from the site should enhance the probability that the interpreted results will be quickly made known at the site.

Figure IV-2 shows the spatial perspective of the marking system to the repository and the underground shafts which supported the repository during its construction, operation, and closure. Figures IV-3 and IV-4 will support the Level III message. Figure IV-3 is a cartoon showing the spatial perspective of the marking system to the underground repository. It depicts as a warning a sequence of activities which lead to releasing the waste from the repository and causing death to the individual digging or drilling down to the repository level. Figure IV-4 (Diagram 3 of the message text in Appendix 1) provides the skilled and technically knowledgeable reader a method to determine independently when the repository was closed after waste emplacement. The constellation formations for Ursa Minor, Draco, Cygnus, Ursa Major, and the brightest star, Vega are shown with respect to

the precession of the north celestial pole of thousands of years. The reader can estimate when the repository was closed by comparing the pole position at closure to its position at the reader's time. The decreasing size of the ☢ (Trefoil) is shown to convey the idea that the amount of radioactivity is decreasing with time. The faces (from Trauth 1993) show disgust at the time of closure to neutral at 10,000 years and contentment well beyond 10,000 years.

The Level IV message is the most comprehensive and complex message located at the WIPP site. Appendix 2 provides the text of the Level IV message in the seven languages in which it is to be presented. The text portion of the Level IV message expands upon the brief Level III message. In particular the Level IV message provides the following details:

- It describes the potential leakage path for radioactive material through ground water should deep drilling occur
- It specifies the disease cancer as the potential human impact from radiation poisoning and explains that cancer is a long term result
- It specifies the particular radioactive isotopes, their individual quantities, and the hazardous chemicals which were originally buried
- It identifies that the U.S. Government was responsible for this long term solution of isolating waste derived from its bomb making activities
- It describes why the Salado formation was chosen as the repository site
- It describes the general layout of the repository and the original configuration of the emplaced waste
- It provides an explanation of the Trefoil and Toxic symbols
- It gives an explanation of the diagram showing the four brightest stars at the time of burial of the waste including their azimuth angles to provide an independent means for future generations to

determine when the waste was buried

- It provides an explanation of the diagram showing the precession of the north celestial pole through constellations and the diminution of the radioactive waste with time
- It provides an equivalency of the year of WIPP closure with five other calendar dates
- It provides an explanation of the diagrams associated with the Level IV message
- It urges the reader to check the other locations around the world where radioactive wastes are buried for consistency with the markings used at the WIPP and the basic criteria used for establishing the message character and protection of the message

Figure IV-5 through Figure IV-11 are associated with the Level IV message. Figure IV-5 (Diagram 1 of the message text in Appendix 2) provides a more detailed spatial perspective of the repository than that shown with the Level III message. Figure II-3 (Diagram 2 of the message text) provides information on how the shafts supporting the repository are sealed at closure. Figure IV-6 (Diagram 4 of the message text shows the geologic cross section of the WIPP site and locates the relative position of the repository within the geologic formations shown. Dimensional characteristics are provided as are the names of repository components. Figure IV-7 (Diagram 5 in the message text) is the periodic chart. It identifies the radioactive elements with a ☢ and specifically identifies those elements which have significant quantities of their radioactive isotopes buried at the WIPP site with a ■. The non-radioactive toxic elements which are also buried in significant quantities are identified with a circle on the periodic chart. Figure IV-8 (Diagram 7 in the message text) provides the azimuths of the bright stars, Vega, Arcturus, Sirius, and Canopus as they rise above the horizon at the time of WIPP closure. From this information, future generations can determine the length of time the repository has been closed. Figure IV-9 (Diagram 6 in the message text) is a world map showing the locations throughout the world where radioactive wastes are buried (the locations shown are examples and not necessarily where the wastes will be buried at the time that the WIPP is closed). The ■ symbol is used to identify that "Radioactive Waste Is Buried Here." Figure IV-

10 (Diagram 8 in the message text) is comprised of two circles as described in Trauth 1993. The numbers corresponding to the dots refer to the buried waste storage locations shown on the world map. The outer circle provides the longitudinal position of the storage locations relative to the WIPP. The inner circle provides the latitude of the storage locations relative to the WIPP. According to Trauth 1993, if circles approximately 3 M in diameter are used and the positions are placed with an accuracy of 1mm, the locations of the storage sites can be located to within 4 km. The design of the buried rooms containing the Level IV message accommodate both the map and the 3 meter diameter latitude/longitude circles.

LEVEL II MESSAGE

DANGER



POISONOUS RADIOACTIVE ☢ WASTE HERE
DO NOT DIG OR DRILL



LEVEL III MESSAGE

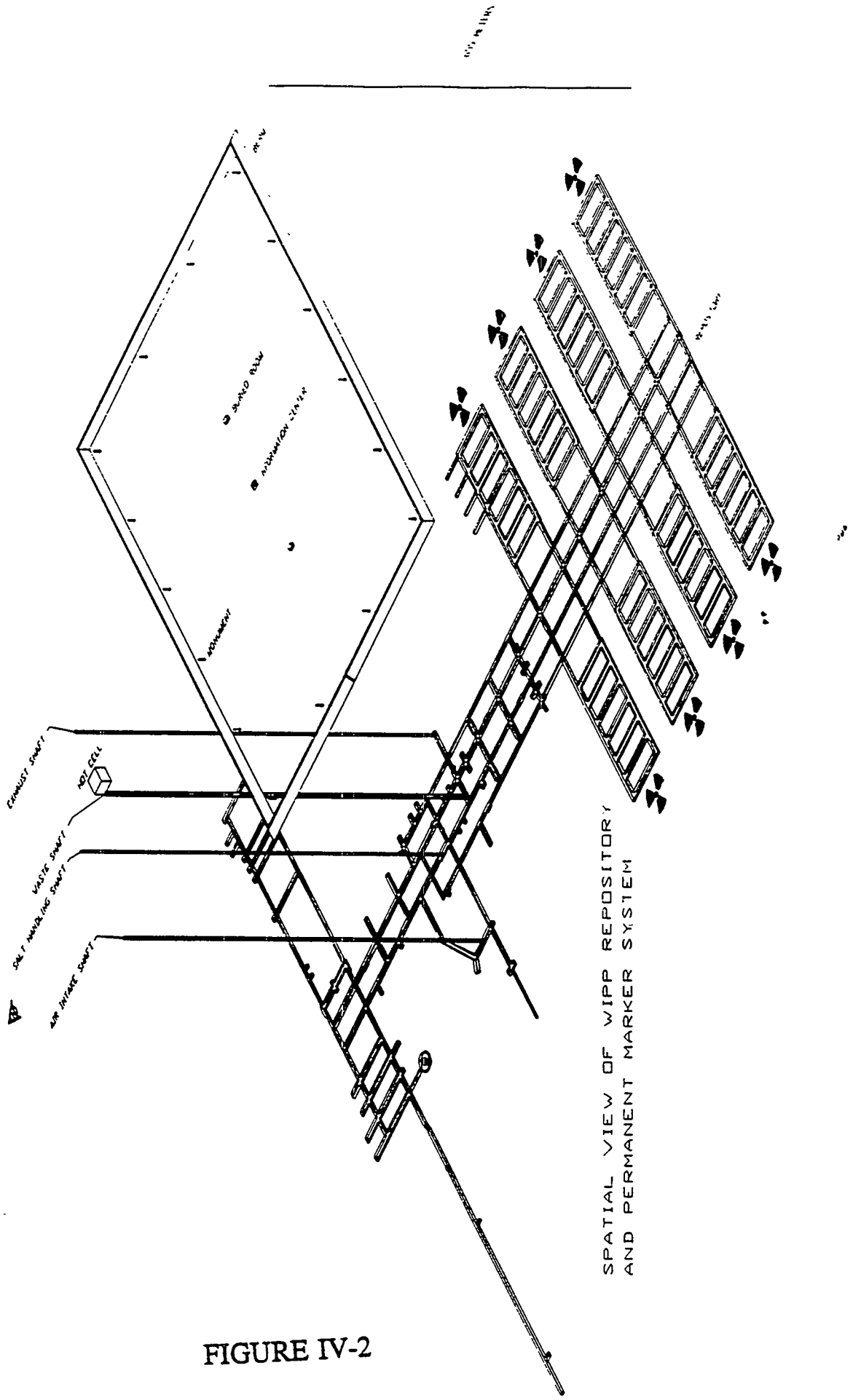
THESE STRUCTURES MARK AN AREA USED TO BURY RADIOACTIVE ☢ WASTES. THE AREA IS 0.66 BY 0.81 KILOMETERS AND THE WASTE IS BURIED 0.66 KILOMETERS DOWN. THIS PLACE WAS CHOSEN TO PUT THIS DANGEROUS MATERIAL FAR AWAY FROM PEOPLE AND OTHER LIVING THINGS. THE ROCK AND WATER IN THIS AREA MAY NOT LOOK, FEEL, OR SMELL UNUSUAL, BUT MAY BE POISONED BY RADIOACTIVE ☢ WASTES. WHEN RADIOACTIVE ☢ MATTER DECAYS, IT GIVES OFF INVISIBLE ENERGY THAT CAN DESTROY OR DAMAGE PEOPLE, ANIMALS, AND PLANTS.

DO NOT DRILL HERE. DO NOT DIG HERE. DO NOT DO ANYTHING WITH THE ROCKS OR WATER IN THE AREA.

DO NOT DESTROY THIS MARKER. THIS MARKING SYSTEM HAS BEEN DESIGNED TO LAST 10,000 YEARS. IF THE MARKER IS DIFFICULT TO READ, ADD NEW MARKERS COMPOSED OF LONGER-LASTING MATERIALS AND COPY THIS MESSAGE IN YOUR LANGUAGE ONTO THEM.

FOR MORE INFORMATION, GO TO THE BUILDING FURTHER INSIDE THIS MARKED AREA. THE SITE WAS KNOWN AS THE WIPP (WASTE ISOLATION PILOT PLANT) SITE WHEN IT WAS CLOSED IN 2020 A.D.

FIGURE IV-1



SPATIAL VIEW OF WIPP REPOSITORY
AND PERMANENT MARKER SYSTEM

FIGURE IV-2

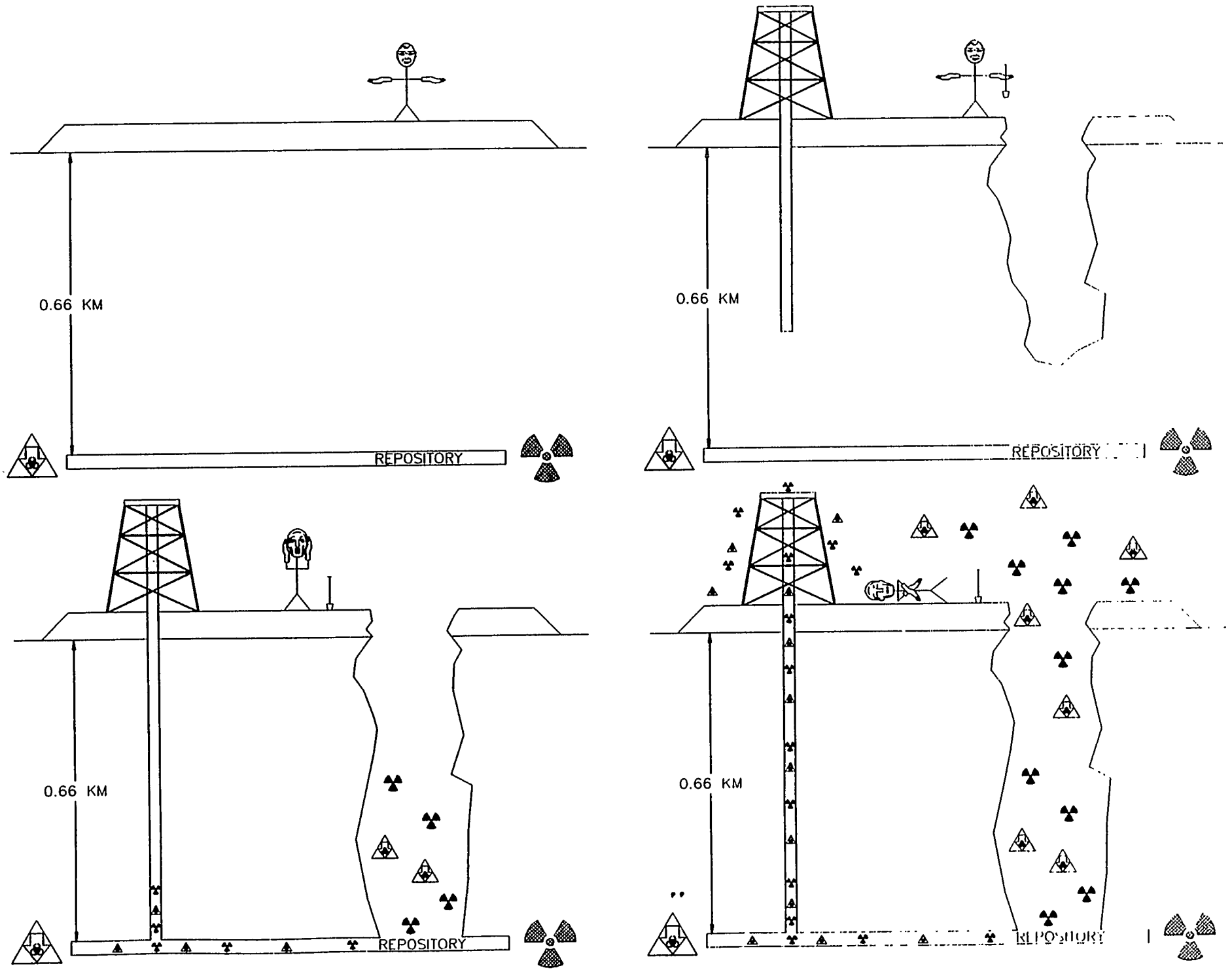


FIGURE IV-3

DRILL

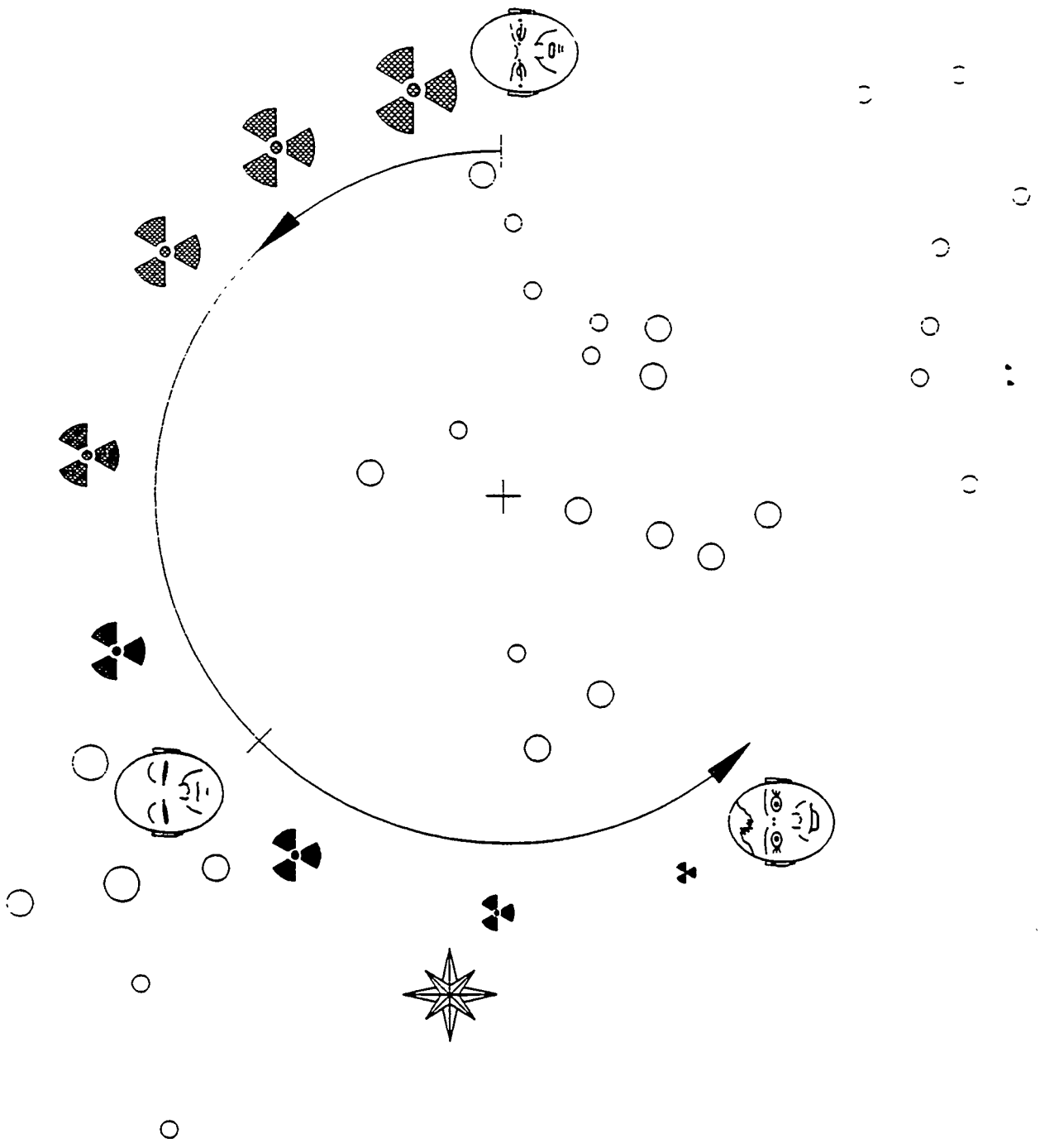


FIGURE IV-4

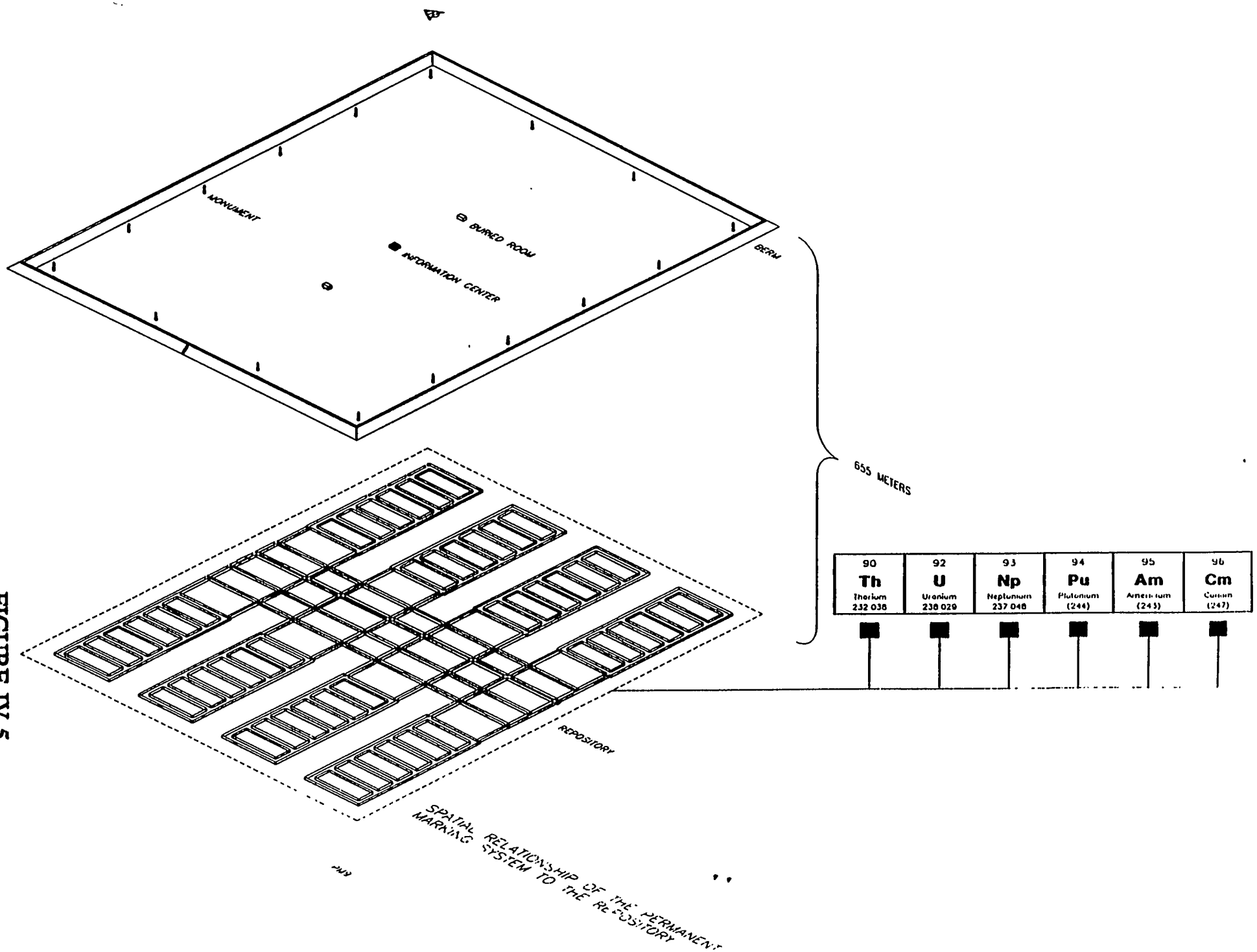
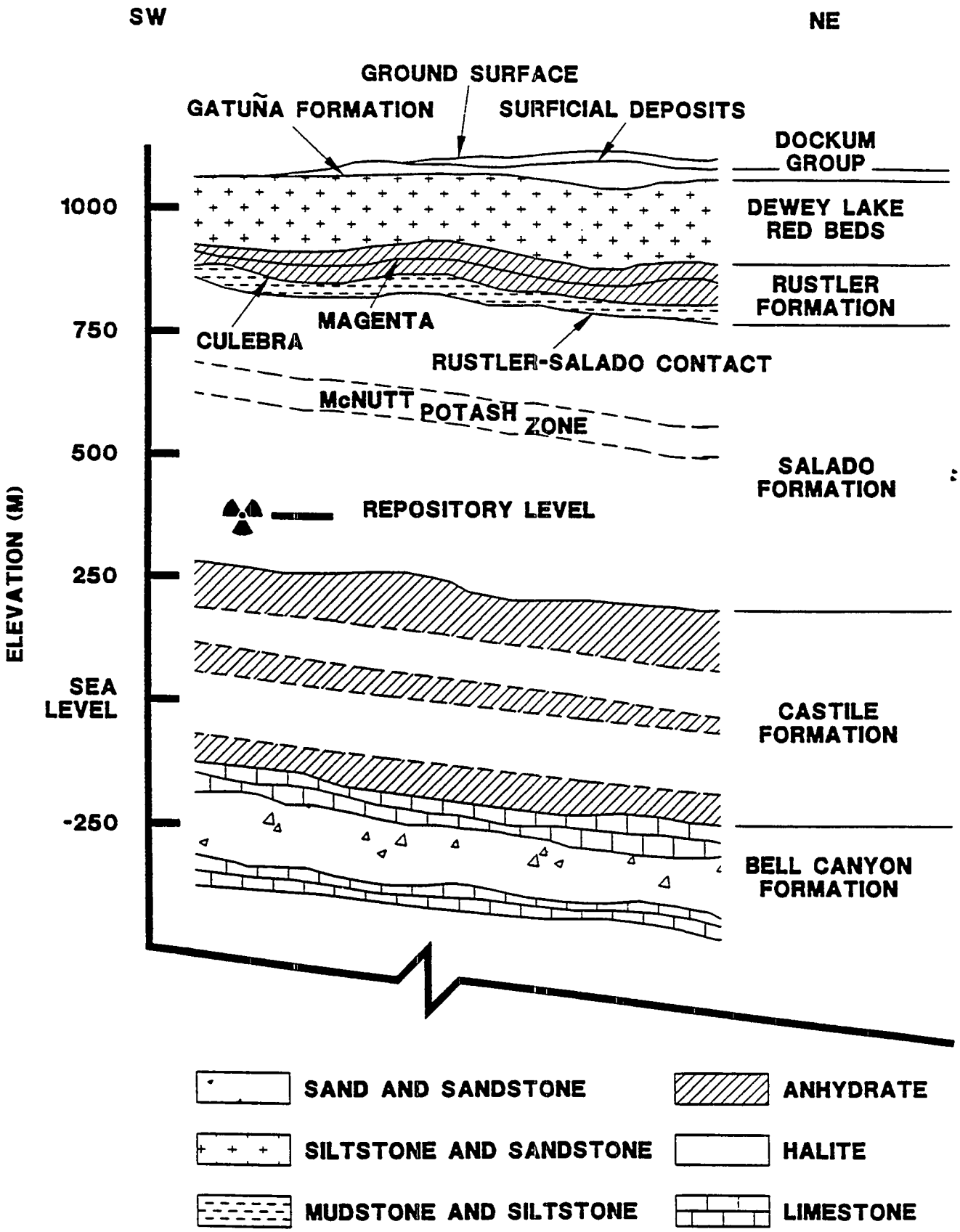


FIGURE IV-5

SPATIAL RELATIONSHIP OF THE PERMANENT MARKING SYSTEM TO THE REPOSITORY

GENERALIZED GEOLOGIC CROSS SECTION



DETAILED GEOLOGIC CROSS-SECTION OF THE SITE

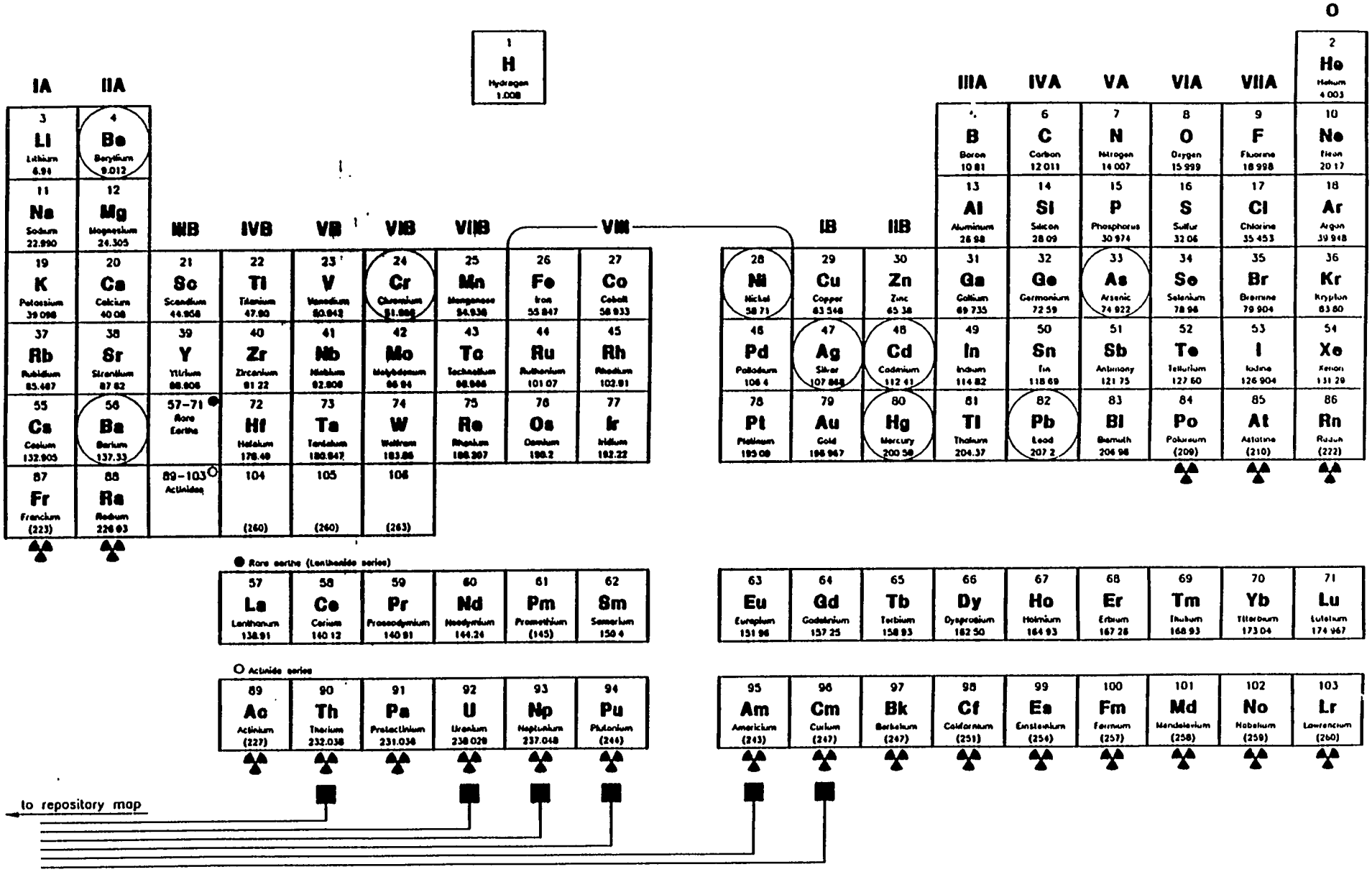
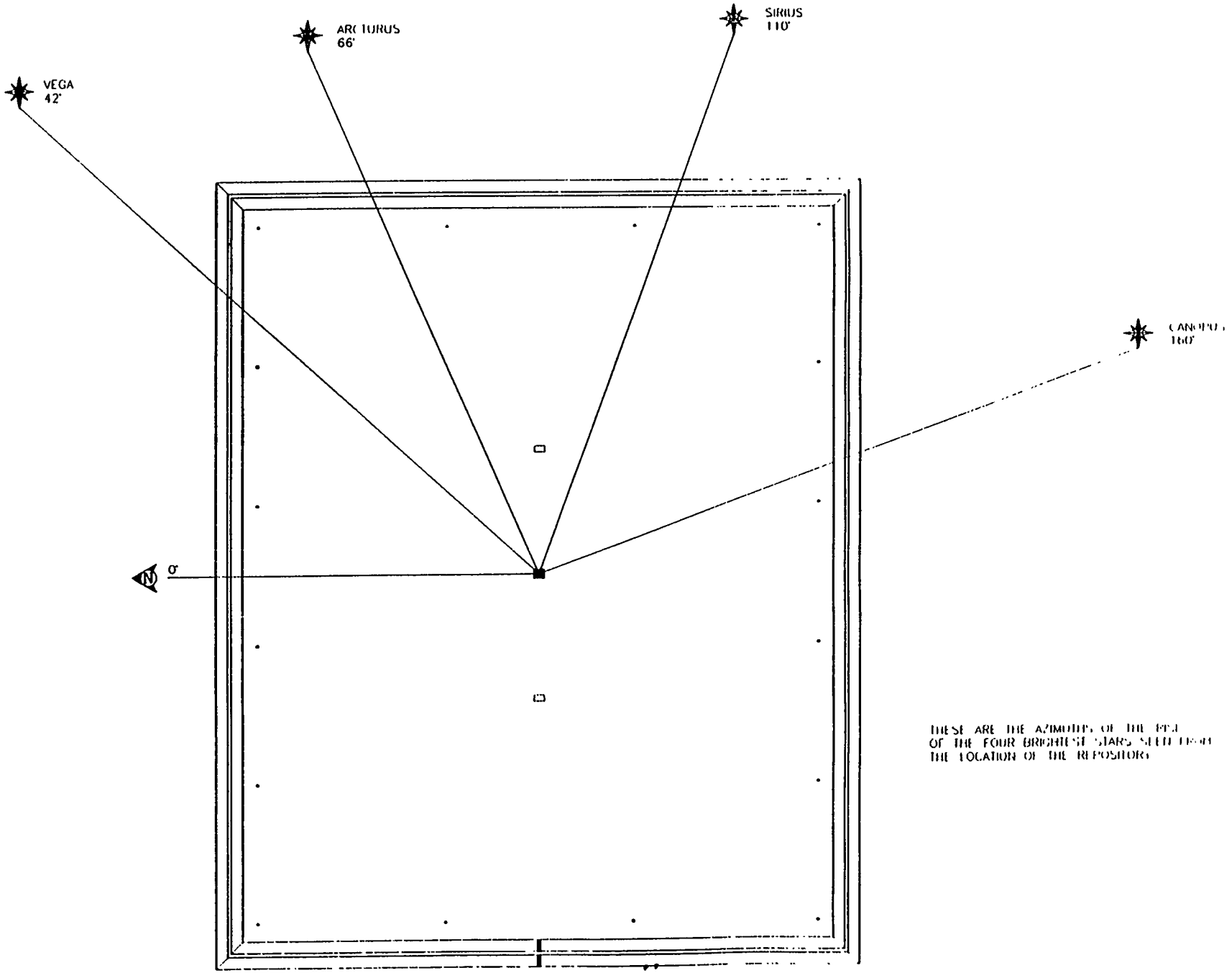


FIGURE IV-7

Level IV diagram of the periodic table of elements. Radioactive elements are indicated with the radiation trefoil and those with major amounts in the repository are further labeled with the symbol (here shown as a filled square) for "radioactive waste buried here." Non-radioactive toxic elements present in the repository are circled.



THESE ARE THE AZIMUTHS OF THE [illegible]
OF THE FOUR BRIGHTEST STARS SEEN FROM
THE LOCATION OF THE REPOSITORY

FIGURE IV—8

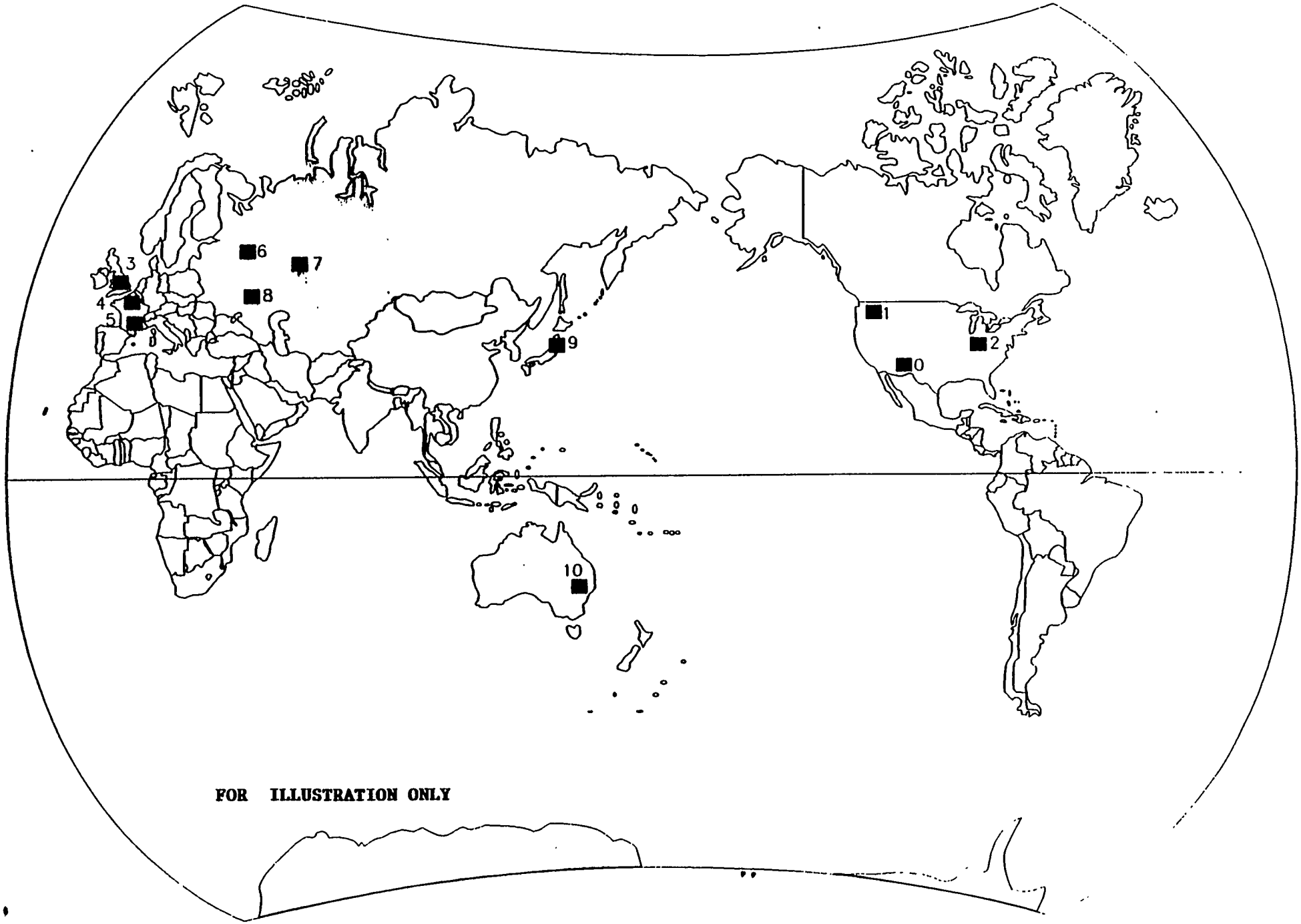


FIGURE IV-9

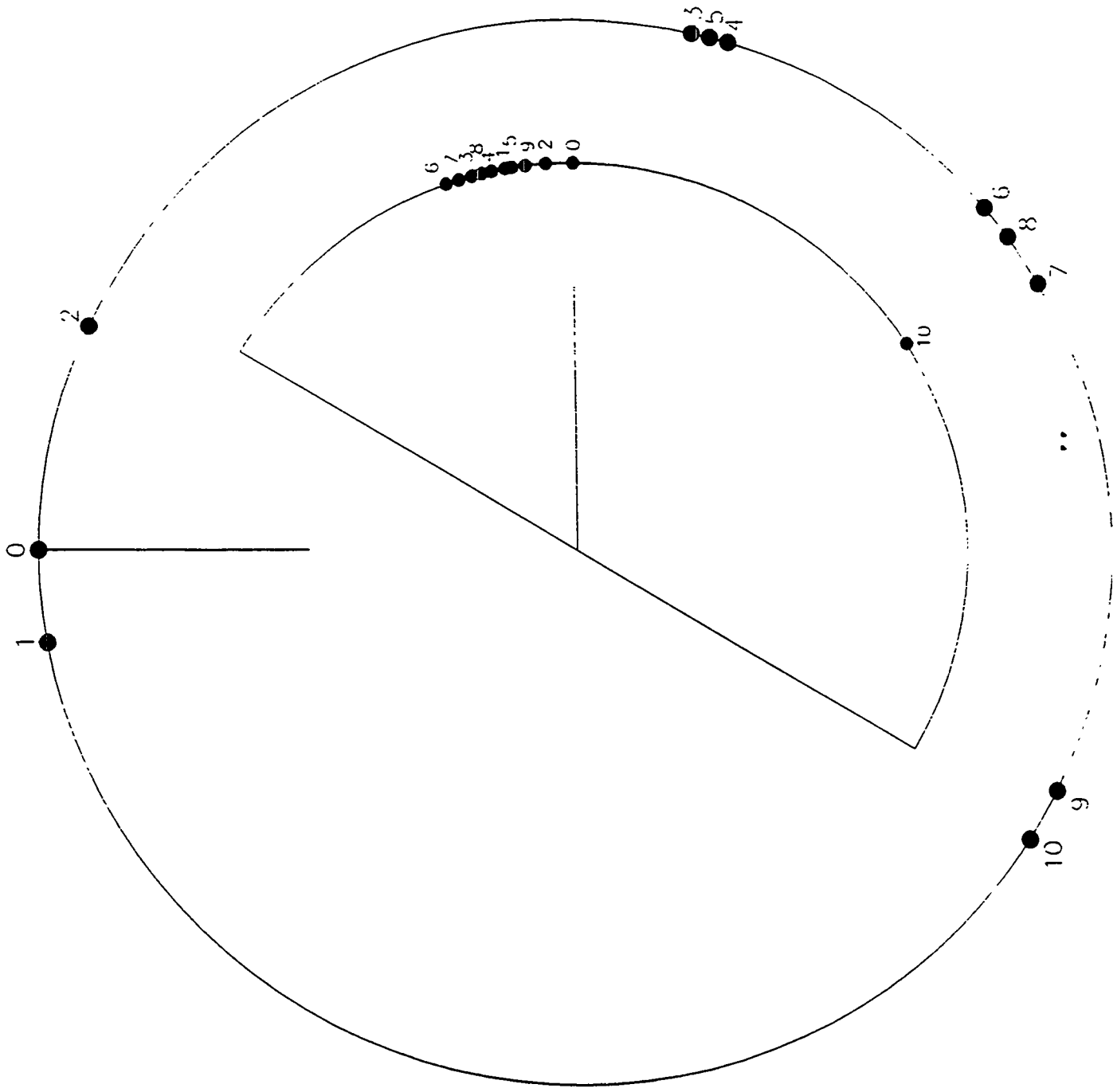


FIGURE IV-10

V. MONUMENT MARKERS

Monument markers are those elements of the marker system consisting of large monoliths (Kaplan, 1982) on the surface and small warning markers buried throughout the repository footprint. To facilitate fabrication and shipping of the monoliths, each monolith will consist of two separate stones connected by a tendon joint. The large monoliths will be engraved with level II and III messages. Figure V-1 provides the dimensional characteristics of the large monoliths. Each monolith will be inscribed with the level II and III messages in seven languages, the six official United Nations languages (English, French, Spanish, Chinese, Russian, and Arabic) and Navajo. Trauth, 1993 discusses in some detail the selection of these languages by the MP. In addition, each monolith will be inscribed with a diagram (Figures IV-2 and IV-4) depicting two concepts. The first concept is comprised of four frames illustrating the danger of digging or drilling into the repository and releasing the radioactive and toxic waste. The second concept illustrates the decay of the radioactive material (decreasing size of the trefoil and improving disposition of the icon) over many thousands of years by depicting the precession of the earth's north pole through the major constellations (Ursa Minor, Ursa Major, Draco, and Cygnus) and the bright star, Vega.

One of the MP recommendations with respect to the monolith placement is for both above ground and below ground inscriptions. Trauth, 1993 prescribes that at least one copy of the level II and III messages should be inscribed at a height well above a position "accessible to a standing person, or a person on horseback or standing on top of common farm equipment (wagons, pickup trucks, tractors)." To meet the intent of this restriction, individual monoliths will have the messages inscribed in the top 1.8M-2.4M (6-8 feet) on all four sides. This places the messages 5.2M-5.8M (17-19 feet) above ground. Three translations and one illustration are inscribed above ground. Four translations are inscribed on the buried portion of the monolith in the area of 1.5M-3.6M (5-12 feet) above the base. Placement of the messages in these areas also provide ample surface area for future generations to inscribe messages in their respective languages. Individual translations will be varied in their locations among all of the monoliths so that copies of all translations will be located both above ground and below ground.

The monoliths will be quarried from granite and shipped by rail to the WIPP site. Monolith locations will be excavated

to at least 1.5M (5 feet) into the caliche. After emplacing the base monolith, the upper monolith will be placed over the base tendon and the excavation will be backfilled. This will provide for suitably supporting the base monolith within the caliche deposit or the Gatuna formation even under conditions in which the overlaying layer of sand is removed through erosion or other weathering phenomena. The center of gravity of the two monolithic stones is 4.7M (15.5 feet) above the bottom of the base. The monolithic structure would require sufficient erosion to tip approximately 14.5 degrees from the vertical before the structure would become unstable.

In discussions with a number of quarry operators and a memorial distributor in the local area it is apparent that granite will come in a variety of grades. Granite is commonly referred to as blue, grey, black, or red. The color is a result of the granite composition and the hardness will vary. As a result of this condition, the testing addressed in Section IX below provides for subjecting a number of different types of granite to long term testing prior to actual purchase of the final monuments. A local memorial distributor with over 40 years of actual experience in the Carlsbad area stated that his experience with one of the harder grades, blue granite from Vermont, has not been as good with respect to durability of the engraved surface as with grey granite from quarries in Georgia. Although this is only a single reference point, it does support the proposed testing of various grades of granite over a period of decades prior to the final monument material decision.

The small warning marker is shown in Figure V-2. The Level II message placed on the small subsurface warning markers will also be in the seven languages described above. However, each marker will have the message in only one of the seven languages. Warning markers will be placed throughout the repository footprint, within the berm, and in the shaft sealing system. The Level II message is shown in Figure IV-1. The warning markers will be made of granite, aluminum oxide, and fired clay to provide a diversity of materials and thus improve the likelihood that at least some materials will endure for a 10,000 year period.

Spacing between warning markers should be approximately 15 feet (4.5M). The warning markers should be buried 6-8 feet (1.8M-2.4M) below the surface but above the caliche. This depth is below that which would be encountered from deep plowing and the protocol governing amateur archaeologists in New Mexico. This burying criteria is based upon two conditions. The first condition is that the soil covering the

caliche in the local WIPP area ranges to a depth of 3M (10 feet). The second condition is based upon discussions with local drilling operators regarding their standard practice for drilling preparation. Discussions with local well drilling service companies reveal that typically an area 200 feet by 300 feet (61M by 91.5M) is cleared down to the caliche in preparation for drilling. Included within this area is the excavation of a "mud pit" that is typically 150 feet (45.7M) square and 10 feet (3M) deep. Thus by placing the small warning markers above the caliche at intervals of approximately 15 feet, over 250 warning markers should be unearthed during the well drilling preparation. This provides a reasonable likelihood that at least some of the warning markers would be discovered by the drilling crew.

Trauth, 1993 discusses the use of deep markers. Discussions were held with local drilling company representatives regarding possible techniques for alerting drilling crews. A practicable scheme of marking the repository in such a manner as to call the attention of drill crews to the potential that radioactive waste is about to be entered by the drill bit was not identified. In discussing drilling routines and the degree to which the drilling fluid is monitored once the routine drilling operation has commenced, the oil field drilling company representatives stated that close observation of the fluid does not occur until the bit is below the local salt formations. Unless an extremely hard material (steel or titanium) was emplaced to encounter the drill bit and dull it quickly, the drilling operation would not likely be stopped based even upon encountering rock that is harder to drill than salt. According to at least one local drilling contractor, most drilling plans identify the depth to which the drilling operation is targeted and after some initial checks of the operation, continuous drilling proceeds to that depth with little or no significant monitoring of the drilling fluid. One drilling company manager stated that if 2-3 inches of steel or titanium were encountered, it would probably impact the drilling operation sufficiently to cause additional investigation. Anything short of this would only be seen as an inconvenience.

A second drilling operations supervisor stated that drilling for oil and gas in the local area required depths of 8,000 and 16,000 feet respectively. Knowledge of the area was such that no examination of the drilling fluid is normally conducted until <u>after</u> the drill has passed through the salt layers. The same supervisor also stated that the drill cuttings ranged in size from about 3 micron grains to small slivers up to 1 1/2 inches in length. Under these conditions, there is no

practical way to provide a message. In addition, current drill materials can typically penetrate even granitic rock at 6-8 feet per hour. It was the opinion of at least one drilling supervisor that for a 1/2 inch steel plate to dull a bit sufficiently to prevent penetration, the steel would require placement at a shallow depth otherwise the weight of the drill string would sufficiently improve the penetration capability of the drill bit to cause penetration of the steel plate without alerting the drill crew to any unusual condition. Placing steel plate near the surface would be counter to the requirement to not use material of intrinsic value. In addition, the corrosion resistance of steel reduces the likelihood of its remaining an effective barrier over the period of 10,000 years.

Emplacement of markers in the panels immediately above the waste would be ineffective since there would be insufficient lag time to alert the crew even if the drilling crew was closely monitoring the drilling fluid content. The use of a dye was also discussed as a possible marking option. Discussions with a number of dye manufacturers and suppliers failed to locate a dye material which would affect the drilling fluid at concentrations that might be developed from dying materials emplaced with the waste. In addition, some means would be needed to provide a message cautioning the drilling crew as to why the dye was present. Finally, the use of pyrotechnics as deep marker components is not practical since significant quantities of drilling fluid under high pressure are used to flush out the drill cuttings. The fluid would extinguish any flammable materials long before the material could be brought to the surface to alert the drilling crew. If thermite were used in such a configuration and quantity as to melt the drill bit, it might stop the operation but without any message to convey to the drillers what they were about to enter, the drillers have one of three choices:

- They could change out the drill bit and commence drilling again. In this case they would successfully pass through the waste unless the design included multiple layers of thermite separated sufficiently to prevent sympathetic detonation

- They could abandon the drill site and setup elsewhere. In this case they might strike another thermite condition and abandon the attempt or simply move a third time

- They could abandon the area altogether

Whatever material was used to "melt" the drill would have to

be designed in a protective cover to remain stable for 10,000 years. In addition, a prodigious quantity of the material would be required and in itself would represent a significant hazard during fabrication and field emplacement.

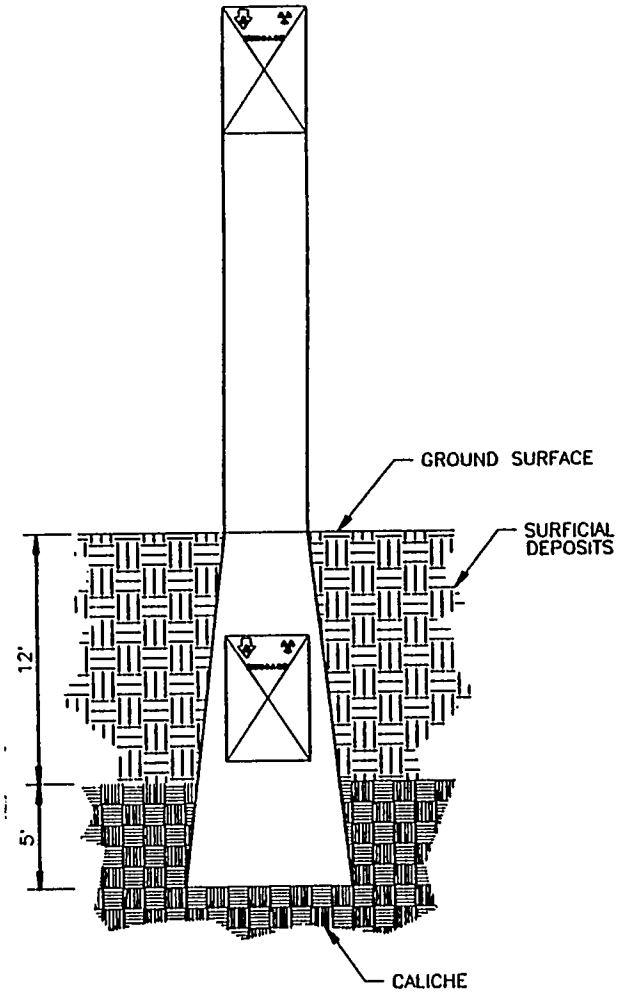
Tolan, 1993 reports that experience with environmental remediation work on old landfills indicate that old tires or steel fencing/baling wire can make effective barriers to at least truck-mounted rotary drilling. He states that in two cases where the material was layered greater than 10 meters, the problems presented to the drillers resulted in their abandoning the boreholes.

The installation of a 10M (30 feet) thick barrier of old tires or steel wire in itself represents a significant construction effort when considering a repository footprint excluding the area of the pillars between repository rooms and panels of 0.13 km^2. Placing the barrier near the surface requires excavating the entire area to provide reasonable assurance that the repository is protected. Emplacing the barrier only over the room footprints and not the pillars would ignore the risks associated with drilling near the pillar/room boundaries and the inaccuracies that might be associated with the vertical trueness of the drilling process. Emplacing the barrier nearer the location of the repository over the room footprints plus some small percentage overlap may require significant additional studying to determine what if any effects this additional mining above the repository may have on the performance of the repository. This additional study time could significantly affect obtaining the required permits to begin waste emplacement and yet result in a barrier that will not be effective against slant or possible future horizontal drilling techniques.

When discussing what action a drilling crew might take upon encountering a barrier made of old rubber tires, the experienced drilling personnel interviewed responded that they would investigate the problem. Under current operating practices, this would entail a review of the maps provided by state and federal agencies to determine what might be the cause. However, unless some means not yet identified provided a message regarding the presence of the repository, drilling would probably recommence. In that a typical 8,000 feet deep oil well in the WIPP locale costs $300,000, abandoning a well after drilling over one thousand feet represents a significant financial loss.

As stated at the beginning of this Section, a practical means of warning the drilling crew that they are about to enter the waste repository has not been identified. Therefore this conceptual design report does not provide a recommendation for emplacing a deep marker system in the strata above the repository.

FIGURE V-1



MONUMENT EMPLACEMENT

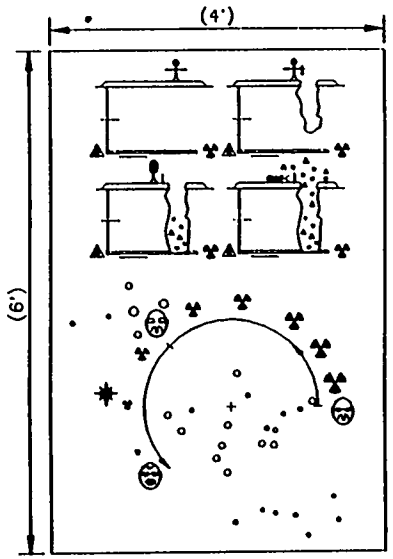
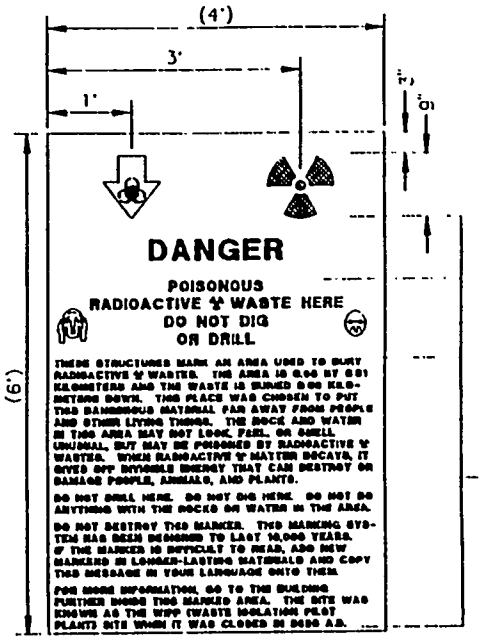
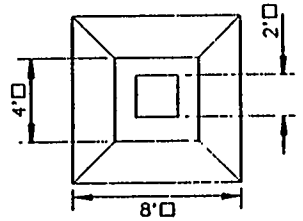
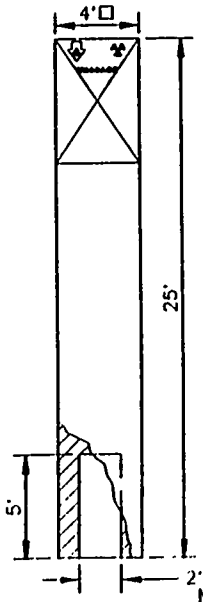


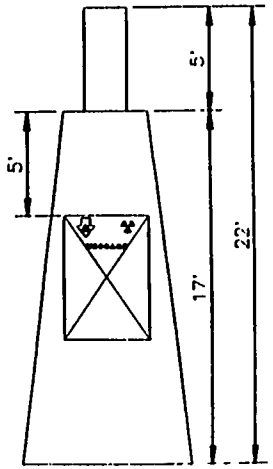
DIAGRAM INSCRIPTION
NOTE 6



MESSAGE INSCRIPTION







MONUMENT FABRICATION

NOTES:

1. MONUMENT TO BE HEWN FROM TWO SOLID PIECES OF GRANITE.
2. MESSAGE TO BE CARVED INTO STONE FACE AND GENERAL LOCATIONS AS SHOWN ON DRAWING. THE MESSAGE WILL APPEAR SEVEN TIMES ON THE MONUMENT, ONCE IN EACH LANGUAGE LISTED BELOW. THE MESSAGE WILL APPEAR AT THE TOP OF THE MONUMENT ON THREE FACES, LEAVING ONE BLANK FACE. IT WILL APPEAR ON FOUR SURFACES AT THE BOTTOM
   A. ENGLISH
   B. SPANISH
   C. RUSSIAN
   D. FRENCH
   E. CHINESE
   F. ARABIC
   G. NAVAJO
3. THE LEVEL I MESSAGE WILL BE IN 3" HIGH LETTERS WITH A 3" SPACE ABOVE AND A 3" SPACE BELOW
4. THE LEVEL II MESSAGE WILL BE IN 1 1/2" HIGH LETTERS WITH A 1" SPACE BETWEEN LINES AND A 2" SPACE BELOW THE BOTTOM LINE OF THE MESSAGE.
5. THE LEVEL III MESSAGE WILL BE IN 1" HIGH LETTERS WITH A 5/8" SPACE BETWEEN THE LINES. THERE WILL BE A 1 1/2" SPACE BETWEEN THE PARAGRAPHS OF THE MESSAGE.
6. THE DIAGRAM INSCRIPTION WILL APPEAR ON THE BLANK FACE ON THE TOP OF THE MONUMENT. THE DIAGRAM DESCRIBES THE HAZARDS OF DIGGING HERE AND HOW LONG THAT HAZARD WILL EXIST

PM4



WARNING MARKER

FIGURE V-2

VI. STORAGE ROOM

The storage room for containing the Level IV message and associated diagrams is designed to endure for the 10,000 year period of the permanent marker system. The design characteristics contributing to this longevity are the material and environmental conditions associated with its construction and location. The room is made of granite with a minimum number of joints. As designed, individual walls, the floor, and the roof are comprised of single granite slabs joined only at the perimeter locations. The internal walls are each made of three sections to provide redundancy of the information provided. Figure VI-1 is an isometric view of the planned buried storage room containing the Level IV message. The magnets shown in the figure are to permit locating the rooms magnetically. Figures VI-2 through VI-4 show views of the building from the top, the side, and the end. They include overall dimensional characteristics. The configuration minimizes the risk of failure due to chemical interactions between the construction material, the joining materials, and the environment.

In each of the conceptual design configurations described later in this report, at least one room is buried. In addition, an Information Center will be located on the surface providing access to the same information contained in the buried rooms. This should limit the incentive to excavate the buried rooms by future generations. Within the Information Center will be details regarding the location of the buried Storage Rooms containing identical information. Appendix 3 contains the "Storage Room Location" message placed in the Information Center. It is anticipated that distribution of archival information regarding the WIPP site in local, state, federal, and international repositories will also preclude the need for future generations to excavate and enter any of the buried rooms for a significant number of years. If societal changes, calamities, or loss of the archival information dictate that society cannot determine what the buried room(s) contain, then it is assumed that at least one of the rooms will be entered and observed. Establishing access control and maintaining active control for at least 100 years after decommissioning of the site should preclude entry into any of the buried rooms from the time they are constructed until at least 100 years. A significant effort will be required to fully excavate the rooms and even occasional surveillance by local law enforcement personnel should thwart any significant damage to the rooms by vandalism or souvenir hunters during the active controls period.

The buried storage rooms overall dimensions are each approximately 11.9M long by 6.7M wide by 4.9M high (39 feet by 22 feet by 16 feet). The message texts in Appendix 2 are engraved on the walls in the arrangement similar to that for the Information Center shown in Figure VII-1. In addition the diagrams are arranged on the walls of the rooms similar to that shown in Figure VII-1 for the Information Center and as depicted in Figure VI-4 for the buried rooms. To provide redundancy, additional granite slabs engraved with the message text and the diagrams are held in place against the interior walls. The room entrance is a single plug in one wall measuring 0.6M (2 feet) at the inner minimum diameter. The tapered plug weighs approximately 1600 pounds. Its removal will require more than a single individual in all likelihood. The opening is small so that the room contents cannot be removed easily by an unorganized group or individuals intent on vandalism. Although some damage could be inflicted by vandals, the granite composition of the message carrying materials provides the greatest opportunity for preventing complete destruction of the information contained within the buried room.

The physical size of the Storage Rooms is dictated by the minimum size lettering which can be engraved in granite. Discussions with a number of quarry operators and local memorial vendors indicate that the minimum lettering size is 5/8". This is limited by the sandblasting technique typically used. Engraving smaller size letters causes "blowout" of small enclosed character such as "A", "P", "R" , etc. No laser engraving capability exists within the granite quarrying industry. Additional discussions with laser manufacturers verified the lack of laser engraving capability on large pieces of granite. One manufacturer stated that he gets called at least once a week by memorial dealers inquiring about laser engraving technology. Two reasons are given for the lack of the technology today. First, high laser power (6-8 kilowatts) would most likely be required. Second, the granite quarry and memorial industry is not willing to spend the research money required to develop the technology. This particular manufacturer suggested perhaps that a national lab attempting to convert defense related technology to commercial use might take on such a development effort. In any event, the technology does not exist today to engrave granite with characters smaller than 5/8".

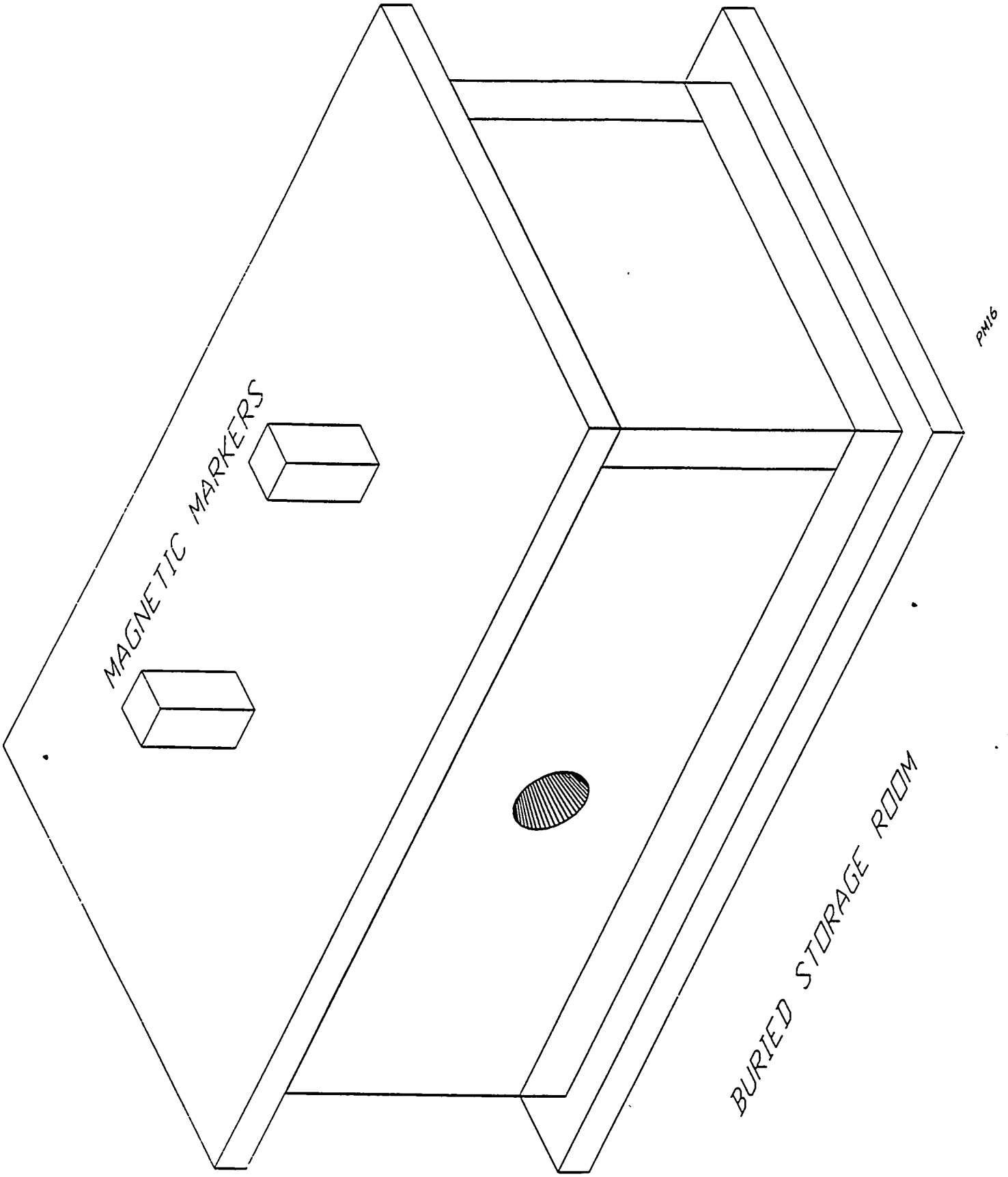
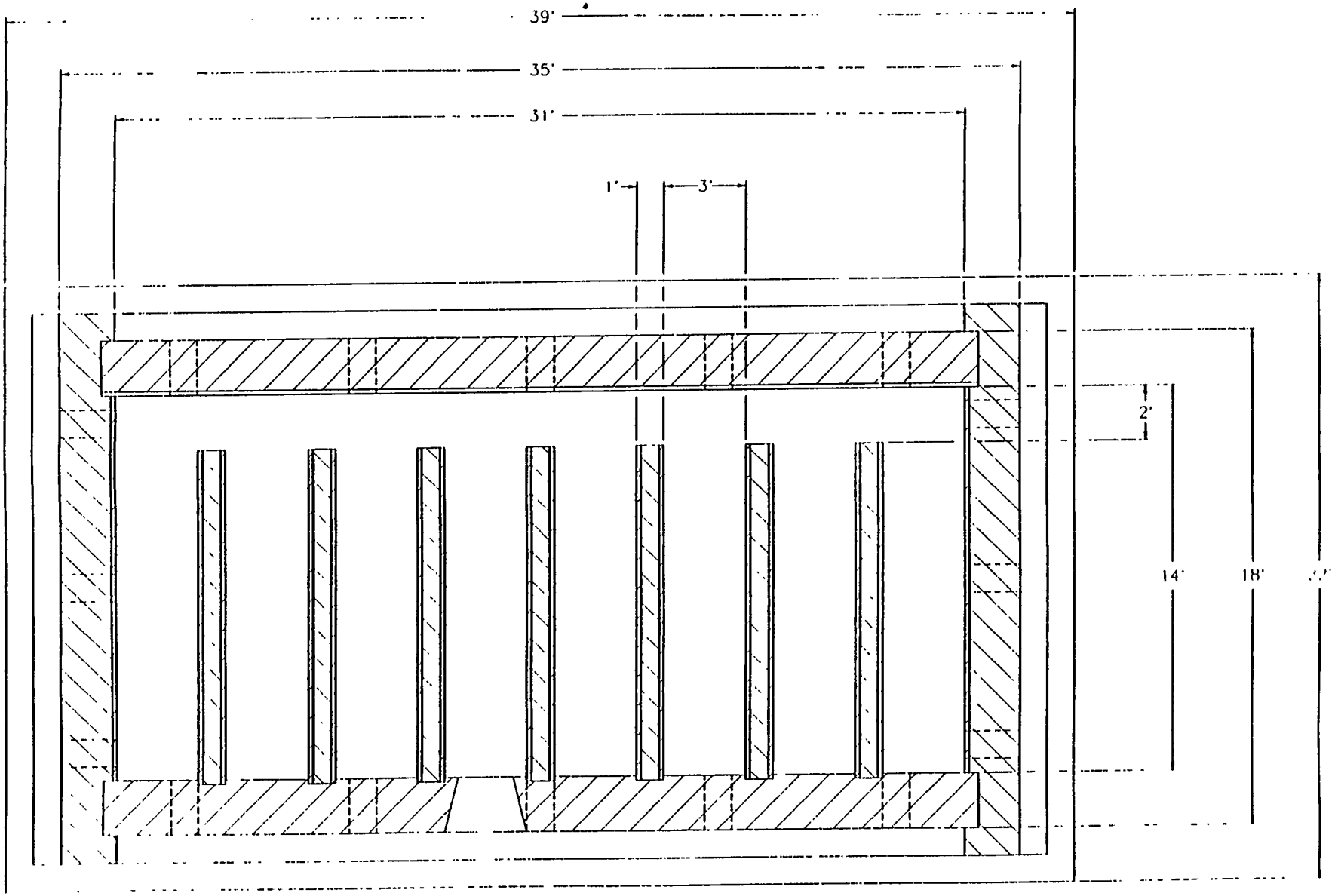


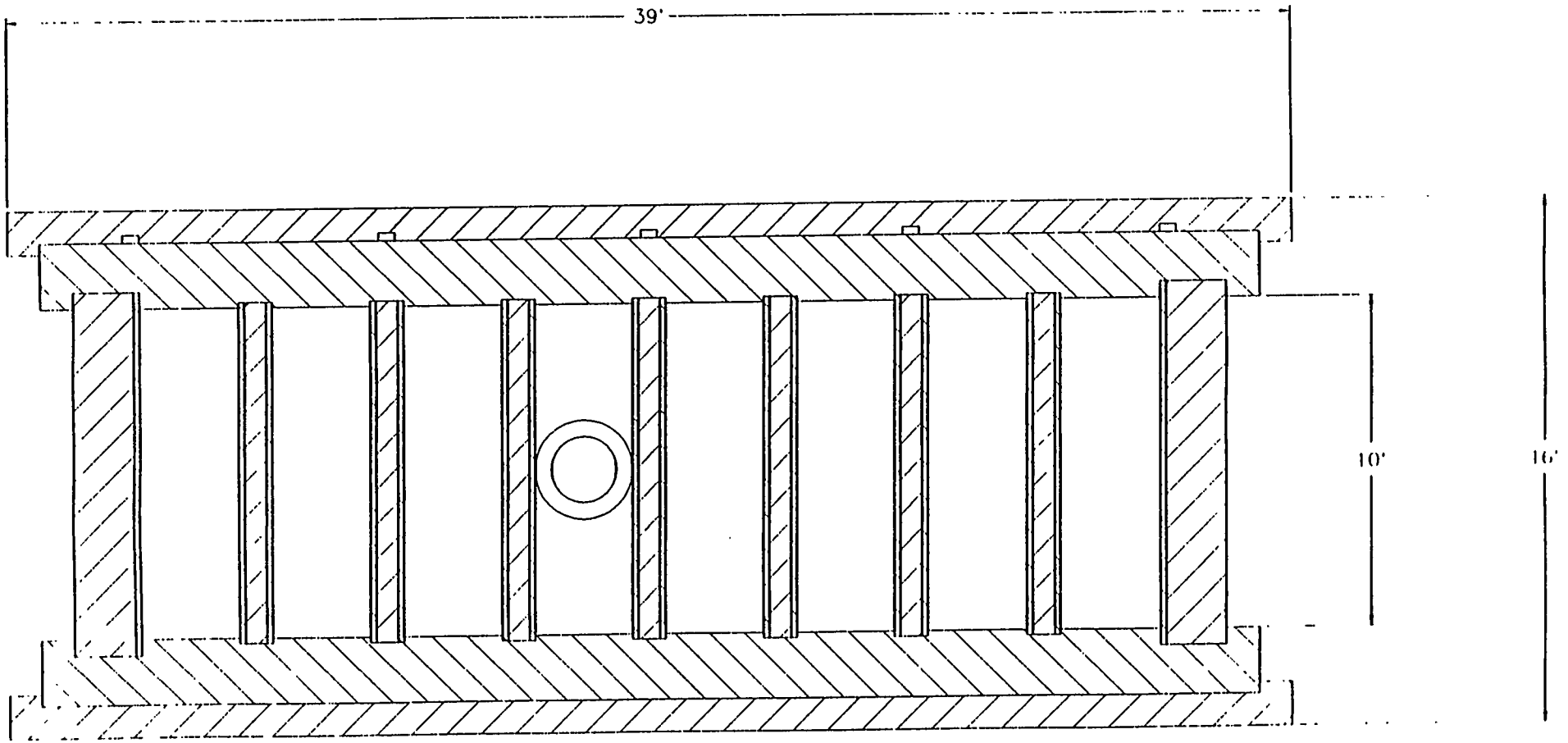
FIGURE VI-1



TOP VIEW
(NOT TO SCALE)

FIGURE VI-2

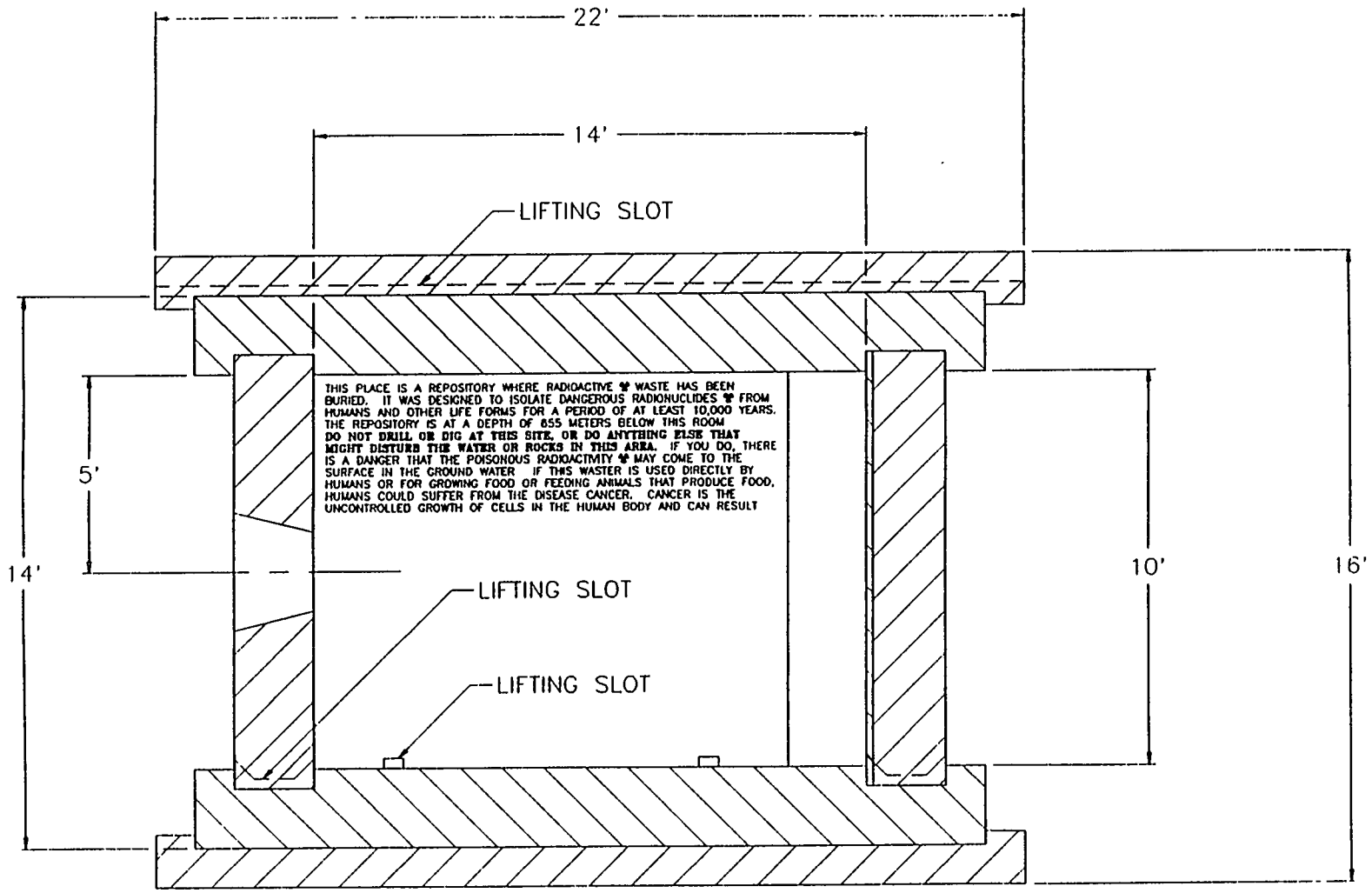
PM17



SIDE VIEW
(NOT TO SCALE)

FIGURE V-13

PM18



END VIEW

(NOT TO SCALE)

FIGURE VI-4

PM19

VII. INFORMATION CENTER

An isometric drawing of the Information Center shown in Figure VII-1 illustrates an above ground structure which contains the same information provided in the buried storage rooms. Construction of the Information Center is comprised of solid granite walls embedded in compacted caliche for support. Engraved on the walls is the Level IV message in seven languages and the graphics information provided in the storage rooms buried underground. In addition, the information center contains a diagram (Figure VII-2) of the PM system locating the buried rooms relative to the Information Center. The Information Center is an open structure allowing natural sunlight to illuminate the engraved information.

In addition to the Level IV message, the Information Center will also contain a message regarding the Storage Rooms. Figure VII-3 illustrates the proposed message. The message provides information for locating the rooms both in relation to the Information Center and by magnetic signature. The magnetic signature is developed by permanent magnets similar to those described in Section VIII below. The message also cautions not to excavate the Storage Rooms arbitrarily but to leave them alone for future generations as a backup in the event that the information presented on the Information Center walls has been lost. It also requests that the rooms be re-buried if conditions have caused them to become exposed. Figure VII-4 provides the dimensional characteristics of the Information Center exterior and interior walls. Placement of the walls and the relatively narrow spacing between the walls will minimize the erosion due to wind driven sand and rain. It is anticipated that barring vandalism, this structure and its information will endure as long as the monoliths. However, should history find this not to be the case, the information will also be available in the underground storage rooms.

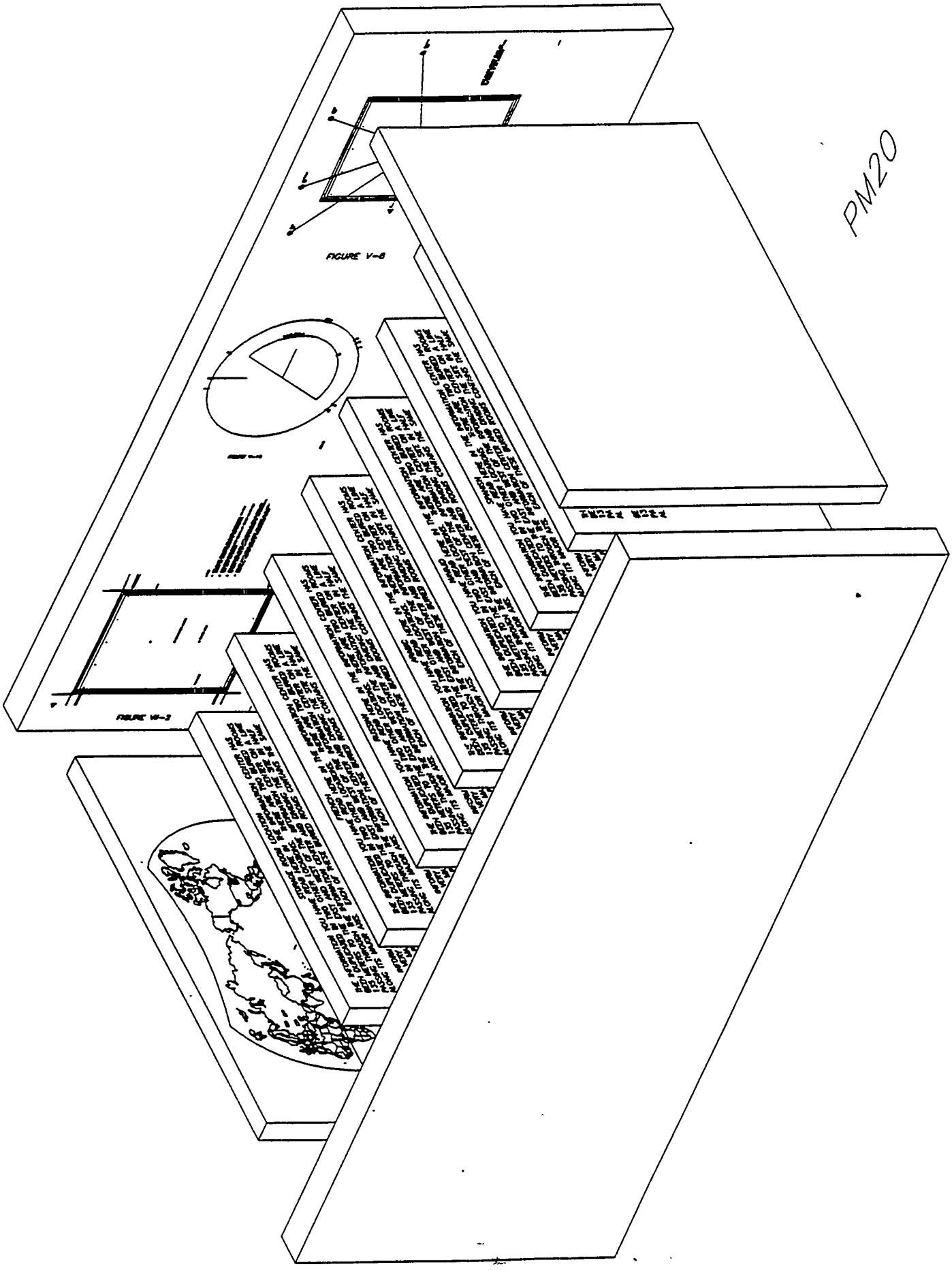
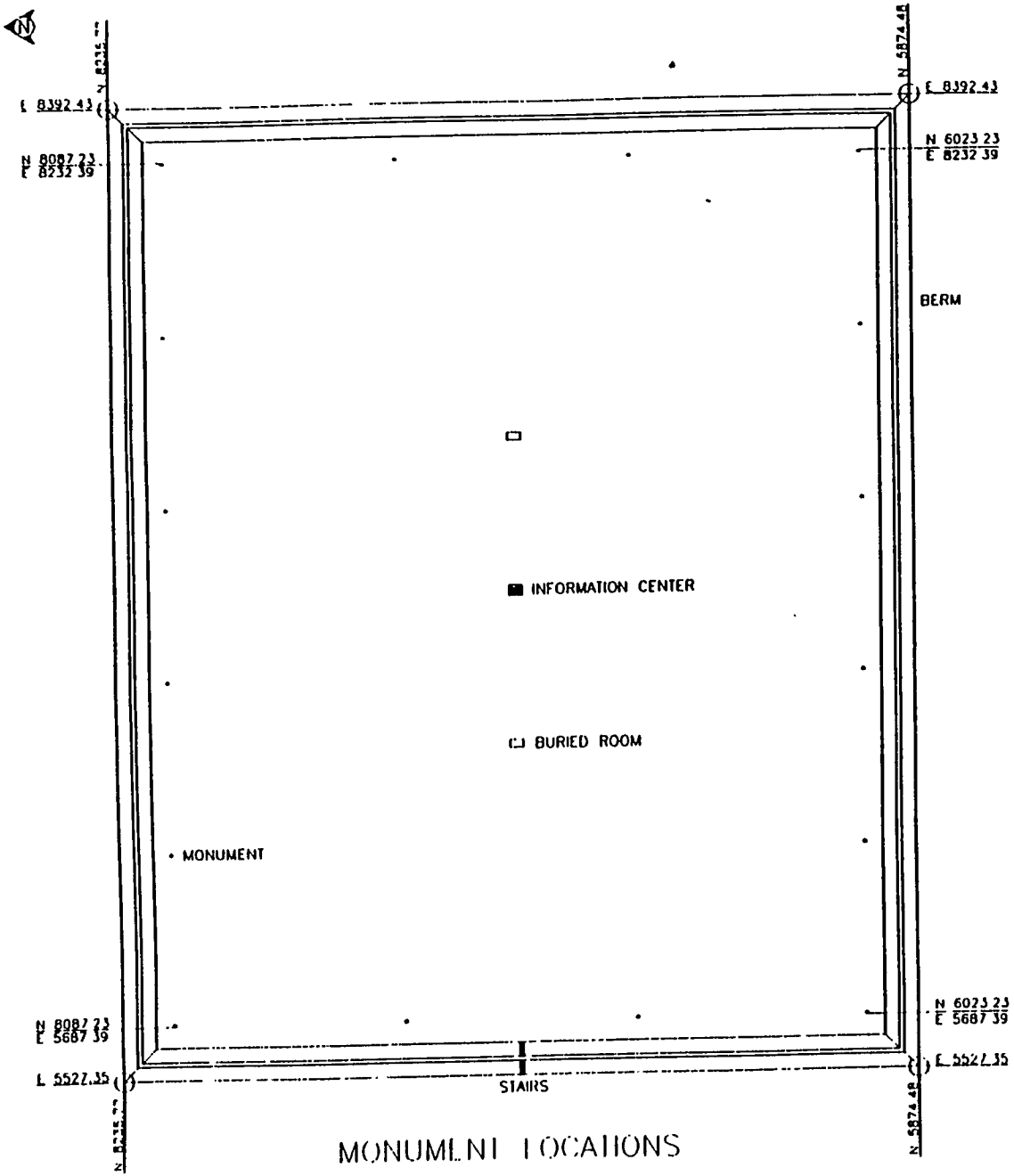


FIGURE VII-1



MONUMENT LOCATIONS

NOTES

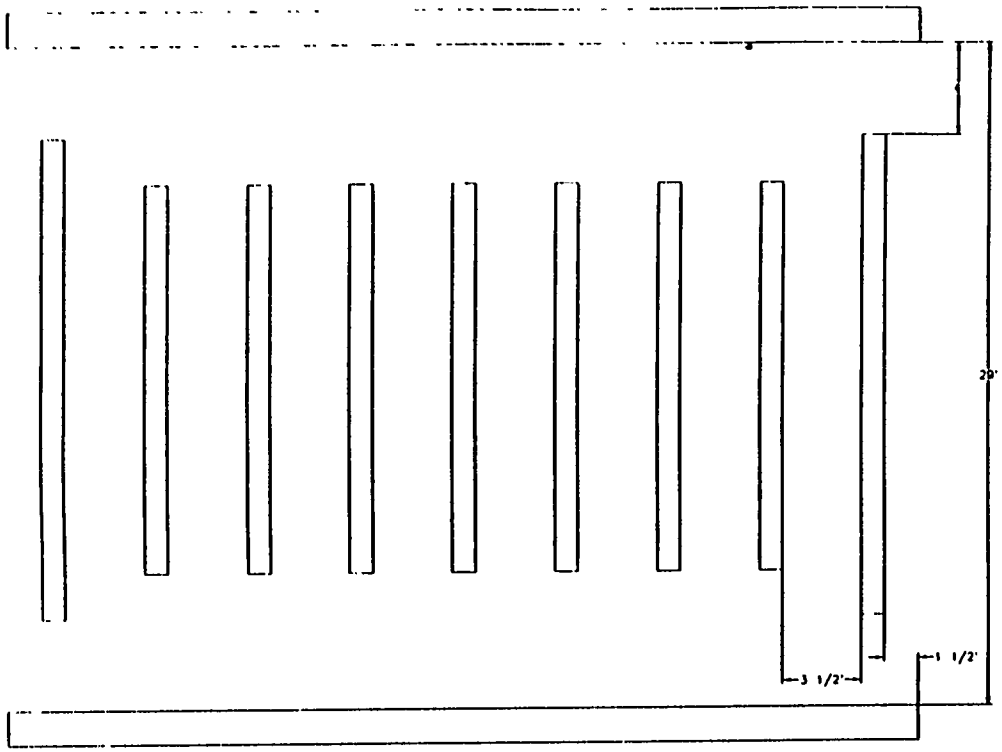
1. THE GRANITE MONUMENTS ARE PLACED APPROXIMATELY 500 FEET APART ON THE NORTH AND SOUTH SIDES OF THE REPOSITORY FOOTPRINT AND APPROXIMATELY 700 FEET APART ON THE EAST AND WEST SIDES OF THE REPOSITORY FOOTPRINT
2. EACH MONUMENT IS FOUR FEET SQUARE AND STANDS TWELVE FEET ABOVE THE SURFACE
3. THE INFORMATION CENTER, WHICH COVERS AN AREA OF FORTY FEET BY THIRTY TWO FEET, IS LOCATED IN THE CENTER OF THE REPOSITORY
4. THE TWO BURIED ROOMS ARE LOCATED 135 METERS ON AN EAST WEST PLANE FROM THE CENTER OF THE INFORMATION CENTER

FIGURE A-1-1

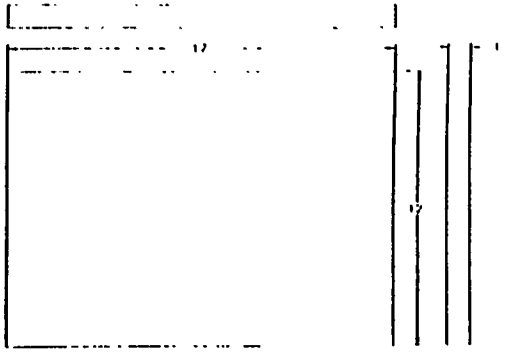
STORAGE ROOM LOCATION

THE INFORMATION YOU HAVE READ HERE IN THE INFORMATION CENTER HAS BEEN DUPLICATED IN TWO OTHER LOCATIONS. THERE ARE TWO BURIED ROOMS 135 METERS TO THE EAST AND WEST OF THE INFORMATION CENTER ON A LINE PASSING THROUGH THE INFORMATION CENTER AND DIVIDING THE SITE IN HALF ALONG ITS MAJOR AXIS. EACH OF THESE BURIED ROOMS CONTAINS THE SAME INFORMATION YOU HAVE FOUND HERE. THE CONSTRUCTION OF THE ROOMS IS VERY SIMILAR TO THE INFORMATION CENTER. THE BURIED LOCATIONS ARE MARKED BY PERMANENT MAGNETS AT EACH LOCATION. THESE ROOMS WERE PLACED APPROXIMATELY 7 METERS BELOW THE SURFACE WHEN ORIGINALLY BURIED. DO NOT EXPOSE THESE ROOMS UNLESS THE INFORMATION PRESENTED IN THIS CENTER HAS BECOME WEATHERED OR OTHERWISE OBLITERATED BEYOND RECOVERY. LEAVE THE BURIED ROOMS FOR FUTURE GENERATIONS. IF THE BURIED ROOMS HAVE BECOME EXPOSED, PROTECT THEM BY ADDITIONAL COVERING.

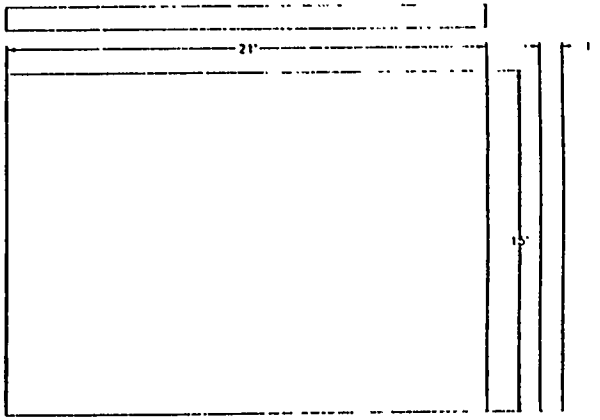
FIGURE VII-3



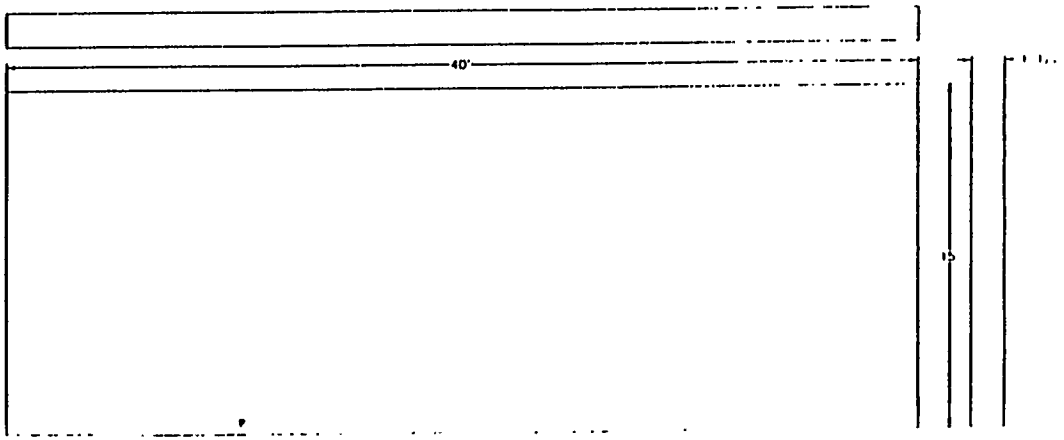
INFORMATION CENTER



INTERIOR WALL



CENTER EXTERIOR WALL



LARGE OUTER EXTERIOR WALL

NOTE
INDIVIDUAL STRUCTURES SHOULD BE SOLID GRANITE SECTIONS MESSAGES SHALL BE ENGRAVED ON BOTH SIDES OF THE INTERIOR WALLS AND ON THE INSIDE OF THE EXTERIOR WALLS

VIII. BERM CONFIGURATION

The premise to base a PM design on the construction of a berm or berm like structure is based upon the following arguments:

- The structure should identify the extent of the surface footprint of the repository but need not follow the footprint outline
- The structure should be sufficiently massive to provide reasonable assurance that it will endure for 10,000 years
- The structure's profile should minimize the likelihood that it can become buried by shifting sands or that characteristics of the profile may lead to fabrication stresses affecting the ability of the structure to retain its configuration
- It should be constructable without the need for high tech equipment or processes
- Its construction materials should be reasonably available to the WIPP site and have as little intrinsic value as is reasonable
- Its cost should be competitive with other alternatives. That is to say its cost should not be disproportionately high for the advantages it provides
- To the extent practicable the nature of the structure should lend itself to valid testing over a period of 2-5 decades

Trauth 1993 explores a number of different techniques and structures for defining the repository's surface footprint. Characteristics unique to the individual structures identified and the resulting recommendation from each of the two teams is to use a berm like configuration. A berm also meets the arguments listed above to a greater extent than any of the other configurations proposed. Each of the conceptual design configurations described below make use of a berm configuration. Although the individual configurations may have an outwardly different appearance, their construction consists of similar materials and material placement. Figure VIII-1 depicts the general cross-sectional berm construction configuration. The core base material to be used is salt remaining from the excavation of the repository. The design capacity of the repository of 6,200,000 ft^3 will provide a

significant amount of material remaining after closure. This material will be used to form the core of the berm(s). Although the salt would be susceptible to water and wind erosion if left unprotected, using it as a base core material for the berm with other material applied as a protective cover should effectively protect the salt. The WIPP site is in a semi-arid region in which, for the worst case, the rainfall will no more than double in the next 10,000 years (Swift 1992). Therefore it is reasonable to assume that water erosion will not become a major issue with respect to berm durability.

A practical and locally available protective covering for the salt core is the caliche soil found locally up to 15 feet below the surface. Large quantities are available. The caliche is reasonably impervious to water penetration in the semi-arid environment of the WIPP. Studies of the locale report that even at the height of an ice age, the annual rainfall is not expected to more than double its current 13 inches per year average. Therefore 2-3 meters of caliche compacted over the salt core should provide significant protection of the salt from water.

A third layer of berm material will be comprised of riprap quarried near Carlsbad, NM. This will provide protection for the caliche from wind erosion. It will also provide for runoff of rainwater to the surrounding desert with minimum water erosion of the caliche layer. The final layer of berm material will consist of a mixture of riprap and native soil. This should support local vegetation and add another erosion resistant characteristic to the overall berm configuration. During the disposal phase of the WIPP, testing will be conducted to determine what combination of rock sizes, soil, and vegetation provide the best likelihood of success, at least in the near term (100 years).

To provide a unique magnetic signature for the berm with respect to the local geology as recommended in Trauth 1993, an investigation into the use of magnetite as a layered material over the salt was conducted. Although magnetite in its natural state often demonstrates a detectable magnetic anomaly, large quantities removed by mining and transported to another locale for the purpose of providing a local detectable magnetic anomaly may not be a prudent course of action. In its natural state, the mineral magnetite (Fe_3O_4) develops its magnetic signal through induced magnetism from the earth's own magnetic field over eons of time. When mined, the magnetite material becomes mixed up and the individual dipoles will not

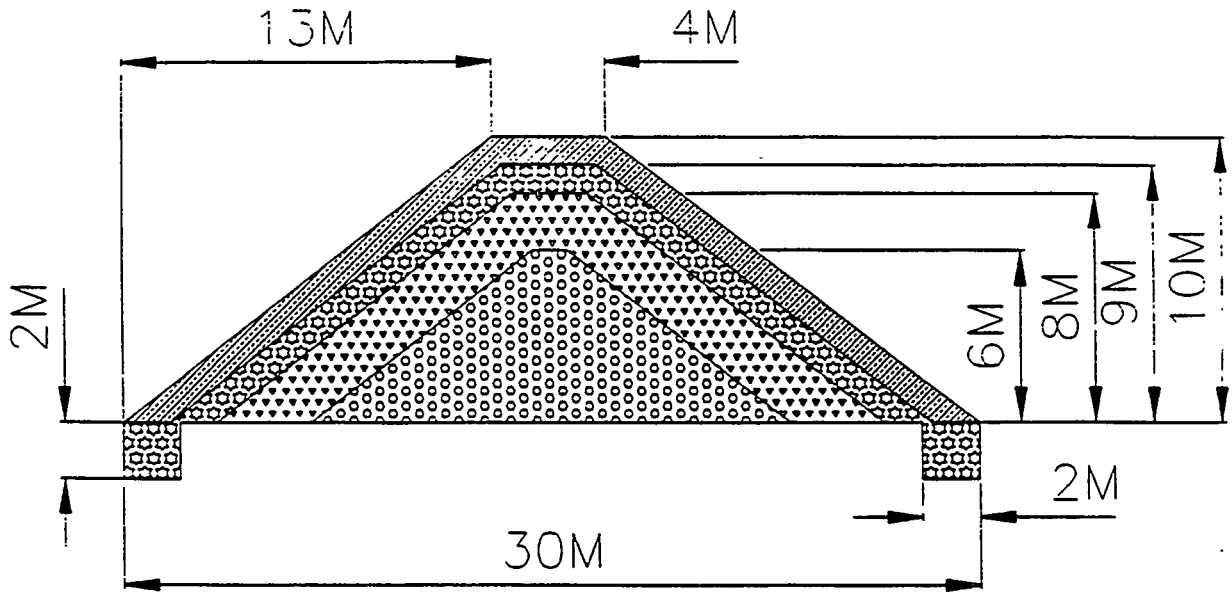
all be aligned to reinforce each other as is found in the natural state. Large quantities of the mineral after being emplaced could be magnetized with a large electromagnet. However, the practicality of successfully completing such a task would require considerable effort to demonstrate and evaluate. Even if successful the retention of the artificially induced magnetic field over thousands of years is unknown and could not be determined with a high degree of certainty. In view of the shortcomings of magnetite, a unique magnetic signature will be provided by large permanent magnets.

To provide a distinctive magnetic signature for the berm, large permanent magnets buried in the berm can be used, Mallick 1994 and Krefta 1994. Large strontium ferrite permanent magnets buried within the berm at intervals of 75-100 meters would give a signal detectable with current state of the art airborne equipment 100 meters above the magnets. The individual magnets would be approximately 1 meter in length and 1/2 meter by 1/2 meter in cross-section. Should future climatic conditions cause sand shifts so extensive that the berm and monoliths become covered (not expected), future generations conducting magnetic surveys of the area should still be able to detect a magnetic anomaly resulting from the permanent magnets. The magnetic signal's geometric form will provide strong indication that it could only have been man made. This should inspire any organization capable of magnetic surveying to investigate this anomaly further prior to initiating any planned drilling activities in the local area enclosed by the magnetic signature.

Bellus 1994 provides a description of the use of trihedrals fabricated from metal as a means of providing a radar reflective signature unique from the surrounding terrain. Figure VIII-2 illustrates the basic trihedral configuration. Current ground penetrating radars operate below 100MHz. Much of the communication allocations occupy frequencies below 100MHz, therefore, radars operating below this range must use filters to avoid problems with communications bands. Bellus reports that recent experience in the middle east with SeaSat operating at 1.2GHz produced excellent images of roads and structures buried under the desert.

The dimensional characteristics of a trihedral facet that will give a peak Radar Cross Section (RCS) is 3X the wave length of the incident radar signal. Assuming a radar operating at 1 GHz, a trihedral with facets measuring 0.9 meters on a side will be optimal. This will provide a peak RCS of 17dBsm/sm (decibels square meter per square meter), Bellus 1994. The

typical peak terrain RCS is -15dBsm/sm. The difference in RCS strength operating at 1 GHz is 32 dBsm/sm. This will give a highly visible signal. The trihedrals will be fabricated from stainless steel and placed within the berm at the surface of the salt core. To provide a unique radar signature, the trihedrals will be grouped in sets of four spaced approximately every 91M (300 feet) around in the berm as shown in Figure VIII-3. In addition, four trihedrals will be placed around each of the buried rooms to provide a unique radar signature at the room location. One trihedral will be placed adjacent to each room exterior wall approximately midway along the wall. During the testing period conducted throughout the disposal phase and for some period after decommissioning, buried bare stainless steel trihedrals and trihedrals encased in concrete should be evaluated for performance of their respective RCS. Encasing the trihedral in concrete reduces the likelihood of its being efficiently salvaged and also may add to the effective lifetime of the trihedral by the protective concrete covering.



BERM CROSS SECTION

BERM CONSTRUCTION PROFILE

NOT TO SCALE

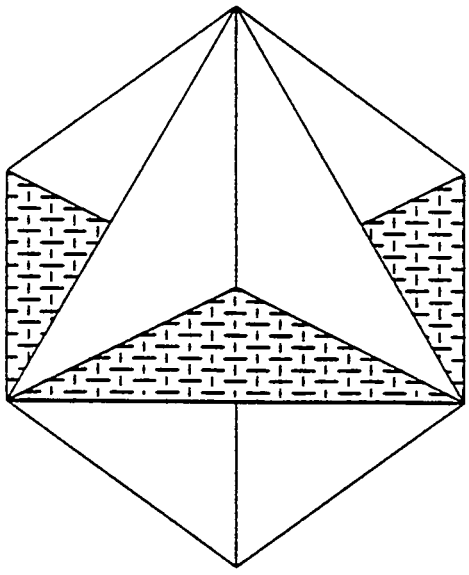
SALT

CALICHE

RIPRAP

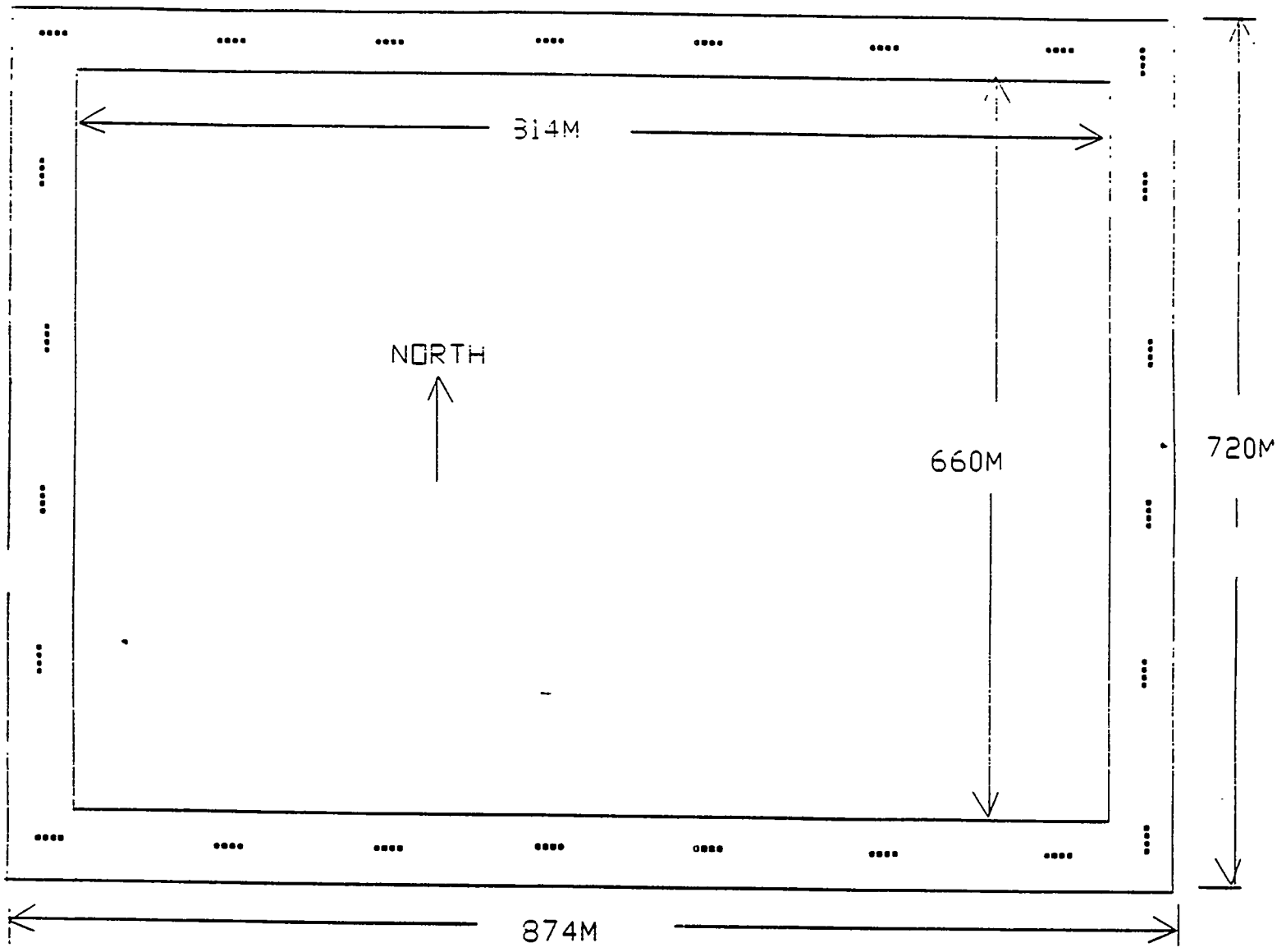
SOIL/RIPRAP

FIGURE VIII-1



TRIHEDRAL CONFIGURATION

FIGURE VIII-2



GENERAL TRIHEDRAL ARRANGEMENT

FIGURE VIII-3

IX. TESTING

Upon closure of the WIPP, at the conclusion of the Disposal Phase, active controls will be implemented to control the access to the site and long term monitoring systems will be managed to detect significant deviations in repository performance. With active control provided over the site, the schedule for construction of the PM system is a management option which could be extended out to decades after disposal. In that the design of the PM system has a 10,000 year lifetime goal, it is prudent that the DOE conduct some long range testing of the construction materials planned for use as PM material.

One aspect of the long term testing is the construction of a section of the berm. The overall size (height and width) of the test section of the berm will match the design of the PM berm. However, the test berm length will be shorter than the full size berm. A section approximately 50 to 100 meters will provide a length sufficient to test a number of different configurations. Included within the test section will be varying thicknesses of the salt core, the caliche layer, and the top layer of riprap and soil material. The DOE will construct a section of the berm for the purpose of evaluating materials and construction techniques. Actual construction and testing will initiate during the Disposal Phase to provide a maximal time for testing. The major subjects which may be evaluated during this testing program are:

- The system for unloading and moving large quantities of material from the railroad spur to the PM site
- Performance of the railroad spur and maintenance required. This may impact a decision of whether to conduct periodic maintenance of the spur or refurbish it at the time of initiating construction of the PM system
- Survey representative monuments within a 150 mile radius of the WIPP to more extensively evaluate the climatic environmental affects on granite
- Identification of a suitable local source of caliche and establishing the required contractual and regulatory agreements to obtain and move the caliche in the quantities required
- Identification of a suitable local source of riprap and establishing the required contractual and regulatory agreements to obtain and move the riprap in the

quantities required

- Construction techniques applicable to a large berm. Determine what, if any, configuration changes may have significant impacts on the cost of construction

- Evaluate various berm surface materials (e.g., size of rocks, types of soil, types of vegetation) for durability and success in supporting vegetation overgrowth

- Procure, ship, erect, and evaluate long term environmental effects of wind, rain, and shifting sand for various types of monument rock (granites and sandstones). This will provide experience to be applied for contractual specifications developed for procurement and erection of multiple monuments. In addition concrete should be emplaced underground and tested for durability as a substitute for the granite in construction of the Storage Rooms proposed above

- Evaluate the magnetic signature provided by sample permanent magnets buried within the berm to determine optimum locations and spacing

- Evaluate the affects of various soils used as protective backfill for granites and sandstones

- Evaluate the effects of chemical interaction with the backfill material

- Evaluate the environmental effects on the berm caused by wind, rain, and shifting sand including the depth of infiltration under a variety of climatic conditions

- Evaluate the effects of plant root and burrowing animal intrusion into the berm and potential for salt dissolution and berm slumping

- Evaluate the effectiveness of sample radar reflectors buried within the berm at various distances. Evaluations should include reflectors directly buried in the berm and buried reflectors encased in concrete

- Develop cost estimates for various options of configurations and materials tested

Other testing to be conducted should address the refinement of the messages, diagrams, and the method of presentation. As recommended in Trauth 1993, the translated versions of the

message text should be evaluated by presentations to groups indigenous to the countries whose language is represented in the message. This should provide input into how comprehensible the messages are. When considering that the messages were developed by educated individuals residing in the U.S., it is prudent that the effectiveness of the messages to convey their intended content to a broader cross-section of individuals be thoroughly tested. The testing therefore should include cross-cultural groups in evaluating the effectiveness of conveying the intended messages through diagrams and pictures as well as script.

Testing also should be conducted on the various materials used for the warning markers buried near the surface. Warning markers made of aluminum oxide, granite, fired clay, glass (specifically lanthanumborate made by Corning, Trauth 1993), and polyethylene should be fabricated and buried at depths of 1.5M-3M (5-10 feet) below the surface. It is anticipated that subsurface warning markers made from some of these materials will be used in the final design. However, by burying these "test" warning markers for 40-60 years and then evaluating their condition it can be established whether some of these materials seem unsuitable for burying in the WIPP soil/caliche environment. Each of the "test" warning markers should also be engraved with the Level II message.

During a conversation with the proprietor of a Carlsbad, NM memorial distributor it was determined that local experience with granite memorials in cemeteries indicate that artificial watering accelerates the weathering of granite. Therefore, any judgments made with respect to the effects of weathering due to local conditions would be biased by the artificial watering phenomenon. To provide for a more accurate assessment of the environmental effects on granite at the WIPP site, granite monuments made from materials from multiple quarries within the U.S. will be engraved and emplaced at the WIPP site during the disposal phase. Over a period of decades, data will be taken to better judge the affect of weathering on both the granite material and the lettering. The data will be developed for both the buried and above ground surfaces. These data will then be used in developing the final design specifications for the monolithic monuments emplaced as permanent markers.

A variety of permanent magnet materials and protective coating for the magnets should be buried at the bottom of the berm. In addition, this permanent magnet test program should evaluate the effectiveness of providing a directional magnetic signal. These signals should be detectable from an airplane

equipped with appropriate equipment. Testing should also be conducted at ground level to verify detectability. Verification of the capability to permit the fixing of a particular location within the repository footprint through triangulation of multiple magnetic signals should also be conducted. Subsequent to being buried for a significant number of years, the magnets should be recovered and the condition evaluated against the risk of their failure over a 10,000 year period. At least one manufacturer stated that some permanent magnets lose their strength at the rate of 0.1% per 10,000 hours. If this is a constant rate, a magnet would only have 10% of its strength remaining after about 2700 years.

X. CONCEPTUAL DESIGN A

Figure X-1 represents the surface plan view of design A. The salient features of this PM design consist of the repository footprint delineated by monolithic monuments along the rectangular perimeter with an earthen berm constructed in the shape of a Trefoil. At the center of the trefoil is the Information Center described above. The trefoil is built up of halite (salt) originally excavated from the repository, caliche, riprap, and a mixture of riprap and soil used to support vegetation on the surface of the berm. The type of vegetation planted on the berm should be representative of vegetation occurring in the local WIPP region.

Figure X-2 provides a cross-sectional view with dimensional characteristics for the trefoil circle and typical trefoil circle sections. Ghosted in the figure is the repository footprint. This illustrates the relative location of the trefoil over the actual repository. As shown in Figure X-1, the footprint outline is described by the monuments erected outside of the trefoil dimensions. Approximately 1,100,000 M^3 of material would be required for the trefoil. Buried within the trefoil and the remainder of the site are the small warning markers described above.

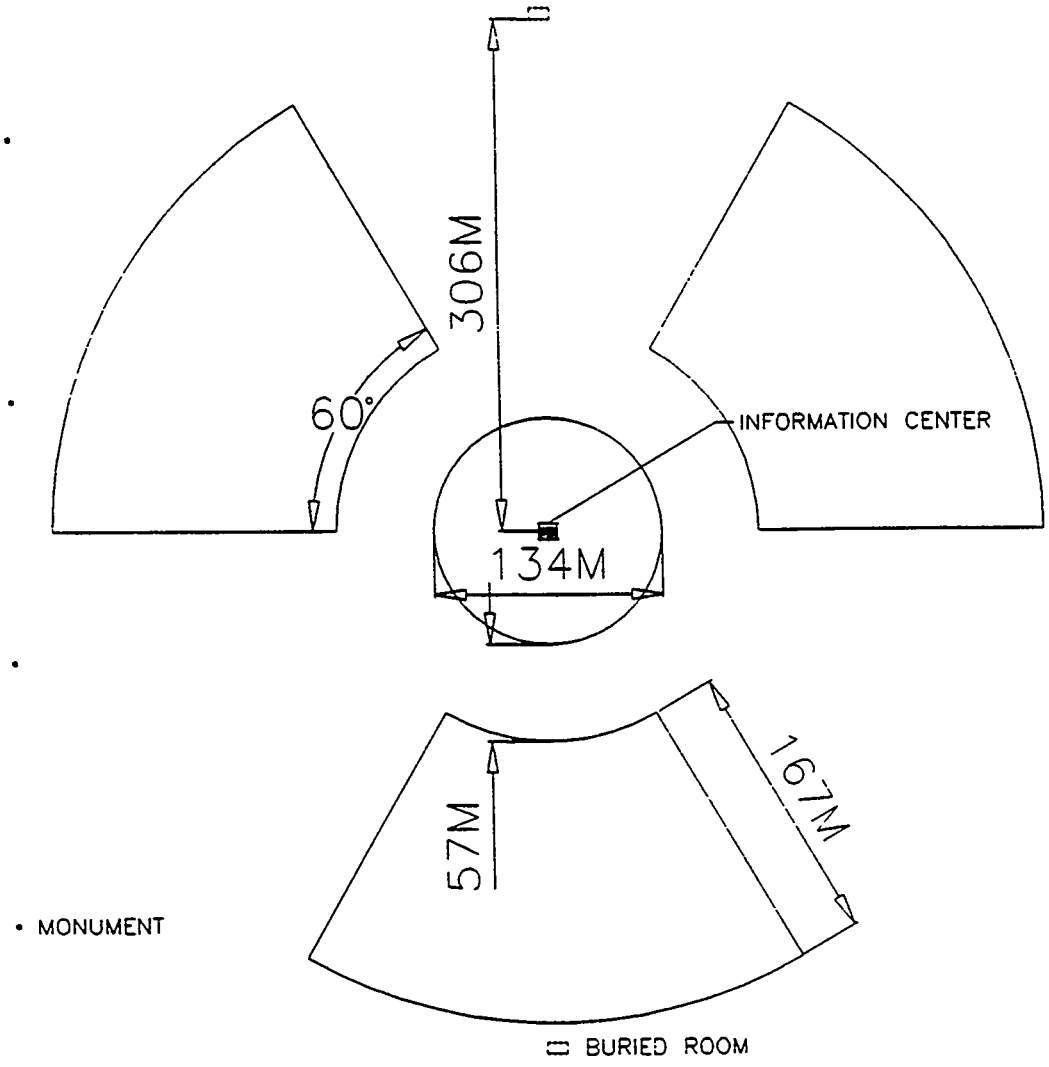
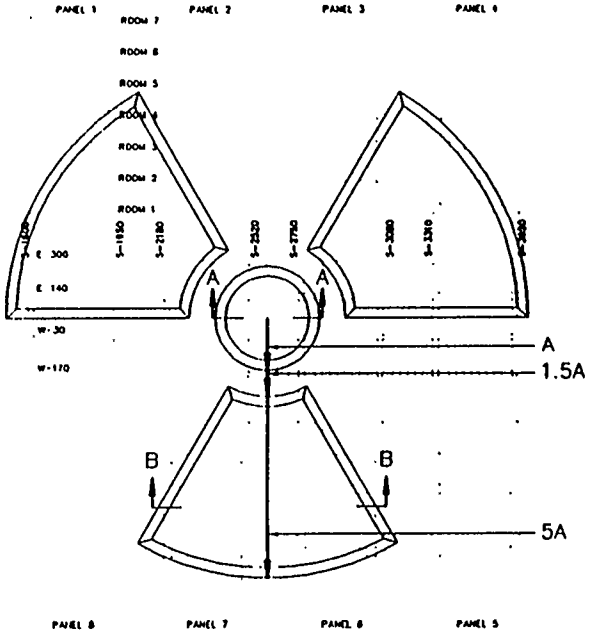
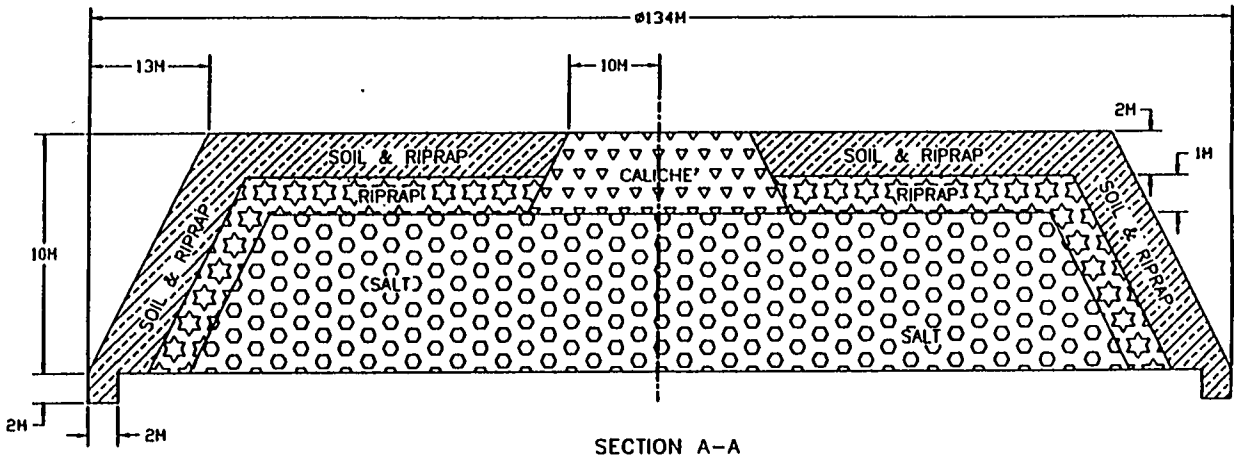

306M
60°
INFORMATION CENTER
134M
57M
167M
• MONUMENT
BURIED ROOM

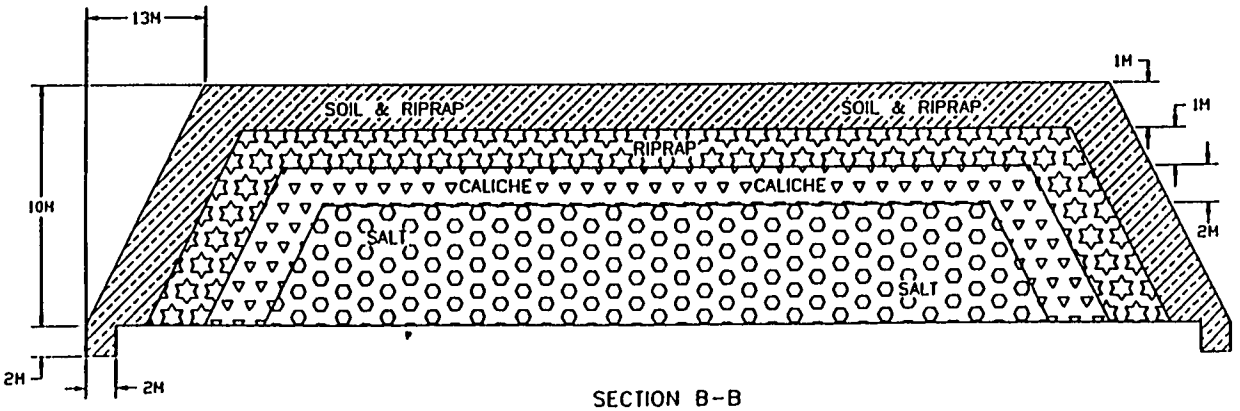
FIGURE X—1

TREFOIL





SECTION A-A



SECTION B-B

CALICHE

SOIL/RIPRAP

RIPRAP

SALT

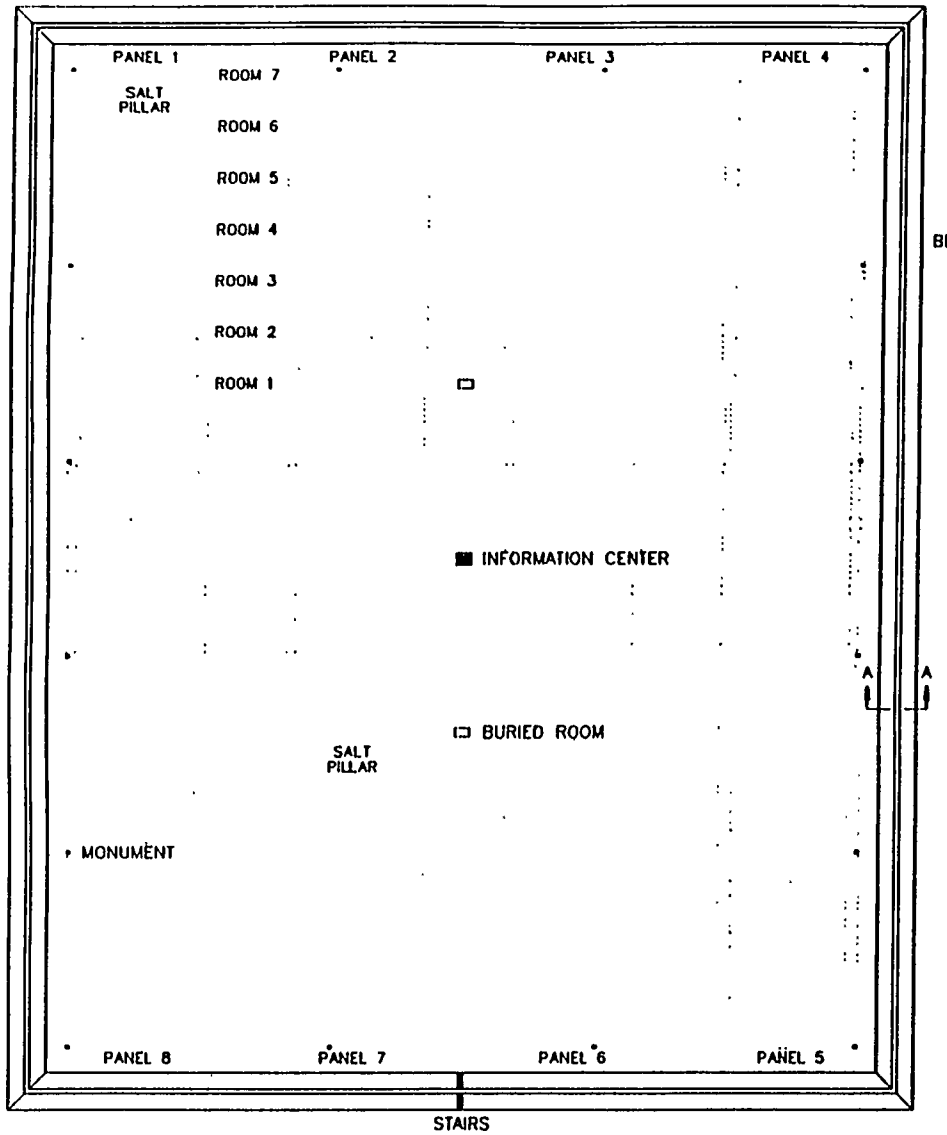
NOTE - THE AREA OF THIS DRAWING SHOWING THE TREFOIL COVERING THE REPOSITORY IS DRAWN TO SCALE SECTIONS A-A AND B-B ARE NOT DRAWN TO SCALE. THE FORMULA FOR A TREFOIL IS AS SHOWN ABOVE. THE INNER CIRCLE RADIUS IS A THE INNER AND OUTER ARCS OF THE OUTER SECTION ARE 1.5A AND 5A THE OUTER SEGMENTS COVER AN AREA OF 60° AND ARE 60° APART

FIGURE X-2
65

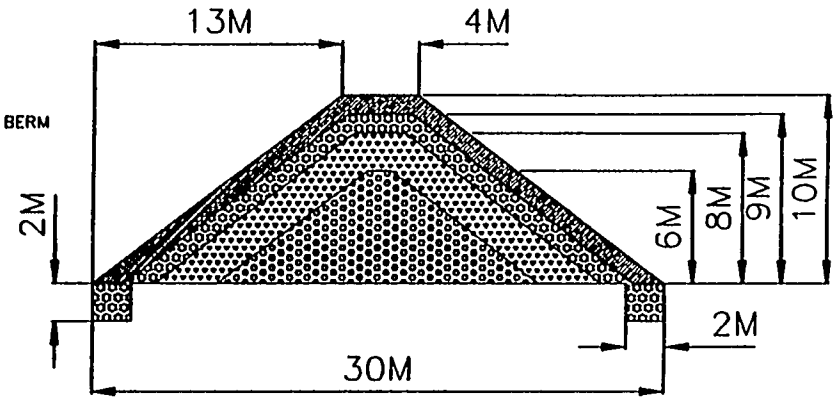
XI. CONCEPTUAL DESIGN B

Figure XI-1 represents the surface plan view of design B. The repository footprint and its panels, rooms, and salt pillars are ghosted with dotted lines within the berm area. This design concept features a rectangular berm enclosing the repository footprint and slightly larger than the footprint dimensions. Immediately within the berm enclosure and along the dimensional perimeter of the repository footprint, the sixteen (16) granite monoliths are emplaced. At the center of the footprint, the Information Center described above is erected. The small warning markers are buried below the surface throughout the footprint area. Within the enclosed footprint the two Storage Rooms containing the level IV message are buried approximately 6M (20 feet) below the surface. Access across the berm will be provided by a stairway along the berm's western edge.

Outside the berm perimeter the concrete Hot Cell structure will remain as an archeological remnant. During the test program, the Hot Cell structure will be periodically monitored to determine the erosion resistance of concrete in the WIPP environment. The stairway will be constructed of concrete or granite stones. The volume of material required to construct the berm is approximately 535,000 M^3. This is considerably less material than is required by design concepts A or C.



BERM LOCATION



SECTION A–A
BERM CONSTRUCTION PROFILE
NOT TO SCALE

SALT
CALICHE
RIPRAP
SOIL/RIPRAP

NOTES:

1. THE DISOPOSAL AREA PERIMETER MEASURES 629M BY 776M.
2. THE INNER PERIMETER OF THE BERM MEASURES 660M BY 814M.
3. THE OUTER PERIMETER OF THE BERM MEASURES 720M BY 874M.
4. PANELS, ROOMS, AND SALT PILLARS REFER TO THE REPOSITORY FOOTPRINT SHOWN AS DOTTED LINES.

FIGURE XI-1

XII. CONCEPTUAL DESIGN C

Figure XII-1 represents the surface plan view of design C. This design concept incorporates the "Menacing Earthworks" concept recommended in Trauth 1993. Sections of earthen berms radiate outward from the perimeter of the repository footprint. The repository footprint outline is described by the emplacement of sixteen (16) granite monoliths as utilized in designs A and B above. At each corner of the earthworks,a large earthwork structure is located. A Storage Room is buried within each of the four corner earthworks. Each Storage Room configuration is as described in Section VI. The Information Center is located at the center of the footprint and the small warning markers are buried within the footprint.

Figures XII-2 through XII-5 provide the profile structural details of the various earthwork configurations used to make up the "Menacing Earthworks" including the approximate total volume of material for each configuration. The various configurations and their mirror images are used in making up the total earthworks structure. The cross sectional material composition of the structure is similar to that shown in Figure XI-1. The total volume of material required to construct the berms is approximately 930,000 cubic meters. Discussions with at least one construction contractor raised some significant issues with respect to erecting earthworks configured as depicted in Concept C or any similar earthwork. Providing a steep slope (a ratio of 1.3:1.0 horizontal to vertical) combined with a zig-zag configuration results in a safety issue with respect to turning large construction equipment to create the zig-zag. This is especially true during the final stages when the top of the berm is narrowed. Increasing the width of the berm top, or increasing the slope adds additional material either in a higher profile or a broader base. This increases the expense of the construction effort. In addition, those portions of individual earth work configurations which have a narrow or almost non-existent upper roadway offer an additional construction difficulty. Conventional berm or earth dam construction activities will not lend themselves to the final stages of construction for those berm portions which have no upper roadway.

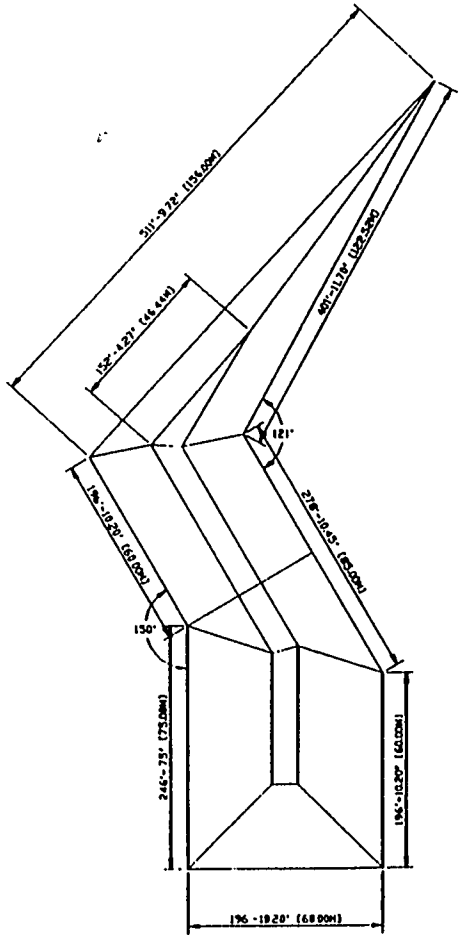
Conducting an informal survey of what the "menacing earthworks" conveyed among technical individuals not associated with intrusion scenarios provided some interesting results. When asked what the configuration conveyed, no one answered that it conjured up anything menacing. Typical responses were:

- Visitors from outer space were here
- It is definitely manmade and not a natural phenomenon
- It looks like a barrier protecting the confined space
- Some kind of Indian hieroglyphics

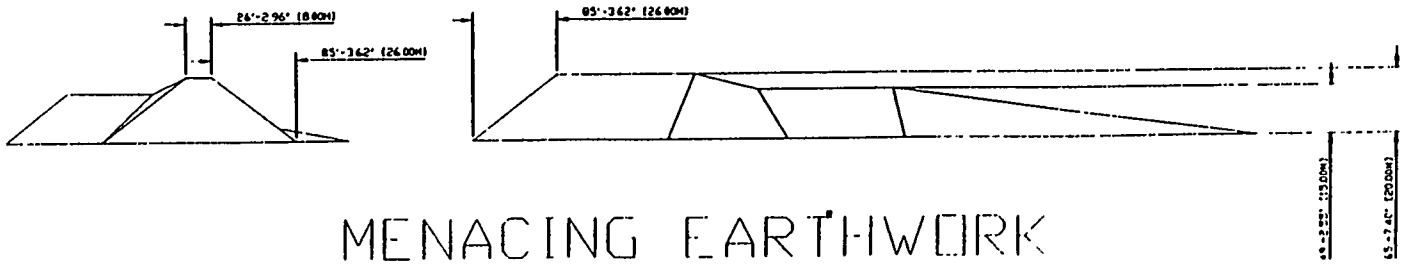
MENACING EARTHWORKS

FIGURE XII—1

FIGURE XII-2

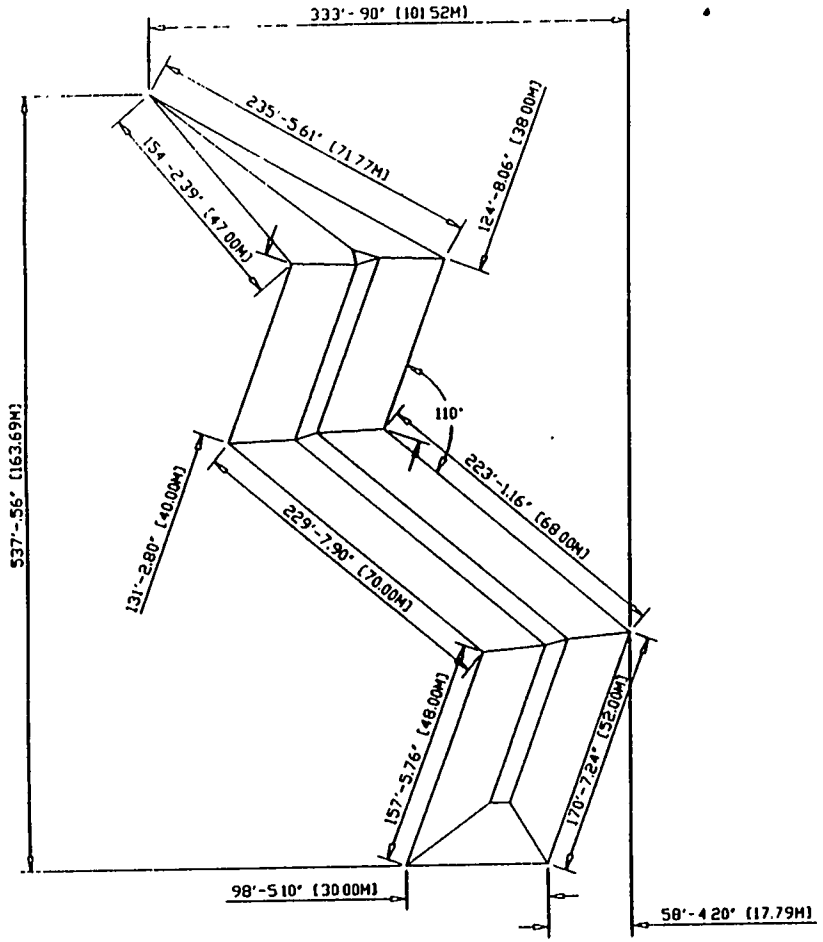


$$V_T = 76{,}243\ M^3$$

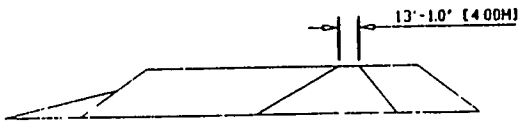


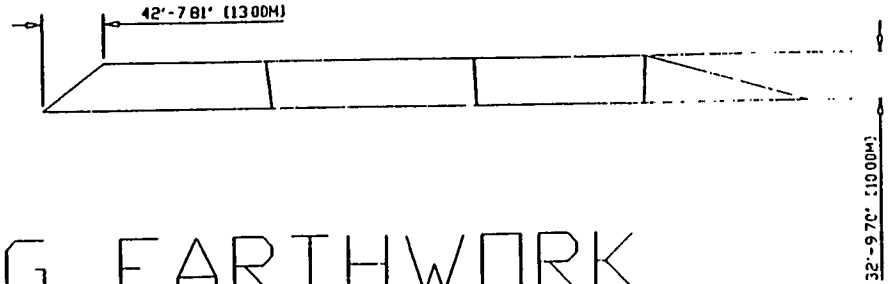
MENACING EARTHWORK

PM.99



$$V_T = 27{,}854\ M^3$$



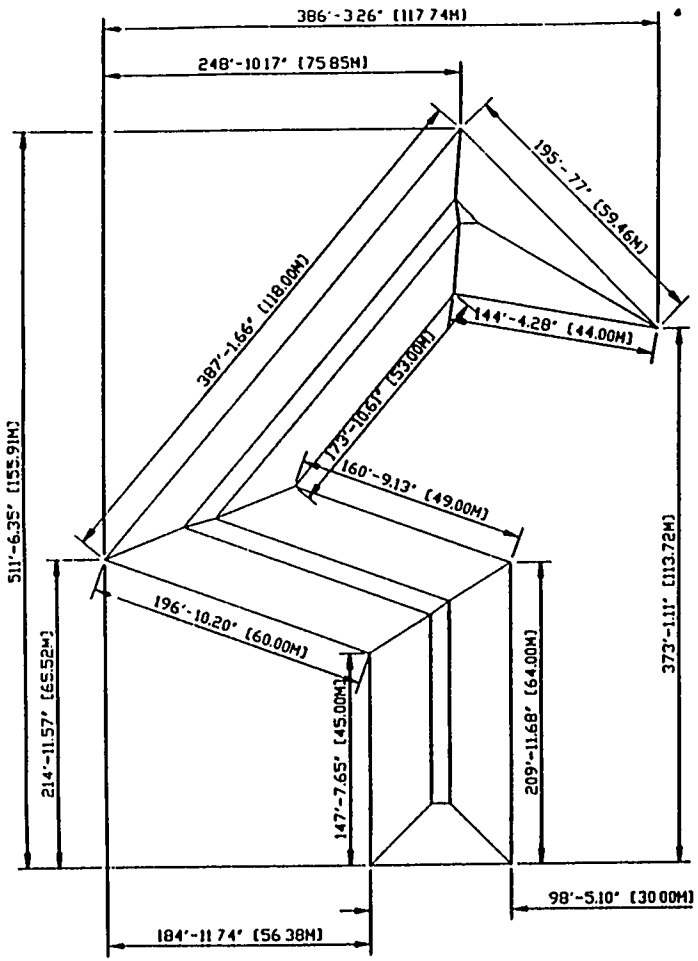


MENACING EARTHWORK

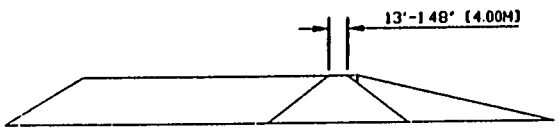
FIGURE XII.3

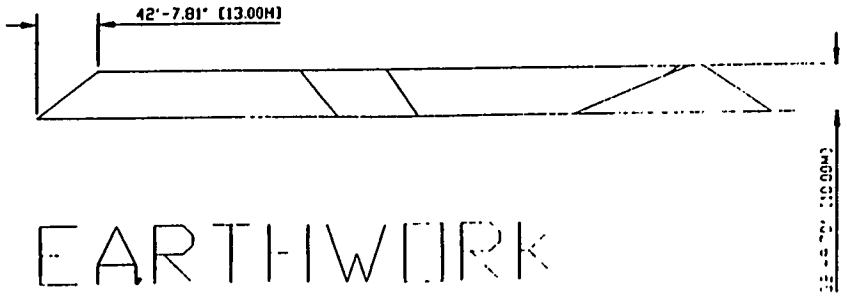
I'M

FIGURE XII-4



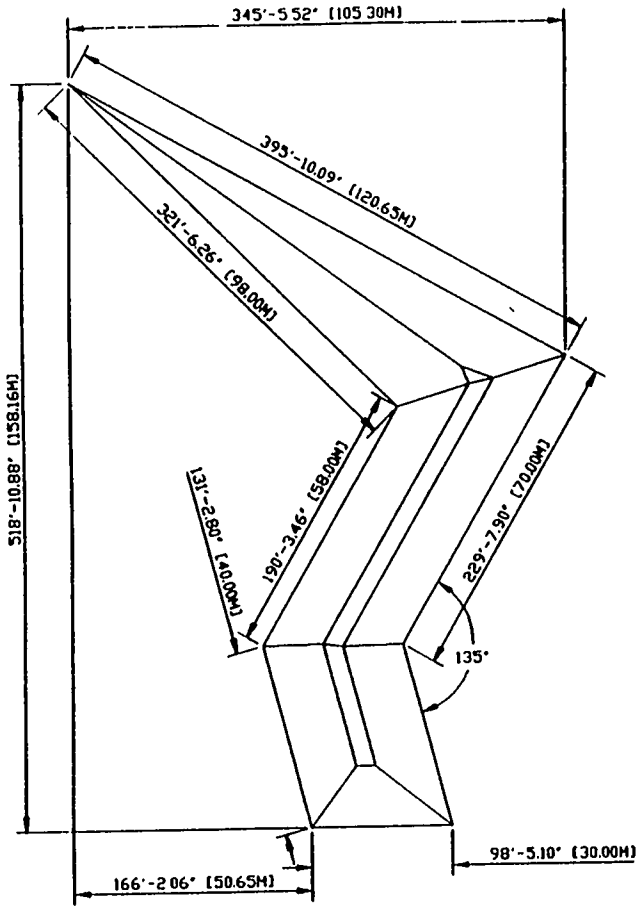
$$V_T = 30{,}898\ M^3$$



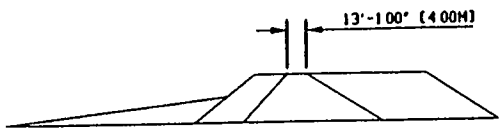


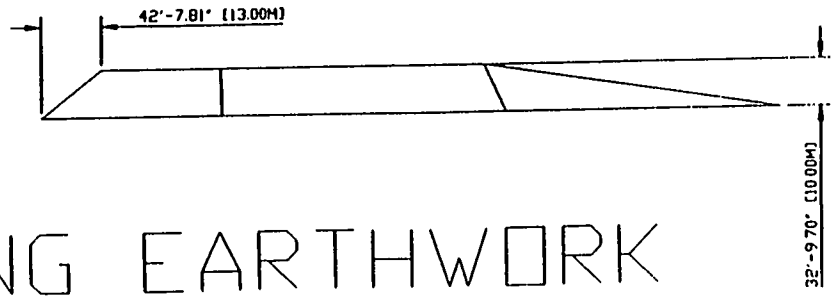
MENACING EARTHWORK

FIGURE XII-5



$V_T = 19,857\ M^3$





MENACING EARTHWORK

XIII. CONCEPT SELECTION

The following discussion addresses the selection of conceptual design B as the recommended design for permanently marking the site.

The distinguishing features of the individual designs considered are the berm configurations. This arises from the various configurations addressed in Trauth 1993. The quantity of material and general configuration of the berms give rise to a significant construction effort in their erection. For total quantity of material required, designs A and C each represent on the order of 1,000,000 cubic meters. Design B is approximately 600,000 cubic meters. In addition, the shape of the various berm sections for design C add an additional degree of construction complexity over that of designs A and B. Although design C is more "menacing", the actual warning of danger is conveyed effectively by the inscribed information on the monoliths. The primary purpose of the berm is to convey the Level 1 message that something manmade is here. All of the berm configurations will perform this function.

Design A does not provide the degree of "protection"(i.e., enclose the repository footprint) that is conveyed by either design B or C. It is acknowledged that access to much of the footprint is inhibited by an additional 10 meters of material when design A is considered. However, other than causing some additional effort to set up a drilling platform, it adds little when considering that the repository is 655 meters below the surface. The volume of the Trefoil shaped berm is also considerably more than that required to construct design B. Design A would appear not to provide the same degree of protection from wind drive erosion of the monoliths as does design B. The proximity of the monuments to the berm in design B may provide more protection to at least one face of a monument than would be available to the more exposed monuments in design A. Although barriers can be erected to improve protection of the inscribed material there is no apparent advantage of the Trefoil over that of the perimeter berm. The location of the Information Center in design A may also be subjected to greater wind driven erosion affects than the location provided by design B.

The berm aspect of the three permanent marking concepts considered is the major design variable. The Monoliths, the Information Center, the Storage Rooms, and the Subsurface Warning markers will not significantly vary in cost for any of the three configurations. When all the salient features including total materials required, ease of construction,

meeting design requirements/criteria, and establishing permanence are compared, the conceptual configuration using a rectangular berm to enclose the entire repository footprint is the best. For this reason, Concept B is the configuration of choice for the Permanent Marker System.

XIV. OFFSITE ARCHIVAL STORAGE

This report has described the PM system with emphasis on those portions of the system which are in close proximity to the waste repository location. A significant part of the overall system is the archiving of important information remote from the repository. The archived material should include information that is important to defining the location, design, content, and hazards associated with the WIPP. This information will be more extensive in volume than that available within the PM system at the repository footprint location and should be widely distributed in a number of locations including some locations worldwide. The initial form of the information should be on archival quality paper and high quality micro-film. Jensen 1993, a Scandinavian paper, describes a specification which prescribes that the archival quality paper contain fibers from cotton, linen, and/or bleached chemical pulp with any other type pulp making up less than 5% of the fiber content. In addition the pH is specified as 7.5-10 with a minimum 2% calcium carbonate alkaline reserve.

Specific documents which should be included in the archived information portfolio include:

1. The Final Safety Analysis Report (FSAR) and the addenda which describes the disposal phase of the WIPP.

2. The Final Environmental Impact Statement for WIPP and the Supplement(s) to the Environmental Impact Statement

4. The No-Migration Variance Petition and the No-Migration Determination for Disposal

5. The Resource Conservation and Recovery Act (RCRA) Permit

6. The Certification of Demonstration of Compliance with Title 40 CFR 191

7. Environmental and ecological background data collected during the pre-operational phase of WIPP and summaries of data collected during the disposal and decommissioning phases of WIPP

8. Records of the waste containers contents and disposal locations within the WIPP repository

9. Drawings defining the construction and configuration of the repository and shafts

10. Drawings, procedures, and the design report(s) describing how the waste was emplaced; how the rooms, drifts, and panels were closed; and how the shafts were backfilled and sealed.

11. Detailed maps describing the exact location of the repository

Locations for this information should include public funded organizations which may be more likely to expend the resources necessary to preserve the documents in well controlled environments. However, the most likely strategy for long term protection of the information is through widespread distribution. The information will be submitted to the following facilities/organizations for archiving.

- Library of Congress
- National Archives
- Within the States of New Mexico and Texas
  - The State Archives
  - The State Library
  - The City Libraries of population centers exceeding 15,000 within 150 miles of the WIPP site
- The state libraries of the remaining 48 states
- The local office of the Bureau of Land Management
- The local office of the Bureau of Mines
- The local office of the Bureau of Reclamation
- The national library and national archives of the nations worldwide which possess nuclear weapons and/or operate nuclear power generating plants
- The archive of the United Nations
- The national archive/libraries of the signatory nations to the nuclear non-proliferation treaty
- The U.S. Nuclear Regulatory Commission
- The 53 Federal Regional Depository Libraries

Location and hazards information should be submitted to various Federal and State of New Mexico mapping agencies to ensure that the WIPP location and drilling or mining restrictions are identified on widely distributed maps used by almost all public and private organizations. These agencies include:

- Bureau of Land Management
- U.S. Geological Survey
- Library of Congress
- National Archives and Records Service
- Defense Mapping Agency
- International Boundary Commission

- Federal Highway Administration
- New Mexico State Highway Department Planning and Research Division, Cartography Section
- One-Call System of notification of underground utilities

To ensure wide spread location information of the WIPP site and the hazards associated with the emplaced waste, detailed maps and descriptions of the hazardous material should be sent to national and international professional societies of cartographers and geographers. Weitzburg 1982 suggests the following organizations and societies receive this location and hazards information:

- The American Congress on Surveying and Mapping
- The American Society of Cartographers
- The Commission for the Geological Map of the World
- The International Cartographic Association
- The American Geographical Society
- The Association of American Geographers
- The International Geographical Union
- The Society of Women Geographers
- The American Geological Institute
- The American Geophysical Union
- The American Society of Professional Geographers
- The National Geographic Society
- The Federal Aviation Administration
- Mining, Oil, and Gas Professional Organizations

Many of the members of these various organizations are employed in secondary and college education providing an opportunity for this information to become more widely disseminated among students during their formal education.

XV. QUALITY ASSURANCE

Quality Assurance and Quality Control discipline should be applied to a number of aspects of the PM procurement and construction efforts.

The basic PM building materials are granite and possibly concrete and can be subjected to QC inspection and testing to ensure that the final specifications for the materials and their properties are met. In the case of the granite monoliths and the granite slabs for fabrication of the storage rooms, the final products lend themselves to measurements and evaluation of cutting tolerances and alignment. If the final Storage Room design does use granite instead of poured concrete it will be prudent to have QC inspection at the quarry for verification of configuration alignment and tolerances prior to shipping the massive granite slabs and monuments. Similarly, the engraving of such a large quantity of letters and characters to provide the messages in different languages will offer a unique challenge to both the supplier and the DOE's QA program. For concrete work the testing techniques of individual pour characteristics is well established and can be applied where applicable to support the PM construction effort.

Construction of the berms consisting of layers of materials and their compaction also lends itself to QC inspection techniques developed for the construction of earthen dams. Although permeability is not a concern for the PM berms, other testing and measuring techniques can be applied for quantities of specified materials applied, required slopes, degree of compaction, and overall dimensional requirements.

QA/QC will also be applied to the fabrication of the small warning markers. These warning markers will be made of different materials to provide a higher level of confidence that no single adverse material characteristic will render all of the small warning markers ineffective over the prescribed 10,000 year design life required of the PM system. Ceramic, granite, and fired clay warning markers will be utilized in the small marker system.

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APPENDIX 1

MARKER SYSTEM COMPONENT COMPARISON FOR TEAM A AND TEAM B OF SANDIA'S EXPERT PANEL

TEAM A	TEAM B
ARCHITECTURAL DESIGN	
Mark area over panels plus buffer possibly to potential radionuclide migration distance	Mark area over panels only
Multiple components to marker system	Multiple components to marker system
• large earthen berms • monoliths (inscribed) • message chambers for complex information • buried message disks (e.g., clay, glass) • world map of other nuclear disposal sites • stone markers in the sealed shafts and in the repository • part of the WIPP surface facilities (e.g., hot cell)	• large earthen berms • monoliths (inscribed) • message chambers for complex information • buried message capsules (e.g. clay, ceramics, glass, sintered alumina) • world map of other nuclear disposal sites • stone markers in the sealed shafts • part of the WIPP surface facilities (e.g., the hot cell)
No sense of center ("nothing" is there)	Attract to center to inform
Progressively encounter higher levels of information from outside toward (but not at) center	Progressively encounter higher levels of information from outside to center
LINGUISTICS	
Less emphasis on pictographs	Prominent role for pictographs
Use human facial expressions (horror and sickness)	
Use several languages	Use several languages
Greater reliance on sense of place	Purely functional area; not artistic
Reliance on language	Reliance on language
Accurately convey the risk of intrusion (not an attempt to scare)	Accurately convey the risk of intrusion (not an attempt to scare)

APPENDIX 1

MARKER SYSTEM COMPONENT COMPARISON FOR TEAM A AND TEAM B OF SANDIA'S EXPERT PANEL (CONTINUED)

TEAM A	TEAM B
MATERIAL PROPERTIES	
Use low-value materials • local materials for berms • "common" rock for monoliths (e.g., granite)	Use low value materials • local materials for berms • "common" rocks for monoliths (e.g., granite)
MESSAGE LEVELS	
5 levels of messages	4 levels of messages
Levels based on complexity of messages	Levels based on complexity of messages
OTHER MESSAGE MEDIA	
Star map and celestial marker to indicate time since closure	Star map and celestial marker to indicate time since closure
Placement near the surface of materials with magnetic and electrical conductivity properties anomalous to those of the naturally occurring materials in the area	Placement near the surface of materials with magnetic and electrical conductivity properties anomalous to those of the naturally occurring materials in the area
Periodic table of the elements	Periodic table of the elements and diagrams of nuclear reactions
Aeolian structures	
Models of the WIPP's surface facilities, stratigraphy, shafts, and waste panels	Models of the WIPP's surface facilities, stratigraphy, shafts, and waste panels
International radiation symbol used with test and other media	International biohazard symbol used with test and other media
OTHER MARKING COMPONENTS	
Public information effort (current)	
International standard for the basic design features for long-term marking	International standard for the basic design features for long-term

APPENDIX 1

**MARKER SYSTEM COMPONENT COMPARISON
FOR TEAM A AND TEAM B
OF SANDIA'S EXPERT PANEL
(CONTINUED)**

TEAM A	TEAM B
	marking
Testing for the longevity of markers and the interpretability of messages across cultures	Testing for the longevity of markers and the intepretability of messages across cultures
Off-site archives	Off-site archives

APPENDIX 2

MESSAGES

LEVEL II MESSAGE:

1.  DANGER 

2. POISONOUS RADIOACTIVE ☢ WASTE HERE

3. DO NOT DIG OR DRILL.

LEVEL III MESSAGE:

THESE STRUCTURES MARK AN AREA USED TO BURY RADIOACTIVE ☢ WASTES. THE AREA IS 0.66 BY 0.81 KILOMETERS AND THE WASTE IS BURIED 0.66 KILOMETERS DOWN. THIS PLACE WAS CHOSEN TO PUT THIS DANGEROUS MATERIAL FAR AWAY FROM PEOPLE AND OTHER LIVING THINGS. THE ROCK AND WATER IN THIS AREA MAY NOT LOOK, FEEL, OR SMELL UNUSUAL, BUT MAY BE POISONED BY RADIOACTIVE ☢ WASTES. WHEN RADIOACTIVE☢ MATTER DECAYS, IT GIVES OFF INVISIBLE ENERGY THAT CAN DESTROY OR DAMAGE PEOPLE, ANIMALS, AND PLANTS.

DO NOT DRILL HERE. DO NOT DIG HERE. DO NOT DO ANYTHING WITH THE ROCKS OR WATER IN THE AREA.

DO NOT DESTROY THIS MARKER. THIS MARKING SYSTEM HAS BEEN DESIGNED TO LAST 10,000 YEARS. IF THE MARKER IS DIFFICULT TO READ, ADD NEW MARKERS IN LONGER-LASTING MATERIALS AND COPY THIS MESSAGE IN YOUR LANGUAGE ONTO THEM.

FOR MORE INFORMATION, GO TO THE BUILDING FURTHER INSIDE THIS MARKED AREA. THE SITE WAS KNOWN AS THE WIPP (WASTE ISOLATION PILOT PLANT) SITE WHEN IT WAS CLOSED IN 2020 A.D.

LEVEL IV MESSAGE:

THIS PLACE IS A REPOSITORY WHERE RADIOACTIVE ☢ WASTE HAS BEEN BURIED. IT WAS DESIGNED TO ISOLATE DANGEROUS RADIONUCLIDES ☢ FROM HUMANS AND OTHER LIFE FORMS FOR A PERIOD OF AT LEAST 10,000 YEARS. THE REPOSITORY IS AT A DEPTH OF 655 METERS BELOW THIS ROOM. DO **NOT DRILL OR DIG AT THIS SITE, OR DO ANYTHING ELSE THAT MIGHT DISTURB THE WATER OR ROCKS IN THIS AREA.** IF YOUR

DO, THERE IS DANGER THAT THE POISONOUS RADIOACTIVITY ☢ MAY COME TO THE SURFACE IN THE GROUND WATER. IF THIS WATER IS USED DIRECTLY BY HUMANS OR FOR GROWING FOOD OR FEEDING ANIMALS THAT PRODUCE FOOD, HUMANS COULD SUFFER FROM THE DISEASE CANCER. CANCER IS THE UNCONTROLLED GROWTH OF CELLS IN THE HUMAN BODY AND CAN RESULT FROM THE DAMAGE TO CELLS CAUSED BY THE ENERGY FROM DECAYING RADIOACTIVE☢ MATERIALS. IT SOMETIMES TAKES MANY YEARS FOR THE SICKNESS AND DEATH DUE TO CANCER TO BECOME EVIDENT. IF YOU SUSPECT THAT RADIOACTIVITY ☢ MAY HAVE REACHED THE SURFACE, CHECK THIS SITE FOR (1) FAILED SEALS IN THE SHAFTS OF THE ORIGINAL REPOSITORY AS SHOWN ON DIAGRAMS 1 AND 2 AND (2) DRILLHOLES OR MINE SHAFTS THAT MAY HAVE PROVIDED A MEANS FOR ESCAPE OF THE RADIOACTIVITY ☢.

THIS REPOSITORY WAS CONSTRUCTED DURING THE PERIOD AD 1985 TO 1998, WAS FILLED WITH WASTE FROM 1998 TO 20.., AND HAS BEEN SEALED IN 20.. THIS IS A MAJOR EFFORT BY HUMANS TO ATTEMPT A LONG-TERM SOLUTION TO THE PROBLEM OF RADIOACTIVE ☢ WASTE DISPOSAL, FOR WE BELIEVE THAT WE HAVE AN OBLIGATION TO PROTECT FUTURE GENERATIONS FROM THE HAZARDS THAT WE HAVE CREATED. THIS REPOSITORY IS KNOWN AS THE WASTE ISOLATION PILOT PLANT AND HAS BEEN BUILT AND OPERATED BY THE GOVERNMENT OF THE UNITED STATES OF AMERICA. THE LONG-TERM RADIOACTIVE ☢ WASTES BURIED HERE CONSIST OF RADIONUCLIDES ☢ WITH ATOMIC NUMBERS GREATER THAN 92, HALF-LIVES EXCEEDING 20 YEARS, AND CONCENTRATIONS EXCEEDING 3700 NUCLEAR DISINTEGRATIONS PER GRAM PER SECOND (A GRAM IS THE MASS OF ONE MILLIONTH OF A CUBIC METER OF WATER, AND THERE ARE 31,600,000 SECONDS IN A YEAR, THE ORBITAL PERIOD OF THE EARTH).

THE INFORMATION IN THIS ROOM IS THE MOST DETAILED ON THE SITE. OTHER ROOMS IDENTICAL TO THIS ONE ARE LOCATED ....., BUT WE URGE YOU TO KEEP THE ROOMS INTACT AND BURIED AS THEY ARE, SO THAT THEY MAY BE PRESERVED FOR FUTURE GENERATIONS. IF THE LANGUAGES AND DIAGRAMS IN THIS ROOM ARE DIFFICULT FOR YOU TO UNDERSTAND, WE URGE YOU TO ADD NEW TRANSLATIONS OF OUR TEXTS FOR THE BENEFIT OF FUTURE GENERATIONS. THIS SHOULD BE DONE FOR TEXTS IN THIS ROOM AND THROUGHOUT THE SITE; ALSO ADD NEW MARKERS AND OTHER STRUCTURES IF NECESSARY TO MAINTAIN THE MARKING SYSTEM IN GOOD, EFFECTIVE CONDITION. HOWEVER, DO NOT DEFACE OR REMOVE THE ORIGINAL TEXTS, DIAGRAMS, OR MARKERS, FOR THEY WILL REMAIN VALUABLE TO FUTURE PERSONS TRYING TO UNDERSTAND YOUR OWN TRANSLATIONS AND ADDITIONS. IF YOU WANT MORE INFORMATION THAN IS AVAILABLE IN THIS ROOM, SEARCH IN HISTORICAL AND ARCHAEOLOGICAL LIBRARIES, MUSEUMS, AND ARCHIVES APPROPRIATE TO OUR TIME.

THE SALT BED AT THIS SITE AT A DEPTH OF 655 METERS IS ABOUT 220 MILLION YEARS OLD AND IS CONSIDERED VERY STABLE ON A TIME-SCALE OF 10,000 YEARS AGAINST GEOLOGICAL EVENTS SUCH AS EARTHQUAKES AND VOLCANISM. DIAGRAM 4 SHOWS THE GEOLOGICAL STRATA AT THIS SITE AND

THE LOCATION OF THE REPOSITORY. SALT IS CONSIDERED A GOOD MEDIUM FOR THE PERMANENT STORAGE OF THESE WASTES BECAUSE ITS PRESENCE INDICATES A LACK OF CIRCULATING GROUNDWATER, IT IS EASY TO MINE, AND IT IS MOBILE IN THE SENSE THAT IT RELATIVELY QUICKLY SEALS ANY FRACTURES OR VOIDS, SUCH AS THOSE OF A WASTE REPOSITORY. THE SITE IS ALSO CONSIDERED ACCEPTABLE IN THAT FEW RESOURCES ATTRACTIVE FOR EXTRACTION ARE KNOWN IN THE VICINITY. THE MAIN SUCH RESOURCES KNOWN IN THIS REGION ARE POTASH AND SOME NATURAL GAS. THE SITE ALSO IN NOT ASSOCIATED WITH ANY POTABLE AQUIFER AND HAS A VERY DRY CLIMATE (0.3 M OF RAIN PER YEAR); MOREOVER, WE EXPECT THE CLIMATE TO REMAIN DRY OVER THE NEXT 10,000 YEARS.

THE REPOSITORY AS CONSTRUCTED CONSISTED OF A SERIES OF ROOMS CARVED OUT OF THE SALT, EACH ABOUT 10-M WIDE BY 4-M HIGH BY 100-M LONG. THE ROOMS COVERED A TOTAL AREA OF APPROXIMATELY 625 M BY 800 M AND WERE ACCESSED BY A WASTE SHAFT APPROXIMATELY 7 M IN DIAMETER AND ACCESS DRIFTS WITH CROSS SECTIONS OF APPROXIMATELY 8-M BY 4-M, DIAGRAM 1. OTHER SHAFTS WERE PROVIDED FOR REMOVAL OF SALT, AND FOR AIR INTAKE AND EXHAUST. ALTOGETHER OVER 800,000 BARRELS, EACH OF VOLUME OF 0.2 CUBIC METERS, WERE BROUGHT TO THIS SITE IN ABOUT 20,000 TRUCK SHIPMENTS. THE AVERAGE MASS OF A BARREL IS .... GRAMS. THE BARRELS CONTAIN MOSTLY ORDINARY ITEMS THAT BECAME RADIOACTIVE ☢ AT SOME STAGE IN THE DEVELOPING, TESTING, CONSTRUCTING, AND RENEWING OF NUCLEAR WEAPONS. BURIED ITEMS INCLUDE RAGS, CLOTHING, BAGS, AND CONTAINERS; THESE ARE MADE OF FABRICS, PLASTIC, GLASS, AND METAL. THERE ARE ALSO COMPLEX MACHINES SUCH AS MOTORS, HAND TOOLS, AND MACHINE TOOLS. ABOUT 60 PERCENT OF THE RADIOACTIVE ☢ WASTE ALSO CONTAINS HAZARDOUS CHEMICAL WASTES SUCH AS LEAD, CADMIUM, CHROMIUM, BARIUM, METHYLENE CHLORIDE (CH_2Cl_2), AND TOLUENE ($C_6H_5CH_3$). MOST OF THE RADIOACTIVE ☢ WASTE HAS MINIMAL EMISSIONS OF GAMMA RAYS, BUT ABOUT 3 PERCENT HAS ENOUGH GAMMA-RAY EMISSION THAT IT HAD TO BE REMOTELY HANDLED AT ALL STAGES, WITH HUMANS WELL REMOVED FROM THE BARRELS. THE ESTIMATED AMOUNT AT THE TIME OF BURIAL OF THE MAJOR RADIONUCLIDES ☢ BURIED HERE IS: NEPTUNIUM-237 (... GRAMS, EACH WITH ... NUCLEAR DISINTEGRATIONS PER SECOND, HALF-LIFE OF 2,100,000 YEARS); PLUTONIUM-238 (... GRAMS, EACH WITH ... NUCLEAR DISINTEGRATIONS PER SECOND, HALF-LIFE OF 88 YEARS); PLUTONIUM-239 (... GRAMS, EACH WITH ... NUCLEAR DISINTEGRATIONS PER SECOND, HALF-LIFE OF 24,000 YEARS) ; PLUTONIUM-240 (... GRAMS, EACH WITH ... NUCLEAR DISINTEGRATIONS PER SECOND, HALF-LIFE OF 6,500 YEARS); AMERICIUM-241 (... GRAMS, EACH WITH ... NUCLEAR DISINTEGRATIONS PER SECOND, HALF-LIFE OF 432 YEARS); AMERICIUM-243 (... GRAMS, EACH WITH ... NUCLEAR DISINTEGRATIONS PER SECOND, HALF-LIFE OF 7,380 YEARS); CURIUM-244 (... GRAMS, EACH WITH ... NUCLEAR DISINTEGRATIONS PER SECOND, HALF-LIFE OF 18); AND URANIUM-233 (... GRAMS, EACH WITH ... NUCLEAR DISINTEGRATIONS PER SECOND, HALF-LIFE OF 158,000 YEARS). WE ESTIMATE THAT AFTER 10,000 YEARS THE TOTAL NUMBER OF

DISINTEGRATIONS IN THE BURIED WASTE HERE WILL BE REDUCED TO ... PER SECOND, WHICH MEANS THAT SOMEONE STANDING NEXT TO THIS WASTE WOULD ENCOUNTER A LEVEL OF RADIOACTIVITY ☢ CORRESPONDING TO .. PERCENT OF THE NATURAL BACKGROUND AT THE SURFACE, OR ABOUT THE AMOUNT CORRESPONDING TO TYPICAL URANIUM ORE. DIAGRAM 5 IS A PERIODIC TABLE OF THE ELEMENTS, WITH THE RADIOACTIVE ☢ ELEMENTS INDICATED BY THE INTERNATIONAL "RADIOACTIVITY HAZARD" SYMBOL "☢" THAT HAS BEEN USED IN OUR TIME SINCE 1950. ELEMENTS WITH A LARGE AMOUNT OF RADIONUCLIDES ☢ BURIED HERE ARE ALSO MARKED WITH A "■" THAT MEANS "RADIOACTIVE ☢ WASTE BURIED HERE"; THESE SYMBOLS ARE THEN CONNECTED BY LINES TO THE REPOSITORY, SEE DIAGRAM 1. THESE TWO SYMBOLS HAVE ALSO BEEN USED WIDELY ELSEWHERE IN OUR MARKING SYSTEM. NON-RADIOACTIVE, CHEMICALLY TOXIC ELEMENTS BURIED HERE ARE INDICATED WITH A CIRCLE ON DIAGRAM 5. A DOWNWARD-POINTING  IN A TRIANGLE IS USED IN THE MARKING SYSTEM TO INDICATE THAT "BIOHAZARD MATERIAL IS BURIED HERE".

AFTER EACH ROOM WAS FILLED WITH BARRELS OF WASTE, THE REMAINING SPACE WAS THEN COMPLETELY FILLED WITH SALT. GROUPS OF SEVEN ROOMS WERE EACH SEALED WITH CEMENT PLUGS AND RECONSOLIDATED SALT. UPON COMPLETE FILLING OF THE REPOSITORY IN AD 2020 EACH OF THE FOUR SHAFTS TO THE SURFACE WAS SEALED WITH A SERIES OF MATERIALS, DIAGRAM 2, TOPPED BY A CONCRETE CAP ..M THICK. THE WASTE ROOMS ARE EXPECTED TO COLLAPSE FROM THE WEIGHT OF ROCK ABOVE THEM WITHIN 100 YEARS AND THE STEEL BARRELS WILL BREAK. THE SALT IS EXPECTED TO PREVENT THE RADIONUCLIDES ☢ FROM ESCAPING TO THE SURFACE; THE EXPECTED OUTWARD DIFFUSION INTO THE SALT IS ONLY .. METERS PER YEAR. WE BELIEVE THAT THE GREATEST POSSIBILITY FOR RADIONUCLIDES☢ TO MAKE THEIR WAY TO THE SURFACE IS THROUGH HUMAN INTRUSION, AND HENCE WE HAVE DESIGNED AND BUILT THIS ELABORATE MARKING SYSTEM TO WARN YOU OF THE DANGERS. **DO NOT DRILL OR DIG AT THIS SITE, DO NOT DO ANYTHING ELSE THAT MIGHT DISTURB THE WATER OR ROCKS IN THIS AREA.** WE BELIEVE THAT THE MOST LIKELY TYPE OF ACCIDENTAL INTRUSION IS DRILLING A HOLE THAT PENETRATES BOTH THE SITE AND THE SALTY WATER FOUND AT SOME LEVELS ABOVE AND BELOW THE REPOSITORY. THIS WATER MAY THEN BECOME CONTAMINATED AND REACH THE SURFACE THROUGH THE DRILLHOLE.

A DETAILED MAP OF THE MARKER SYSTEM IS GIVEN IN DIAGRAM 6. THE ALIGNMENTS SHOWN ON THE MAP TOWARD THE AZIMUTH ANGLES OF 110 DEGREES, 160 DEGREES, 66 DEGREES, AND 42 DEGREES CORRESPOND TO THE LOCATIONS WHERE THE FOUR BRIGHTEST STARS NOW VISIBLE FROM THIS SITE RISE: SIRIUS, CANOPUS, ARCTURUS, AND VEGA. BECAUSE OF PRECESSION OF THE POLES, THESE STAR-RISE LOCATIONS CONSTANTLY CHANGE AND THUS

A MEASUREMENT OF THESE ALIGNMENTS ALLOWS AN ACCURATE DATING OF THIS SITE.

IN ORDER TO INCREASE THE CHANCES OF SUCCESSFUL TRANSMISSION, THE DETAILS OF THE MESSAGE HAVE BEEN GIVEN MANY DIFFERENT, REDUNDANT FORMS, IN MATERIALS, LOCATIONS, LANGUAGES, GRAPHICS, AND AMOUNT OF DETAIL. MOST COMMON IS THE APPROXIMATELY 10-WORD BASIC MESSAGE FLANKED BY TWO HUMAN FACES, WHICH WE BELIEVE WILL CARRY FOR DISTANT FUTURE GENERATIONS THE SAME EFFECT AS FOR US. THE ONE ON THE LEFT CONVEYS HORROR AND TERROR  AND THE ONE ON THE RIGHT CONVEYS THE PRESENCE OF SOMETHING NAUSEOUS OR POISONOUS  . IN THIS MESSAGE THE INTERNATIONAL "RADIOACTIVITY HAZARD" SYMBOL ☢ IS ALSO INTRODUCED BY PLACING IT NEXT TO THE WORD "RADIOACTIVE" ☢ WITH AN ARROW BELOW IT POINTING DOWNWARDS, TO INDICATE THAT THE RADIOACTIVITY ☢ IS BELOW THE GROUND, NOT ON THE SURFACE. THIS AND ALL OTHER MESSAGES ARE GIVEN IN THE FOLLOWING SIX LANGUAGES, WHICH ARE THE OFFICIAL LANGUAGES OF THE UNITED NATIONS ORGANIZATION: CHINESE, RUSSIAN, ENGLISH, SPANISH, ARABIC, AND FRENCH. WE ALSO GIVE THESE MESSAGES IN NAVAJO.

THE NEXT TYPE OF MESSAGE IS ENGRAVED LESS FREQUENTLY ON THE SITE AND IS MORE DETAILED THAN THE BASIC MESSAGE DESCRIBED ABOVE, BUT STILL DOES NOT ASSUME ANY SCIENTIFIC KNOWLEDGE ABOUT RADIOACTIVITY ☢. IT IS FLANKED BY TWO DIAGRAMS. THE ONE ON THE LEFT IS A PERSPECTIVE, SCALE VIEW OF THE REPOSITORY IN RELATION TO THE SURFACE AND ITS MARKING SYSTEM; THIS IS A SIMPLER VERSION OF DIAGRAM 1. IT ALSO SHOWS WITH AN ARROW WHERE THE READER IS LOCATED. THE RIGHT DIAGRAM 3 SHOWS THE PATH OF THE NORTH CELESTIAL POLE THROUGH THE SKY DUE TO THE PRECESSION OF THE EARTH'S AXIS OF ROTATION. BRIGHT STARS ARE INDICATED BY CIRCLES (THE BRIGHTEST STAR, ON THE LEFT, IS VEGA) AND PORTIONS OF OUR CONSTELLATIONS URSA MINOR, DRACO, AND CYGNUS ARE SHOWN BY DASHED LINES CONNECTING STARS. THE ILLUSTRATED SECTION OF ARC CORRESPONDS TO THE PERIOD FROM AD 2020, WHEN THE POLE WAS CLOSE TO THE STAR POLARIS AND REPOSITORY WAS SEALED, TO AD 12,000, WHEN THE POLE WILL BE IN CYGNUS. THE FACES AT THE TWO EPOCHS EXPRESS DIFFERING EMOTIONS ABOUT THE SAFETY OF INTRUDING INTO THE REPOSITORY, AND THE SEQUENCE OF "RADIOACTIVE WASTE BURIED HERE SYMBOLS ☢ OF DIMINISHING SIZE

EXPRESSES THE DIMINISHING AMOUNT OF RADIOACTIVITY ☢ PRESENT IN THE REPOSITORY AS 10,000 YEARS PASS. THE LEVEL OF RADIOACTIVITY ☢ IN THE WASTE DECREASES OVER TIME, BUT IT WILL NOT ALL BE GONE AFTER 10,000 YEARS. IF YOU HAVE ACCURATELY OBSERVED THE CHANGING POSITION OF THE POLE IN YOUR OWN TIME, THIS DIAGRAM SHOWS YOU HOW TO DETERMINE THE DATE OF THE SEALING OF THIS REPOSITORY REASONABLY ACCURATELY EVEN IF YOU DO NOT UNDERSTAND THE "AD" (ANNO DOMINI) NOTATION USED FOR GREGORIAN CALENDAR DATES IN THIS MESSAGE. IN OTHER CALENDARS OF OUR TIME, THE END OF THE YEAR AD 2020 OCCURS DURING THE FOLLOWING YEARS: 7529 IN THE BYZANTINE CALENDAR, 5781 IN THE JEWISH CALENDAR, 1441 IN THE ISLAMIC CALENDAR, AND 4718 IN THE CHINESE CALENDAR. IT ALSO OCCURS ON JULIAN DATE 2459275. THIS RADIOACTIVE WASTE REPOSITORY AND MARKER SYSTEM IS IN FACT ONLY ONE OF MANY CONSTRUCTED ALL OVER THE EARTH; DIAGRAM 7 SHOWS A MAP OF THE WORLD WITH THE WASTE SITES INDICATED BY THE "RADIOACTIVE WASTE BURIED HERE " SYMBOL ☢. IN ORDER TO LOCATE THESE SITES MORE ACCURATELY, EACH SYMBOL ON THE MAP HAS BEEN LOCATED WITH A NUMBER THAT CAN ALSO BE FOUND LABELING TWO DOTS FOUND IN DIAGRAM 8. EACH DOT ON THE CIRCUMFERENCE OF THE OUTER CIRCLE GIVES THE LONGITUDE OF ANOTHER WASTE SITE RELATIVE TO THE LONGITUDE OF THIS SITE; THIS RELATIVE LONGITUDE IS EQUAL TO THE ARC TRAVERSED FROM THE DOT LABELED 0 AT THE TOP (WHICH CORRESPONDS TO THIS SITE), DOTS TO THE RIGHT REPRESENT SITES TO THE EAST. IN A SIMILAR MANNER, THE INNER PARTIAL CIRCLE GIVES THE RELATIVE LATITUDE OF A SITE, WHICH IS EQUAL TO THE ARC TRAVERSED FROM THE DOT LABELED 0. DOTS ON THE UPPER SIDE ARE SITES TO THE NORTH. THE FABRICATION OF THESE PANELS (ACCURACY OF 1 MM) HAS BEEN SUCH THAT WE BELIEVE THAT YOU CAN DETERMINE THE LOCATION OF ALL OTHER RADIOACTIVE ☢ WASTE SITES FROM OUR TIME TO AN ACCURACY OF ABOUT 4 KM. WE URGE YOU TO CHECK THESE LOCATIONS AROUND THE WORLD AND MAKE CERTAIN THAT THE MARKINGS SYSTEMS FOR THESE OTHER MARKING SYSTEMS ARE IDENTICAL TO THOSE HERE. THE INTERNATIONAL STANDARD FOR THESE MARKING SYSTEMS CAN BE SUMMARIZED THUS:

> **"EACH SITE MUST (1) DISPLAY ITS BASIC WARNING MESSAGES IN AT LEAST THE FOLLOWING LANGUAGES: CHINESE, RUSSIAN, ENGLISH, SPANISH, FRENCH AND ARABIC; (2) PROMINENTLY DISPLAY THE SYMBOL FOR INTERNATIONAL RADIOACTIVE WASTE BURIAL ☢; (3) DISPLAY IN A PROTECTED CHAMBER A WORLD MAP OF ALL DISPOSAL SITES, TOGETHER WITH A STANDARD DIAGRAM THAT GEOMETRICALLY ALLOWS THEIR LOCATION TO AN ACCURACY OF AT LEAST 5 KM; AND (4) INCLUDE EARTHEN BERMS TO DELINEATE THE DISPOSAL AREA WITH HEIGHTS OF AT LEAST 10 M."**

655 METERS
90 Th Thorium 232.038
92 U Uranium 238.029
93 Np Neptunium 237.048
94 Pu Plutonium (244)
95 Am Americium (243)
96 Cm Curium (247)
BERM
BURIED ROOM
INFORMATION CENTER
MONUMENT
REPOSITORY
SPATIAL RELATIONSHIP OF THE PERMANE
MARKING SYSTEM TO THE REPOSITORY
PWJ

DIAGRAM 1

SHAFT SEAL SYSTEM

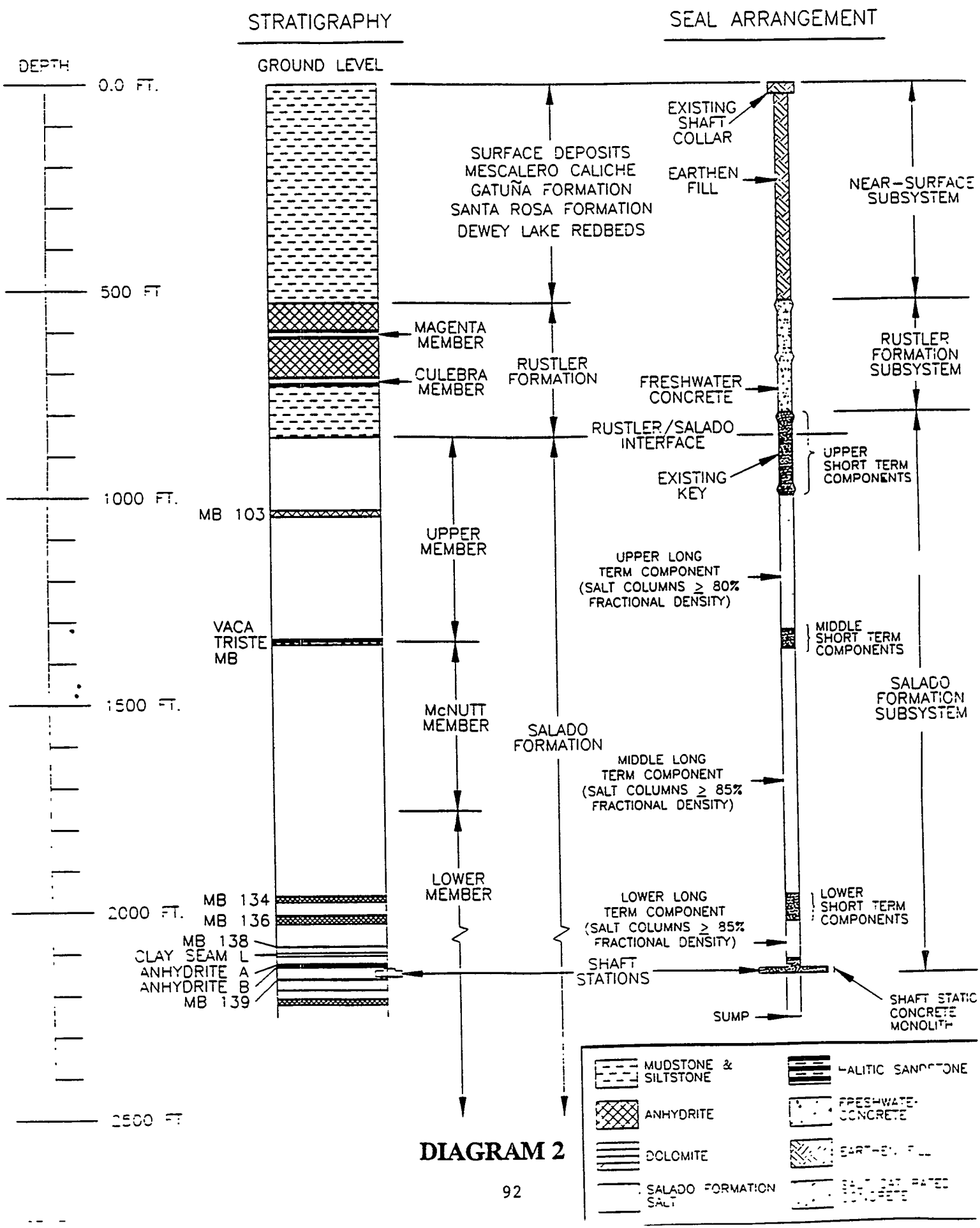
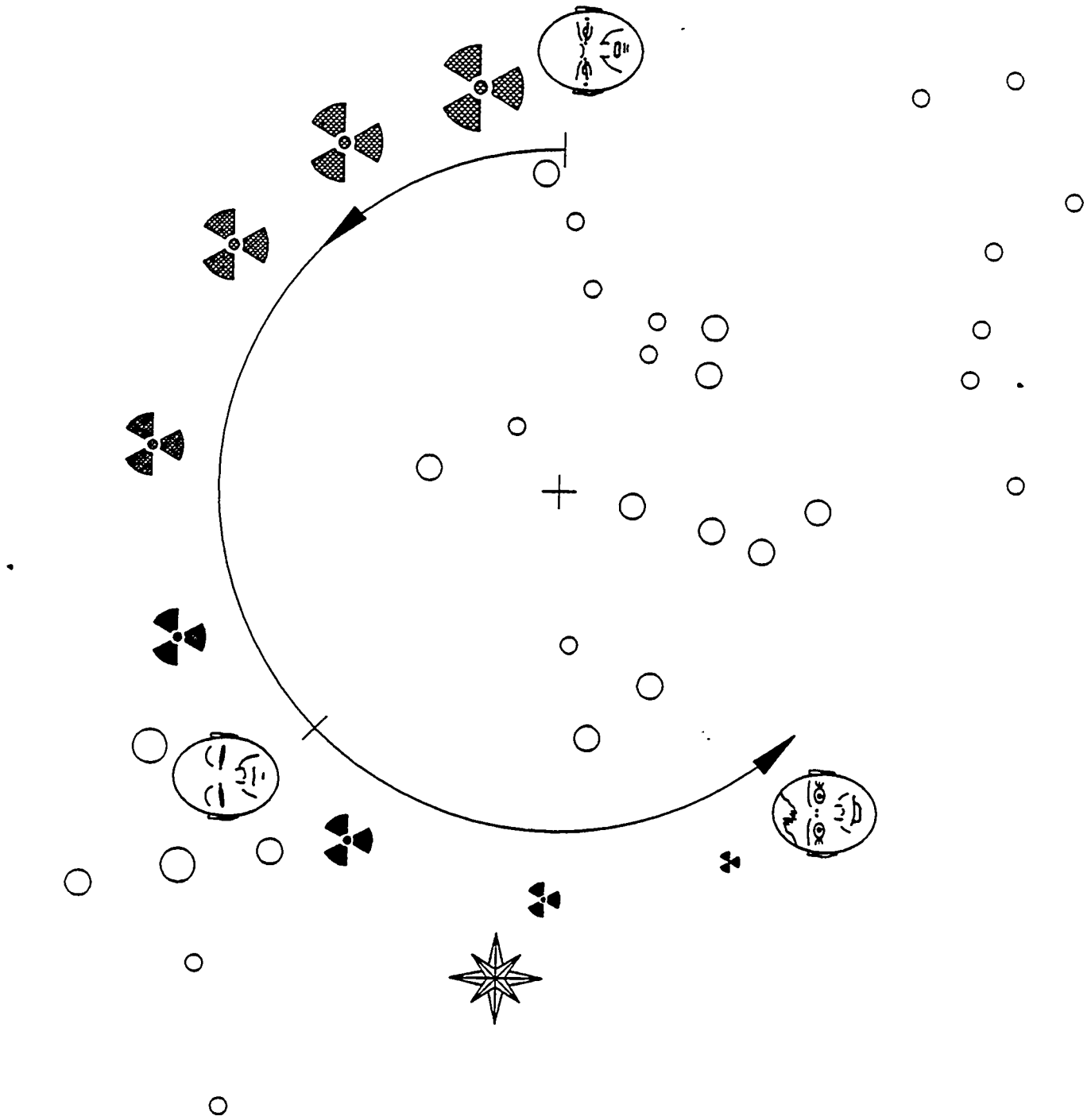


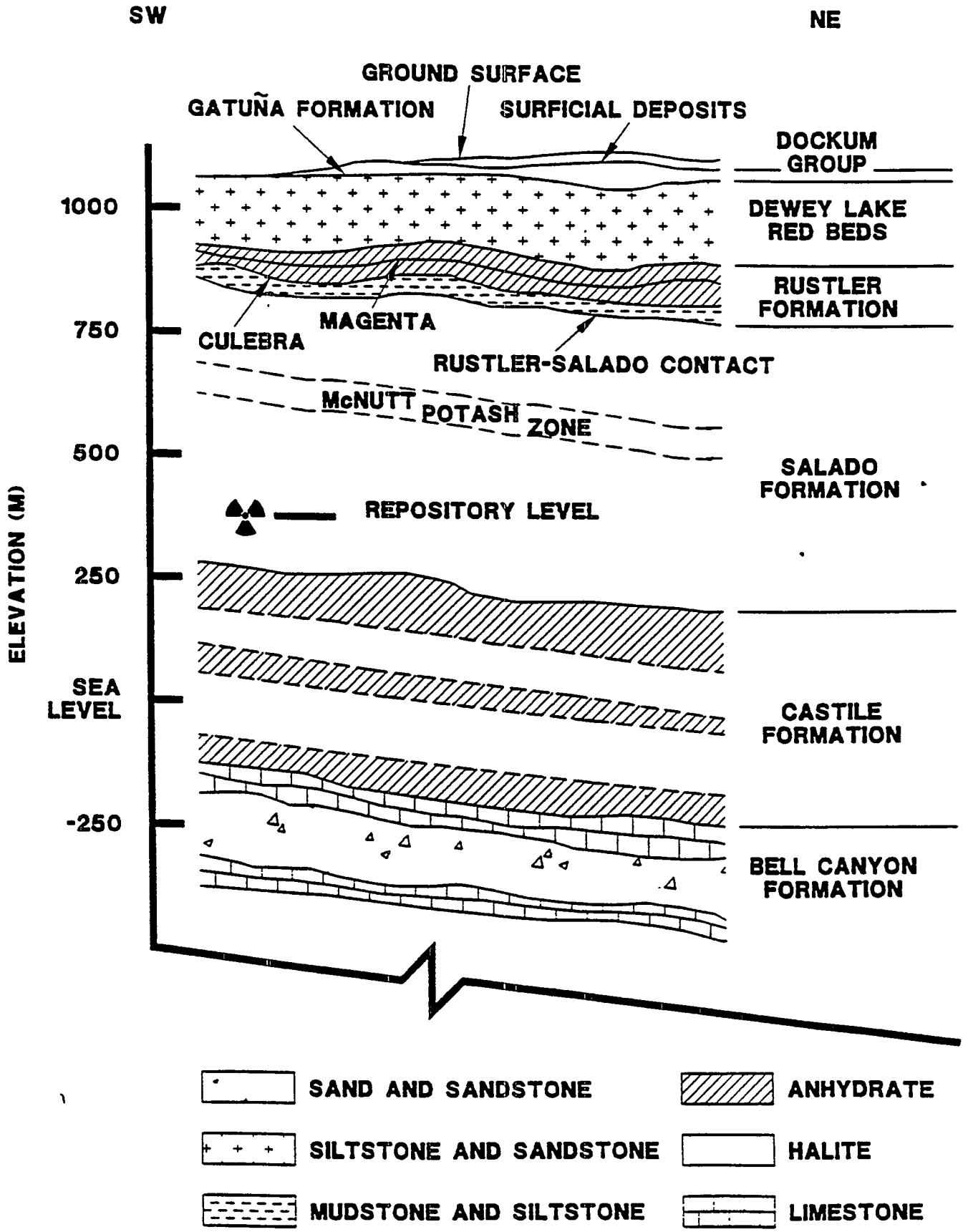
DIAGRAM 2



PM8

DIAGRAM 3

GENERALIZED GEOLOGIC CROSS SECTION



DETAILED GEOLOGIC CROSS-SECTION OF THE SITE

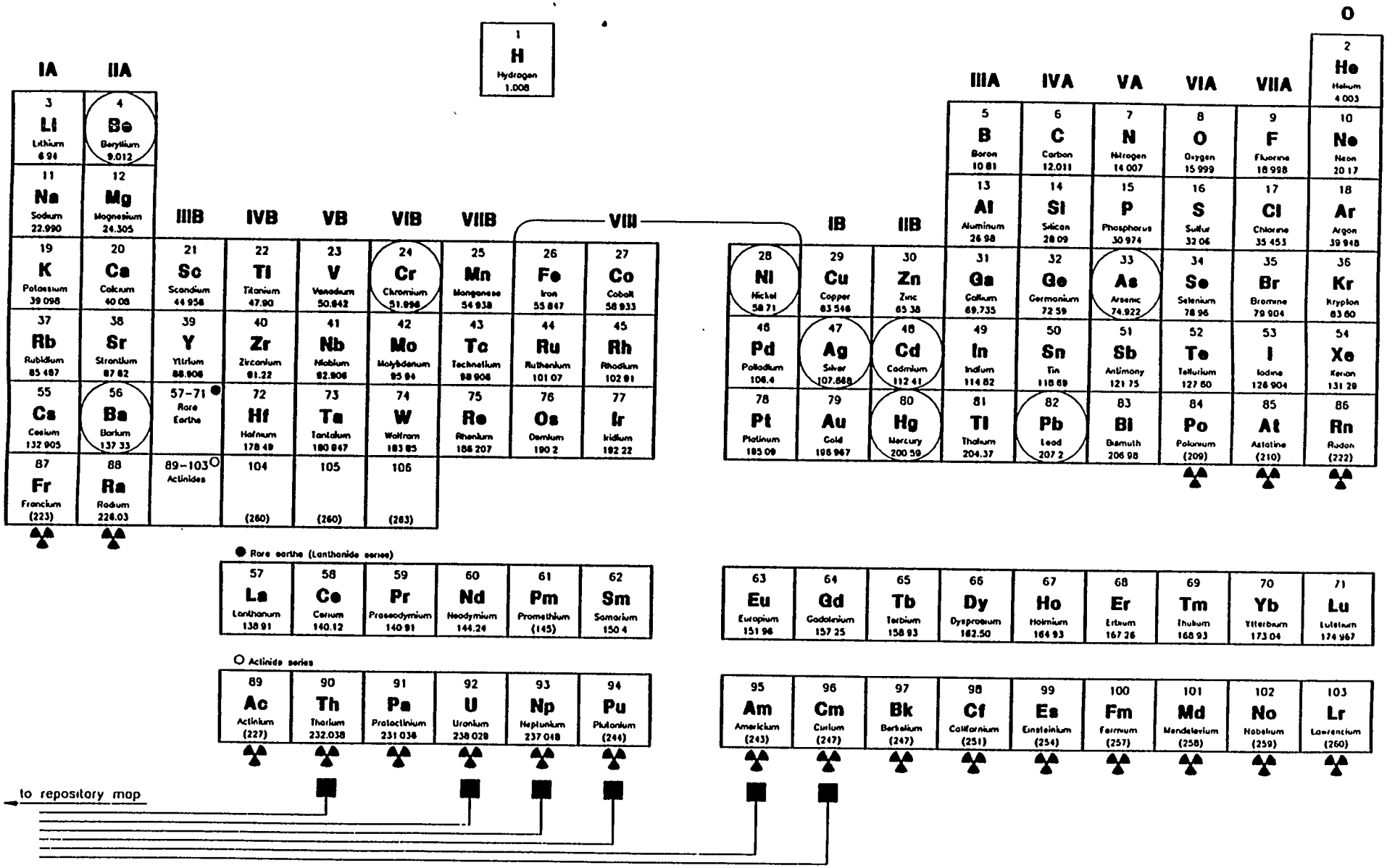
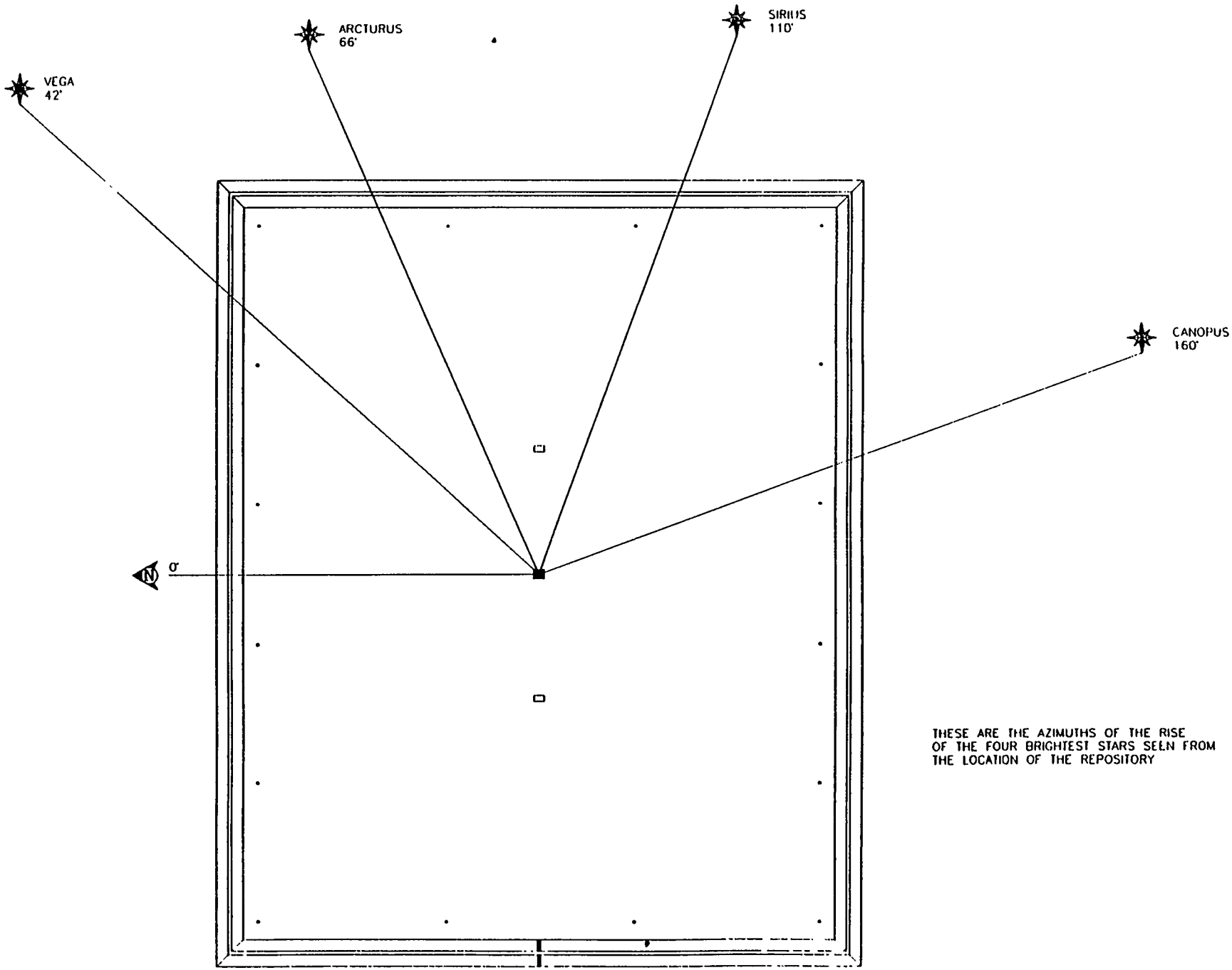


DIAGRAM 5

95

Level IV diagram of the periodic table of elements. Radioactive elements are indicated with the radiation trefoil and those with major amounts in the repository are further labeled with the symbol (here shown as a filled square) for "radioactive waste buried here." Non-radioactive toxic elements present in the repository are circled.

DIAGRAM 6



THESE ARE THE AZIMUTHS OF THE RISE OF THE FOUR BRIGHTEST STARS SEEN FROM THE LOCATION OF THE REPOSITORY

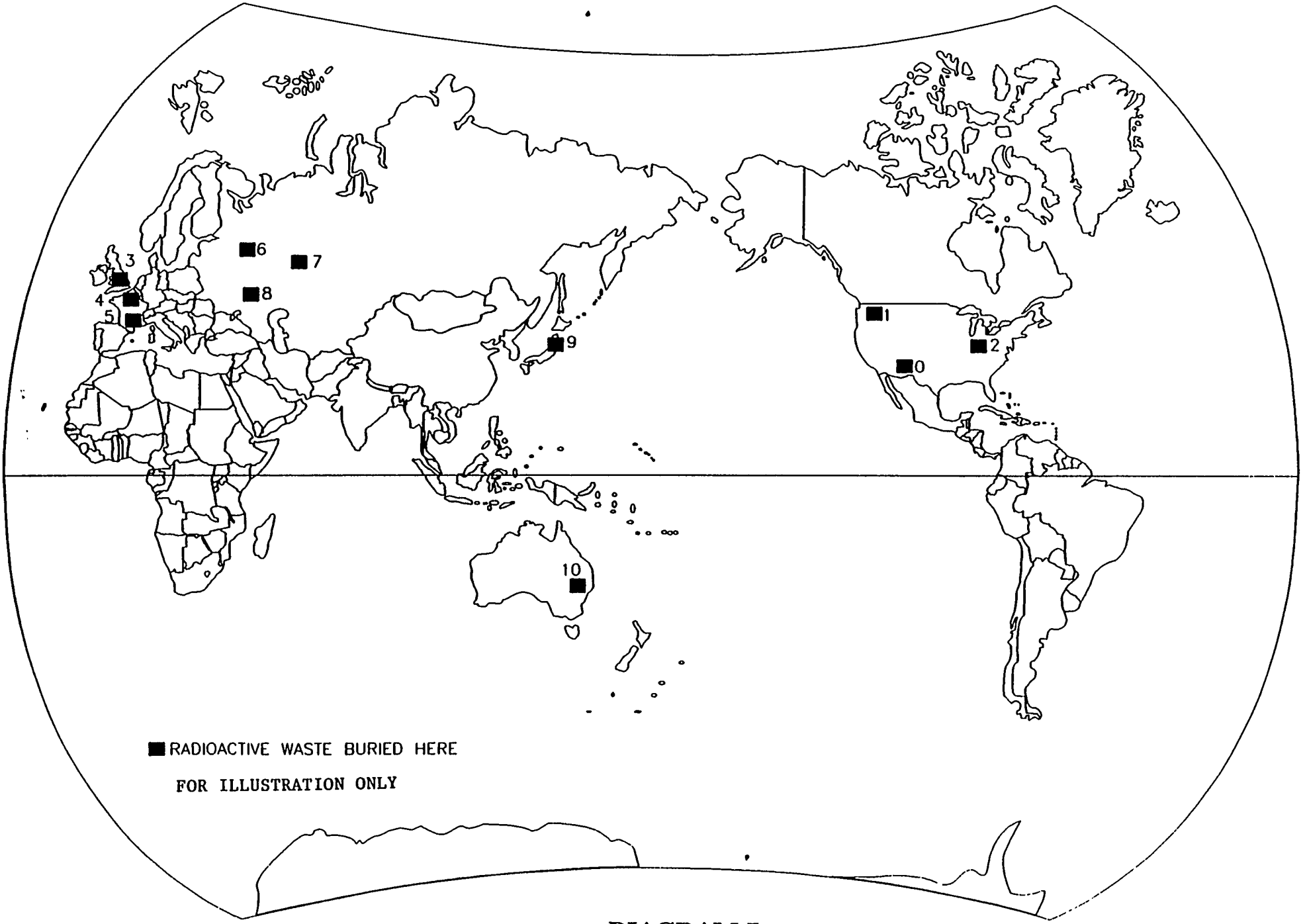


DIAGRAM 7

PM38

DIAGRAM 8

APPENDIX 3

STORAGE ROOM LOCATION

THE INFORMATION YOU HAVE READ HERE IN THE INFORMATION CENTER HAS BEEN DUPLICATED IN TWO OTHER LOCATIONS. THERE ARE TWO BURIED ROOMS 135 METERS TO THE EAST AND WEST OF THE INFORMATION CENTER ON A LINE PASSING THROUGH THE INFORMATION CENTER AND DIVIDING THE SITE IN HALF ALONG ITS MAJOR AXIS. EACH OF THESE BURIED ROOMS CONTAINS THE SAME INFORMATION YOU HAVE FOUND HERE. THE CONSTRUCTION OF THE ROOMS IS VERY SIMILAR TO THE INFORMATION CENTER. THE BURIED LOCATIONS ARE MARKED BY PERMANENT MAGNETS AT EACH LOCATION. THESE ROOMS WERE PLACED APPROXIMATELY 7 METERS BELOW THE SURFACE WHEN ORIGINALLY BURIED. DO NOT EXPOSE THESE ROOMS UNLESS THE INFORMATION PRESENTED IN THIS CENTER HAS BECOME WEATHERED OR OTHERWISE OBLITERATED BEYOND RECOVERY. LEAVE THE BURIED ROOMS FOR FUTURE GENERATIONS. IF THE BURIED ROOMS HAVE BECOME EXPOSED, PROTECT THEM BY ADDITIONAL COVERING.

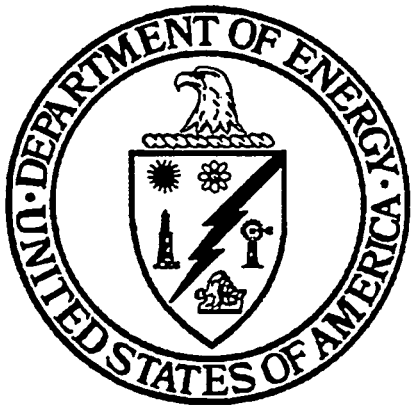
TRANSLATION OF THE ENGLISH VERSION OF THE LEVEL II, III, AND IV MESSAGES INTO ARABIC, CHINESE, FRENCH, SPANISH, RUSSIAN, AND NAVAJO WILL BE COMPLETED DURING THE FINAL DESIGN PHASE AND SUBJECTED TO TESTING AMONG INDIGENOUS PEOPLE PRIOR TO FINALIZATION.

U.S. DEPARTMENT OF ENERGY
CARLSBAD AREA OFFICE

QUALITY ASSURANCE PROGRAM DESCRIPTION

CAO-94-1012

REVISION 0



JUNE 1994

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CARLSBAD AREA OFFICE

QUALITY ASSURANCE PROGRAM DESCRIPTION

REVISION 0

Effective Date
July 15, 1994

Prepared by: Russell Bissing 6/13/94
CAO, QA Manager Date

Concurred by: [signature] 6/13/94
CAO, Chief, Compliance Branch Date

Approved by: George E Dials 6/13/94
Manager, CAO Date

Concurred by: [signature] 6/28/94
Deputy Assistant Secretary for Waste Management, EM-30 Date

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POLICY STATEMENT

The mission of the Carlsbad Area Office (CAO) is to integrate the national transuranic (TRU) waste system and carry out the actions necessary to facilitate the Secretary of Energy's decision to operate the Waste Isolation Pilot Plant (WIPP) as a disposal facility. The National Transuranic Program (NTP), as part of CAO, will integrate the national TRU waste system in order to assure that all TRU waste, under the purview of the Department of Energy (DOE) is effectively and systematically managed from its generation to its disposal. The Secretary of Energy has established the CAO to accomplish this mission. The Secretary of Energy will make a Disposal Phase decision based on:

1. A thorough evaluation of repository and system performance (including operational excellence, transportation, packaging, characterization, and certification),

2. Informed public participation, and

3. Institutional and regulatory acceptance.

The Department of Energy (DOE) strives to reach this decision in a timely, cost-effective, and environmentally sound and safe manner with proactive public, institutional, and regulatory interactions. The WIPP program coordinates with the TRU waste system to ensure readiness to implement the disposal decision.

To help in fulfilling this mission and ensure that risks and environmental impacts are identified and minimized, and that safety, reliability, and performance are maximized, it is the policy of the CAO to establish, maintain, and implement an effective quality assurance program that complies with applicable DOE Orders and requirements and U.S. Environmental Protection Agency (EPA) requirements.

Further, it is the intent of the CAO to promote a work environment in which there is an ongoing commitment to achieve an increasing standard of quality. This environment demands continuous quality improvement in processes, and the methods employed to maintain quality.

As described in this QAPD, quality assurance requirements have the full endorsement and complete support of the CAO Manager, and compliance to these requirements, responsibilities, and authorities is mandatory for CAO personnel.

It is my conviction that achieving and improving quality is the responsibility of all CAO personnel; that senior management will establish and cultivate principles that integrate quality requirements and performance standards into daily work, provide individuals performing work with proper qualifications, training, resources, and support to achieve the CAO organizational and mission objectives; that line organizations achieve and verify quality; and that each individual's role is to implement the CAO quality assurance program and to recommend improvements in the quality of items and process effectiveness.

Based on the risks associated with the work, the *CAO Quality Assurance Program Description* (QAPD) provides guidance for all work, items, and activities conducted in support of the CAO. Organizations supporting the CAO are expected to use the QAPD for guidance in the performance of work important to safety and waste isolation in the engineered WIPP facility.

By this Policy Statement, all CAO senior managers are empowered and expected to demonstrate commitment and leadership to achieve quality through their active involvement in the implementation of the CAO's established and approved quality assurance program.

George E Dials
Manager, CAO

6/13/94
Date

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LIST OF ACRONYMS AND ABBREVIATIONS

ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ASQC	American Society for Quality Control
CAO	Carlsbad Area Office
CFR	Code of Federal Regulations
CRC	Chemical Rubber Company
DOE	Department of Energry
DOE-AL	Department of Energy-Albuquerque
DOE-HQ	Department of Energy-Headquarters
EEG	Environmental Evaluation Group
EM-1	Office of Enviromental Management
EPA	U.S. Environmental Protection Agency
M&DC	Monitoring and Data Collection Equipment
M&TE	Measuring and Test Equipment
NAS	National Academy of Sciences
NIST	National Institute of Standards and Technology
NQA	Nuclear Quality Assurance
NUREG	Nuclear Regulatory Commission Report Designation
QA	Quality Assurance
QAPD	Quality Assurance Program Description
QARD	Quality Assurance Requirements and Description
TRU	Transuranic
WIPP	Waste Isolation Pilot Plant

I – INTRODUCTION

The Carlsbad Area Office (CAO) Quality Assurance Program Description (QAPD) is the quality management document which identifies federal and industry quality requirements applicable to the CAO quality assurance program. This document establishes the minimum requirements for CAO personnel and guidance for the development and implementation of quality assurance programs by all participants managed by the CAO. Requirements and guidance are based on criteria contained in such documents as 10 CFR Part 830, ASME NQA-1, DOE Order 5700.6C, and the EM-1 Quality Assurance Requirements and Description (QARD) document. Table I-1 lists source documents, which fall into one of three categories:

- Regulatory documents that define the requirements necessary for WIPP to be granted a certificate of compliance by the federal government and permit(s) by state governmental agencies to dispose of mixed transuranic wastes in the WIPP repository

- Commitment documents that are imposed by DOE management

- Guidance documents that provide additional information useful in developing quality assurance programs

This list of source documents is not all inclusive.

The QAPD is organized to provide a description of general, management, performance, and assessment requirements, as well as supplementary quality assurance requirements for specific application areas (i.e., Section 5, Scientific Investigation QA Requirements [applicable portions of ASME NQA-3]; and Section 6, Software Quality Assurance [ASME NQA-2, Part 2.7]).

Participant's quality assurance program descriptions describe how they intend to manage their work activities to achieve planned objectives and goals. Quality assurance implementin procedures are utilized to control these work activities.

The requirements and guidance contained in this QAPD are based on the principle that work shall be planned, documented, performed under controlled conditions, and periodically assessed to establish work item quality and process effectiveness and to promote improvement. The requirements described in this document reflect the responsibilities assigned to management and line personnel of the CAO and their responsibility for planning, achieving, verifying and assessing quality and promoting continuous improvement. This QAPD further delineates the quality contributions expected of all personnel and encourages their active participation in accomplishing the CAO's quality assurance objectives.

Table I-1 SOURCE DOCUMENTS

REGULATORY REQUIREMENTS DOCUMENTS	TITLE
10 CFR 830	Nuclear Safety Management
40 CFR 261	Identification and Listing of Hazardous Waste
40 CFR 268.6	Land Disposal Restrictions
10 CFR Part 71	Subpart H, Quality Assurance, Packaging and Transportation of Radioactive Material
40 CFR 264	Standards for Owners and Operators of Hazardous Waste Treatment Storage and Disposal Facilities.
COMMITMENT DOCUMENTS	**TITLE**
DOE Order 5700.6C	Quality Assurance
EM-1 QARD	Quality Assurance Requirements and Description
DOE/AL -57xA	Standards and Calibration Program
ASME NQA-1c (1989, with 1992 Addenda) and Supplementary Requirements	Quality Assurance Program Requirements for Nuclear Facilities
GUIDANCE DOCUMENTS	**TITLE**
ASME NQA-2- Part 2.7 (1989)	Quality Assurance Requirements of Computer Software for Nuclear Facility Applications
ASME NQA-3 (1989), Parts 2.2, 2.3, 2.4,3.1, 3.2, 3.3, 17.3, 18 and 3SW-1	Quality Assurance Program Requirements for the Collection of Scientific and Technical Information for Site Characterization of High-Level Nuclear Waste Repositories
NUREG-1297 (2/88)	Peer Review for High-Level Nuclear Waste Repositories
NUREG-1298 (2/88)	Staff Position-Qualification of Existing Data for High-Level Nuclear Waste Repositories
NUREG-0167 (1993)	Software Quality Assurance Program and Guidelines

NOTE: List is not all inclusive.

SECTION 1 – MANAGEMENT QUALITY ASSURANCE REQUIREMENTS

1.1 ORGANIZATION AND QUALITY ASSURANCE PROGRAM

This section describes the CAO organizational structure, interfaces, functional responsibilities, and levels of authority for performing, managing, and assessing the adequacy of work. It also defines the requirements for the development of quality assurance programs. WIPP participants develop, implement, maintain, and document their quality assurance programs either in accordance with DOE Order 5700.6C or 10 CFR Part 830. These quality assurance programs are expected to include the guidance provided in this QAPD, specific implementing documents, plans, and procedures.

Quality assurance programs define the management systems to be employed to ensure the requirements and guidance described by this QAPD are met. The purpose of specifying requirements and associated guidance for quality assurance programs is to ensure that all participants develop and implement effective management systems to ensure that items, processes, and services meet or exceed applicable CAO quality assurance requirements.

Effective implementation of the CAO QA program is dependent on the efforts of all levels of the CAO organization (including the CAO Manager, senior management, line management, and the personnel performing work). The CAO organization is structured such that the individual performing the work is responsible for achieving and maintaining quality; line management is responsible for verifying the quality; and independent assessors are responsible for independently assessing the quality of the work. The QA section is responsible for defining, integrating, and ensuring effective implementation of quality assurance activities throughout the CAO.

The CAO organization chart is shown in Figure I-1.

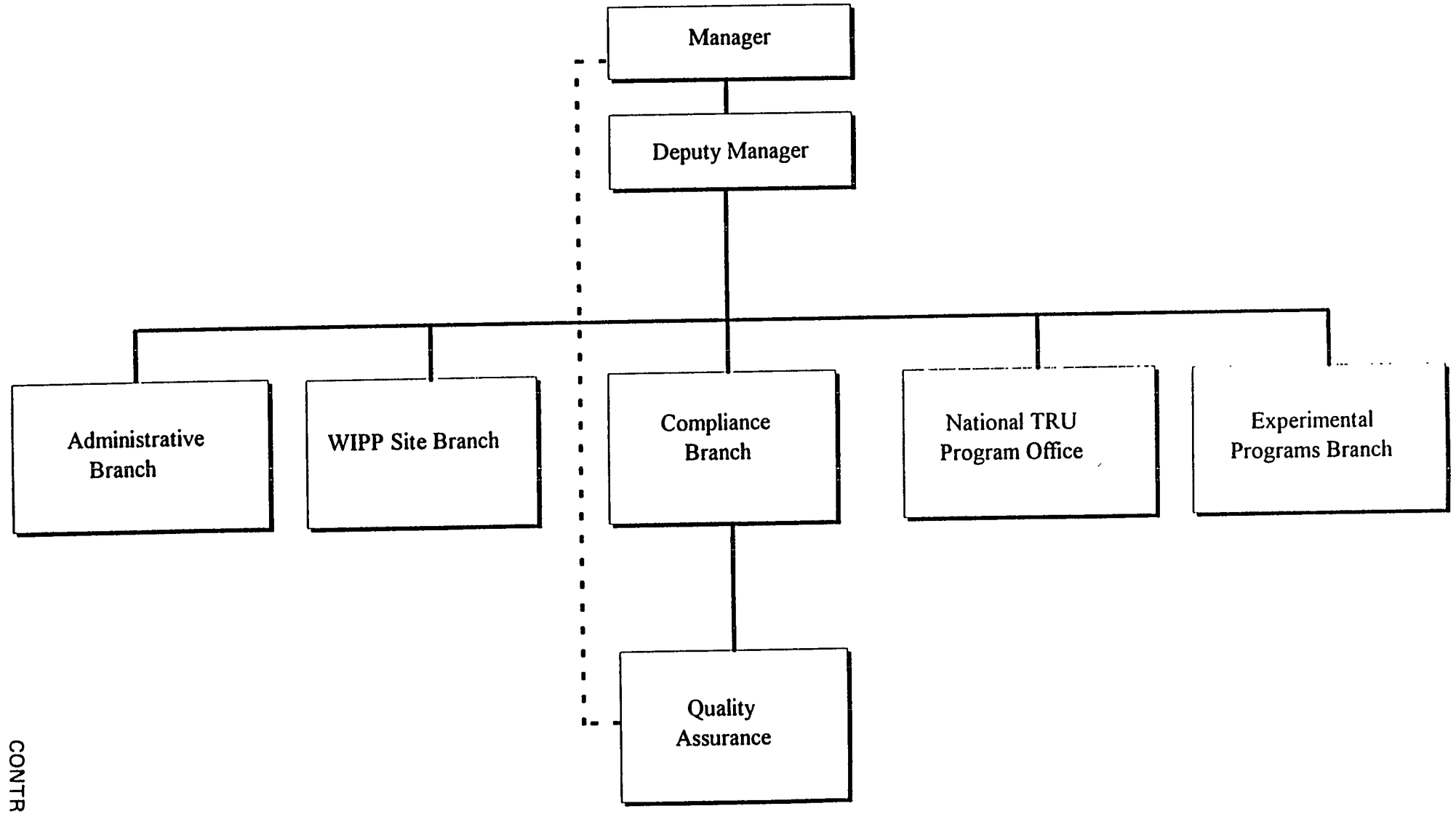
1.1.1 Senior Management

Senior management has overall responsibility for the successful accomplishment of the CAO mission. Senior management will provide the necessary planning, organization, direction, control, resources, and support to achieve the organization's objectives. Senior management will be responsible for planning, performing, assessing, and improving the work.

1.1.1.1 CAO Manager

Overall responsibility for the development and implementation of the CAO quality assurance program belongs to the CAO Manager. The CAO Manager is responsible for approving this document. Authority for execution of the QA function, which includes ensuring effective implementation, is delegated to the CAO QA Manager.

CAO ORGANIZATION CHART



CONTROLLED COPY

FIGU' -1

1.1.1.2 Other Senior Management

The CAO senior management team includes the Deputy Manager, the QA Manager, and managers from the following branches:

- Experimental Programs
- Compliance
- Administrative
- National TRU Program Office
- WIPP Site

CAO senior management is responsible for implementing this QAPD. Senior managers are authorized to establish and implement policies and procedures that control the quality of work in accordance with the QA program. The CAO senior management reports directly to the CAO Manager.

Senior management has various quality related responsibilities which include:

- ensuring that adequate technical and QA training is provided for personnel performing work subject to the controls of this QAPD
- ensuring compliance with all applicable federal regulations, DOE orders and requirements applicable to CAO, and applicable state and local laws
- ensuring that CAO personnel adhere to procedures for the generation, identification, storage, and disposition of QA records
- having the authority to stop unsatisfactory work such that cost and schedule do not override safety considerations
- developing, implementing, and maintaining plans, policies, and procedures that implement the QA program

1.1.2 Line Management

CAO shall identify the responsibilities and authorities of those organizational line management positions responsible for achieving and verifying quality. CAO senior management empowers employees by delegating authority and decision making through delegation to the lowest appropriate level in the organization. Quality achievement is the responsibility of those performing the work. The line management of CAO is responsible for the achievement and verification of quality in their area.

Each CAO line manager is responsible for indoctrination and training of personnel, as necessary, in the performances of activities important to safety and waste isolation and for ensuring the suitable proficiency is achieved and maintained.

Each CAO employee is responsible for the quality of his or her work. The requirements of the CAO QAPD are binding on all CAO personnel, including those having responsibility for planning and scheduling.

1.1.3 Quality Assurance Management

The CAO QA Manager has the overall responsibility to independently assess the effective implementation of the QA program. Other responsibilities of the QA Manager include the following:

- establish and ensure effective implementation of the overall CAO QA policy
- prepare and revise the CAO QAPD
- interface with the CAO technical staff on quality related matters
- schedule and conduct QA audits
- maintain liaison with QA organizations from WIPP participants and other affected organizations
- review and approve CAO procedures that implement this QAPD
- review and approve contractor QAPDs
- participate in the disposition of CAO conditions adverse to quality
- participate in the disposition of contractor-reported nonconformances
- assist other CAO sections and branches with quality planning, problem identification, and the development of problem solutions
- provide guidance to all CAO branches concerning identification, maintenance, handling, and disposition of QA records
- analyze trends in quality problem areas
- ensure QA section awareness in decisions or commitments which directly affect safety or waste isolation of the engineered WIPP site

The CAO QA Manager shall:

A. Have direct access to responsible management at a level where appropriate action can be effected.

B. Be sufficiently independent from cost and schedule considerations.

C. Have the organizational freedom to communicate with other senior management positions.

D. Have no other assigned responsibilities unrelated to the quality assurance program that would prevent full attention to quality assurance matters.

CAO management policy grants the QA section sufficient authority, access to work areas, and organizational freedom to

- identify quality problems
- recommend solutions
- verify implementation of solutions, and
- ensure that unsatisfactory conditions are controlled until proper disposition has occurred.

The QA section has direct access to line and senior management.

1.1.4 Interfaces

1.1.4.1 External Interfaces

Interface organizations external to CAO include the DOE-HQ, EPA, DOE-AL, CAO contractors, EEG, NAS, the State of New Mexico, and others. Work activities important to safety and waste isolation that are conducted between the CAO and external organizations include (but are not limited to) design, procurement, document review and control, DOE systems communication, waste characterization, repository performance assessment, disposition of nonconformances, corrective action requests, records management, and audits.

The extent of the QA program with respect to external interface organizations is bounded by CAO involvement in the activities and is limited in applicability to CAO personnel, with the exception of CAO contractors, who must conform to 10 CFR Part 830 or DOE Order 5700.6C commensurate with the extent specified in approved procurement documents.

Work assigned to parties outside the CAO organization is identified through design specifications and procurement documentation.

1.1.4.2 Internal Interfaces

CAO internal interfaces associated with work activities affecting safety and waste isolation include all CAO Branch Chiefs.

1.1.5 Delegation of Work

Individuals or organizations responsible for planning, accomplishing, and assessing the work may delegate work to other individuals or organizations; however, the individuals or organizations making the delegation shall retain overall responsibility for the delegated work.

1.1.6 Resolution of Disputes

Differences of opinion involving quality assurance program requirements will be brought to the attention of the responsible manager and, if not resolved, will be elevated progressively to successively higher levels of management as necessary.

1.1.7 Establishment and Maintenance of Quality Assurance Programs

CAO shall review and approve participant quality assurance program descriptions based on the guidance specified in this QAPD for a management system for implementing quality assurance requirements. CAO shall review and approve revised plans that address the guidance of this QAPD from the participants who currently possess a CAO quality assurance program description or equivalent. CAO's contractors revised plans shall become effective after approval by the CAO QA Manager. For those participants who do not currently have an approved quality plan, CAO will review and approve a plan that addresses the guidance presented in this QAPD.

1.1.7.1 Quality Assurance Program Documents

A. Quality assurance program descriptions shall include a policy statement signed by the Senior Manager that defines the organization's policy for quality assurance implementation.

B. The following requirements apply to the development and implementation of quality assurance program descriptions and implementing procedures.

   1. Organizations are expected to develop quality assurance implementing procedures as necessary, that provide for top-down implementation of QAPDs.

   2. QAPDs shall provide control over internal and external interfaces. An interface exists when one participant prescribes an activity or requirement to, or shares an activity or requirement with, another participant. Interfaces are expected to be defined and documented.

C. When a QAPD is revised, all affected lower tier QAPDs and implementing procedures are to be reviewed and changed as appropriate. The revised QAPD will be approved by the QA manager at the next higher level in the WIPP organization.

D. When deemed appropriate, participants shall make changes to their approved QAPDs. All changes shall be submitted to the QA manager at the next higher level in the WIPP organization for approval prior to implementation.

1.1.7.2 Grading Items and Processes and Applying Quality Assurance Controls

The graded approach is a systematic determination by which items, services, and processes are analyzed to determine the level of control rigor to be applied to each. The grading process provides the flexibility to design controls that best suit the facility or activity.

The graded approach process should determine the appropriate level of effort necessary in the performance of work important to safety and waste isolation in the engineered WIPP facility.

Quality assurance program descriptions shall include a discussion of how the quality assurance requirements will be satisfied taking into consideration the cost and risk associated with the work. This discussion shall include the rationale and methodology used for the determination of the applicability of the requirements to the work being performed.

The rigor of quality assurance controls shall be commensurate with, but not limited to, the following criteria:

- function or end use of the item
- importance and end use of the data generated
- probability of failure
- complexity or uniqueness of design of fabrication of the item or design or implementation of the activity
- reproducibility of the result
- history of the item or service quality
- necessity for special controls or processes
- ability to demonstrate functional compliance
- impact on the environment, safety, and health
- impact on cost or schedule or both

1.1.8 Planning Work

Planning shall be performed and documented to ensure work is accomplished under suitably controlled conditions. Appropriate, nationally recognized standards shall be used, whenever applicable, to develop and implement methods and processes to control the conduct of work. Standards used to develop and implement the technical procedures shall be documented in work activity planning.

When no recognized standard exists, then the technical procedures shall be reviewed to ensure technical adequacy of the methods and processes to be implemented. As appropriate, planning elements shall include:

- definition of work scope, objectives, and a listing of the primary tasks involved

- identification of scientific approach or technical methods used to collect, analyze, or study results of applicable work
- identification of applicable technical standards and quality criteria
- identification of applicable implementation documents
- identification of field and laboratory testing equipment or other equipment
- identification of, or provisions for the identification of, required records and the recording of objective evidence of the results of the work performed
- identification of prerequisites, special controls, specific environmental conditions, processes, or skills
- identification of computer software

1.1.9 Readiness Reviews

The need for readiness reviews is expected to be identified by senior management for major scheduled or planned work to ensure program objectives are met. If needed, readiness reviews shall be conducted prior to the performance of the work to ensure that:

A. Work prerequisites have been satisfied.

B. Personnel have been suitably qualified and trained.

C. Detailed implementation documents are developed and approved.

1.1.10 Peer Reviews

A. Senior management will determine the need for, and as appropriate, initiate peer reviews.

B. Peer reviews shall be performed when the adequacy of information or the suitability of implementation documents and methods essential to meet specified objectives can not be established through testing, alternative calculations, or reference to established standards and practices.

   The following conditions are situations in which a peer review shall be considered:

   1. Critical interpretations or decisions will be made in the face of significant uncertainty, including the planning for data collection, research, or testing.

   2. Decisions or interpretations having significant impact on performance assessment results will be made.

3. Novel or beyond the state-of-the-art testing, plans and procedures, or analyses will be utilized.

4. Detailed technical criteria or standard industry procedures are not available.

5. Results of tests are not reproducible or repeatable.

6. Data or interpretations are ambiguous.

7. Data adequacy is questionable (i.e., the data were not collected in conformance with an established quality assurance program).

C. In conducting a peer review, management will ensure that:

1. The collective technical expertise and qualifications of the peer reviewers span the technical issues and areas involved in the work to be reviewed, including differing bodies of scientific thought.

2. A reviewer's technical qualifications in the review area are at least equivalent to those needed to perform the work under review.

3. Reviewers are independent from the work under review (independent means that the individual was not involved as a work performer, supervisor, technical reviewer or advisor in the work under review and is, to the extent practicable, free from the funding considerations)

D. A peer review report will be prepared. The report will state the work or issue that was reviewed, identify the reviewers, and the conclusion(s) of the review.

1.2 PERSONNEL QUALIFICATION AND TRAINING

Personnel performing work will be qualified and capable of performing their assigned tasks. Participants shall establish methods for the evaluation, selection, indoctrination, training, and qualification of personnel performing work.

Records generated by qualification and project or work-specific skill training programs are collected and maintained as part of the training records.

1.2.1 Qualification

Qualification requirements for positions or job categories within CAO organizations will be established. These positions include but are not limited to managers, designers, scientists, independent assessment personnel, operators, maintenance personnel, technicians, and inspectors. Management is expected to:

A. Establish qualification requirements for positions commensurate with the scope, complexity, and nature of the work, including minimum education and experience requirements.

B. Ensure qualifications, including minimum education and experience, are verified or, when education and experience cannot be specifically verified, provide a statement and justification for the personnel assignment.

1.2.2 Training

Training shall emphasize correct performance of work and provide understanding of why quality and safety requirements exist and provide an understanding of the fundamentals of the work and its context. Training shall be subject to ongoing review to determine instruction and program effectiveness, and shall be upgraded whenever needed improvements or other enhancements are identified. Management in the CAO is expected to:

A. Ensure personnel are indoctrinated and trained, including on-the-job and hands-on training, as needed, to achieve initial proficiency; maintain proficiency; and adapt to changes in technology, methods, job responsibilities and quality assurance implementing procedures prior to performing assigned tasks.

B. Ensure personnel are indoctrinated in the following:

- general criteria, including this QAPD, applicable codes, regulations, and standards
- applicable implementing procedures

1.3 QUALITY IMPROVEMENT

This section defines senior management's responsibility for building a culture in which continuous improvement is a fundamental and integral part of the organization's mission; therefore, each organization's management will seek continuous improvement in the performance and efficiency of all work processes and activities.

CAO shall establish and implement processes to detect and prevent adverse quality conditions and to ensure quality improvement. Items and processes that do not meet established requirements shall be identified, controlled, and corrected.

Correction shall include identifying the causes of adverse conditions and preventing recurrence. Item reliability, process implementation, and other relevant information shall be reviewed and the data analyzed to identify items and processes needing improvement.

All personnel are responsible for identifying nonconforming items, activities, and processes and are encouraged by management to suggest improvements. Management at all levels should foster a "no-fault" attitude to encourage the identification of nonconforming items and processes. Nonconformances shall be documented, evaluated, and dispositioned.

1.3.1 Nonconformances

1.3.1.1 Identifying Nonconformances

Nonconforming activities and processes shall be identified and documented. Nonconformance documentation shall clearly identify and describe the characteristics that do not conform to specified criteria.

Nonconforming items shall be identified by marking, tagging, or other methods that do not adversely affect their end use. The identification shall be legible and easily recognizable.

If the marking of a nonconformance item is not practical then the item, container, or package, shall be moved to a segregated storage area that is clearly identified and designated, as appropriate, until the item is properly dispositioned.

The segregation area shall be access controlled. If segregation is impractical or impossible due to physical conditions, then other administrative controls and precautions shall be employed to preclude inadvertent use.

1.3.1.2 Identifying and Classifying Conditions Adverse to Quality

Conditions adverse to quality, such as failures, deficiencies, defective items, and nonconformances, shall be documented.

A. Conditions adverse to quality shall be classified in regard to their significance, and corrective actions shall be taken accordingly.

B. Two categories of classification shall be established:

- conditions adverse to quality
- significant conditions adverse to quality

A condition adverse to quality is an all-inclusive term used in reference to failures, malfunctions, deficiencies, defective items, and nonconformances. Significant conditions adverse to quality are conditions that if not corrected, could have a serious effect on safety, operability, waste isolation or compliance demonstration.

1.3.2 Control and Disposition/Correction of Nonconformances

1.3.2.1 Nonconformances

Nonconforming items shall be properly controlled to prevent their inadvertent impact on test, installation, or use. Nonconformance documentation shall include recommended dispositions of nonconforming items.

The nonconformance shall be reviewed by the organization that originally reviewed and approved the item or by a designated organization that is qualified and knowledgeable. Organizations affected by the nonconformance shall be notified.

Reworked, repaired, and replaced items shall be inspected and tested in accordance with original requirements or specified alternatives. Personnel responsible for analyzing and dispositioning nonconformances will have an adequate technical understanding of the item function and have access to pertinent background information relative to the nonconformance. The disposition of nonconforming items will have the concurrence of the quality assurance organization.

A. The disposition of "use as is," "reject," "repair," or "rework" for nonconforming items shall be identified and documented. Further processing, delivery, installation, or use of a nonconforming item shall be controlled pending the evaluation and approval of the disposition.

B. Items that do not meet original design requirements that are dispositioned "use as is" or "repair" shall be subject to design control measures commensurate with those applied to the original design. The technical justification for the acceptability of a nonconforming item that has been dispositioned "repair" or "use as is" shall be documented.

C. The disposition of an item to be reworked or repaired shall contain a requirement to re-examine (inspect, test, or conduct nondestructive examination) the item to verify acceptability. Repaired or reworked items shall be re-examined using the original process and acceptance criteria unless alternative acceptance criteria have been established as part of the nonconforming item disposition.

D. The responsibility and authority for reviewing, evaluating, approving the disposition, and closing nonconformances shall be specified.

1.3.2.2 Conditions Adverse to Quality and Significant Conditions Adverse to Quality

A. Conditions adverse to quality will be investigated and documented by responsible management. Corrective action will be determined, documented, and completed in a timely manner.

B. Line management will investigate the extent of the condition and document the results; determine, document, and complete remedial action; determine the root cause of the adverse condition and take prompt corrective action to prevent recurrence. These may not all apply for conditions adverse to quality. The CAO quality assurance organization shall evaluate and concur, as appropriate, with senior management's approval of the proposed corrective action, including remedial action, the root cause, and actions taken to prevent recurrence to ensure that quality assurance program requirements are satisfied.

C. Significant conditions adverse to quality will be reported to and evaluated by the participant's quality assurance organization and appropriate management responsible for the condition to determine if a stop work order is deemed necessary.

1. Senior management will issue stop work orders to the line management after a stop work condition has been identified. The CAO quality assurance organization may be delegated this activity with written authorization from senior management.

2. Senior management will take appropriate action to lift and close (in part or total) the stop work order based on the resolution of the related significant condition adverse to quality. The CAO quality assurance organization may be delegated this activity with written authorization from senior management.

D. Significant conditions adverse to quality will be documented and reported to line management, senior management, and to the CAO quality assurance organization for tracking.

1.3.3 Verification of Corrective Action

Corrective actions are required to address the following points, as appropriate:

- Determination of the root cause of the problem
- Action to resolve the initial problem
- Action to preclude recurrence of the problem
- Assessment of the extent of the problem
- Forecast completion dates for the required actions, and individuals responsible for follow-up

A follow-up system shall be established to verify proper implementation of scheduled corrective actions and to complete the corrective action in a timely manner. The quality assurance organization shall assess the effectiveness of corrective actions taken for reported conditions adverse to the quality.

1.3.4 Trending Performance

Performance data that affects quality and identifies lessons learned to approve items, activities, and processes, shall be analyzed. Data that shows adverse impacts to quality, such as root cause, internal and external failure cost, prevention cost, and other pertinent information, shall be analyzed to identify opportunities to improve items, activities, and processes. This analysis shall consider information from external sources and not be limited to one type of work or to one organization.

Trend evaluation shall be performed in a manner and at a frequency that provides for prompt identification of trends adverse to quality. It is expected that participants report trending information to line management and to the quality assurance organization of the next higher level in the WIPP organization. Reports of conditions adverse to quality shall be evaluated to identify adverse quality trends and identify root causes. Identified trends adverse to quality shall be reported to the organization responsible for corrective action.

1.3.5 Other Improvement Processes

As a minimum, other processes that provide quality improvement source input shall include:

- self assessment
- root-cause analysis
- independent assessment
- management assessment

1.4 DOCUMENTS

Documents which prescribe processes, specify requirements, or establish design shall be prepared, approved, issued, and controlled.

1.4.1 Document Preparation, Review and Approval

Documents that specify or prescribe work, shall be reviewed for adequacy, correctness, and completeness prior to approval and issuance as controlled documents after changes or revisions have been made. The CAO shall identify the individuals or organizations responsible for the preparation, review and approval of controlled documents. This is to ensure that documents are accurate, adequate, and approved.

Documents that specify quality requirements or prescribe work activities important to safety or waste isolation, such as instructions, procedures, and drawings, shall be reviewed according to the following requirements and for the additional requirements specified by the applicable sections of this QAPD. Documents, such as test plans, quality plans, management plans, and technical reports, shall also be subject to the same review and approval criteria as presented below:

A. Documents shall be controlled during the review and approval phase in accordance with approved procedures.

B. Before performing the review, review criteria shall be established by the organization requesting the review. These criteria shall consider technical adequacy, accuracy, and compliance with established requirements.

C. Pertinent background information or data shall be made available to the reviewers by the organization requesting the review, if the information is not readily available to the reviewer.

D. The review will be performed by individuals other than the originator.

E. Reviewers will be technically competent in the subject area being reviewed.

F. The organization or technical discipline affected by the document shall review the document according to the established review criteria. Changes to the document shall be reviewed by those participant organizations or technical disciplines affected by the change.

G. The CAO's quality assurance organization shall review documents that translate QAPD requirements into work processes. Changes to such documents shall be reviewed and approved at minimum by the same organizations that performed the original review and approval.

H. Review comments shall be resolved by reviewers from the originating organization unless otherwise delegated by management, the resolutions documented, and signed by both the originator and reviewer(s) to signify concurrence. Dispositioned review comments shall be maintained by the originating organization.

I. Documents will be approved by the designated approval authority in accordance with the requirements of this QAPD as authorized by the originating organization prior to distribution.

1.4.2 Document Control and Distribution

The distribution and use of controlled documents and forms that document or prescribe work, including changes and editorial corrections to documents, shall be controlled to meet the following requirements:

A. Documents used to perform work shall be distributed to affected personnel and used at the work location.

B. Effective dates shall be established for and placed on approved documents.

C. The disposition of obsolete or superseded documents and forms shall be controlled to avoid their inadvertent use.

D. Controls shall be established and maintained to identify the current status/revision of controlled documents and forms.

E. Controls shall be established defining the distribution of controlled documents.

1.4.2.1 Expedited Changes to Documents

If an activity cannot be performed as defined in the implementing procedures and the normal change process would cause unreasonable delays (significant impact to cost and schedules), then an expedited change may be made at the work location by responsible management, assuming that the change does not create significant increase in risk.

A. After the expedited change has been authorized in writing, the changes shall be processed through an approved change control process. This processing shall occur promptly and in a manner consistent with the type and nature of the document being changed.

B. Document control procedures shall describe the process used to control expedited changes according to the following requirements:

   1. The level of management with the authority to make expedited changes shall be identified.

   2. The time limits for processing expedited changes through the change process shall be specified.

   3. An evaluation of the work shall be performed if the normal review process results in a change that is different from the expedited change.

   4. The required records for documentation of the change.

1.4.2.2 Editorial Changes to Documents

Editorial changes may be made to documents without being subject to the original level of review.

A. The following items are considered editorial changes:

   - correcting grammar or spelling
   - renumbering sections or attachments
   - updating organizational titles

B. A change in an organizational title accompanied by a change in responsibilities is not considered an editorial correction.

C. The organization responsible for the document shall approve (in writing) editorial corrections.

1.5 RECORDS

Records shall be specified, prepared, reviewed, approved, controlled, and maintained to accurately reflect completed work and facility conditions and to comply with statutory or contractual requirements. A "quality assurance record" is a completed document that furnishes evidence of the quality of items and/or activities affecting safety or waste isolation.

1.5.1 Generating Quality Assurance Records

A. Prior to conducting and/or completing a work activity, the organization shall:

   1. Identify those records that shall become quality assurance records.

   2. Identify the organization responsible for submitting the quality assurance records to the records management system.

B. Individuals will create quality assurance records that are legible, accurate, and complete.

C. Individuals handling quality assurance records will provide reasonable protection for the records from damage or loss until the records are submitted to the records management system (this includes documents generated during field operations).

D. Records shall become quality assurance records when stamped, initialed, or signed and dated as complete. If the nature of the record (such as magnetic or optical media) precludes stamping or signing, then other means of authentication by authorized personnel are required.

E. Quality assurance records may be originals or copies; however, original documents are preferred.

1.5.2 Indexing Quality Assurance Records

The records management system shall provide for the indexing of quality assurance records according to the following requirements:

A. An individual or organization shall be assigned the responsibility of indexing and maintaining quality assurance records.

B. Quality assurance records shall be indexed to ensure retrievability.

1.5.3 Classifying Quality Assurance Records

Quality assurance records shall be classified as either "permanent" or "nonpermanent."

A. Records that fall into one of the following categories shall be classified as "permanent" quality assurance records:

- records that relate to site characterization samples and data
- records that relate to data used in performance assessment of the WIPP facility
- records that relate to the mixed transuranic waste form characterization and acceptance of the mixed transuranic waste form
- records that document regulatory compliance
- records that would be of significant value in demonstrating capability for safe operation
- records that would be of significant value in maintaining, reworking, repairing, replacing, or modifying an item
- records that would be of significant value in determining the cause of an accident or malfunction of an item
- records that assist in preventing actions that could impair the long-term isolation of the waste
- records preserving information that would prevent inadvertent human intrusion, such as the nature and hazard of the waste and the locations of the geologic repository operations area, the underground facility, boreholes, and shafts, and boundaries of the controlled area
- records providing information relevant to post-closure monitoring and assessment of performance of the repository system
- records preserving for future generations information regarding the geologic setting relevant to mitigation of releases of radioactive materials
- records which would be of significant value after decommissioning and closure of a repository

B. Records that provide objective evidence that the quality assurance program has been properly implemented but do not meet the above criteria shall be classified as "nonpermanent" quality assurance records.

1.5.4 Receiving Quality Assurance Records

A. The receipt control system shall permit a current and accurate assessment of the status of quality assurance records.

B. Quality assurance records shall be controlled and protected from damage, deterioration, or loss during the receiving processes.

C. Quality assurance records shall be submitted to storage after the receipt process has been completed.

1.5.5 Storing, Preserving, and Dispositioning Quality Assurance Records

A. Quality assurance records shall be stored and preserved in predetermined storage facilities in accordance with approved quality assurance implementing procedures that provide a:

- description of the storage facility
- description of the indexing system to be used
- method for verifying that the quality assurance records received are in agreement with the transmittal document
- method for ensuring a receipt acknowledgement identifying index number/record location is returned to the sender
- description of controls governing quality assurance record access, retrieval, and removal
- method for filing supplemental information
- method for disposition of superseded quality assurance records

B. The records storage arrangements shall provide adequate protection of records (such as radiographs, photographs, negatives, microfilm, samples, and magnetic media) to preclude damage from moisture, temperature, rodent infestation, excessive light, electromagnetic fields, or stacking as appropriate for the type of record being stored.

C. Records that require special processing and control, such as software and related documentation or information on high density media or optical disks, hardware and software required to maintain and access records, shall be controlled to ensure records are useable.

D. Retention times of quality assurance records depend upon their classification as "permanent" or "nonpermanent." The CAO Manager or designee will retain and preserve permanent quality assurance records. Nonpermanent quality assurance records shall be retained for three years or as otherwise specified. Nonpermanent quality assurance records shall not be dispositioned until the following conditions are met:

1. Regulatory requirements are satisfied.
2. The operational status permits the disposal of such records.
3. Purchaser's requirements are satisfied.

E. Design and construction of a single record storage facility shall meet the following criteria:

- reinforced concrete, concrete block, masonry, or equal construction
- floor and roof with drainage control (if a floor drain is provided, a check valve, or equal, shall be included)
- doors, structure and frames, and hardware shall be designed to comply with the requirements of a minimum 2-hour fire rating;
- sealant applied over walls as a moisture or condensation barrier;
- surface sealant on floor providing a hard wear surface to minimize concrete dusting;
- foundation sealant and provisions for drainage;
- forced air circulation with filter system;
- fire protection system;
- only those penetrations used exclusively for fire protection, communication, lighting, or temperature/humidity control are allowed; all such penetrations shall be sealed or dampened to comply with the minimum 2-hour fire protection rating.
- The construction details shall be reviewed for adequacy of protection of contents by a person who is competent in the technical field of fire protection and fire extinguishing.
- If the facility is located within a building or structure, the environments and construction of that building can provide a portion or all of these criteria.

F. The following are acceptable alternatives to the criteria of E above for a single facility;

- 2-hour fire rated vault meeting NFPA 232-1986 or NFPA 232AM-1986 or both;
- 2-hour fire rated Class B file containers meeting the requirements of NFPA 232-1986 or NFPA 232AM-1986 or both; or
- 2-hr fire rated file room meeting the requirements of NFPA 232-1986 or NFPA 232AM-1986 or both, with the following additional provisions:

  1) Early warning fire detection and automatic fire suppression capability with electronic supervision at a constantly attended central station;

2) Records storage in fully enclosed metal cabinets;

3) Adequate access and aisle ways;

4) Prohibition in the room of work not directly associated with record storage or retrieval;

5) Prohibition in the room of smoking, eating, or drinking;

6) 2-hour fire rated dampers or doors in all boundary penetrations.

G. If storage at dual facilities for each record is provided, the facilities shall be at locations sufficiently remote from each other to eliminate the chance of exposure to a simultaneous hazard. Each facility is not required to satisfy the requirements of either E or F above, but shall meet all other records storage requirements prescribed in this QAPD.

H. Records submitted to a temporary storage area shall be stored in a container certified by a person competent in fire protection, or in a UL one-hour fire rated container, prior to dual storage area or submittal to the WIPP Central Records Facility.

I. Measures shall be established to preclude the entry of unauthorized personnel into the storage area. These measures shall guard against larceny and vandalism. A list designating personnel who are permitted access to the quality assurance records shall be generated, maintained, and posted.

J. Measures shall be taken to provide for replacement, restoration, or substitution of lost or damaged records.

1.5.6 Retrieval of Quality Assurance Records

The records management system shall provide for retrieval of quality assurance records based upon record type (nonpermanent and permanent).

1.5.7 Correcting Information in Quality Assurance Records

A. Corrections to records will include the initials or signature of the person making the correction and the date the correction was made.

B. Corrections to quality assurance records shall be approved by the originating organization.

C. The quality assurance records shall not be corrected through the use of correction fluids or tapes.

2.1 WORK PROCESSES

Work shall be performed to established, approved, and documented technical standards and administrative controls. Work shall be performed under controlled conditions using approved instructions, procedures, drawings or other appropriate means. Items shall be identified and controlled to ensure their proper use. Items shall be maintained to prevent their damage, loss, or deterioration. Equipment used for process monitoring or data collection shall be calibrated and maintained.

The intent of this section is to establish the policy that each person who performs work is responsible for the quality of his or her work, and he or she will have the goal of doing work correctly the first time. To ensure that the person doing the work achieves that goal, management is responsible for establishing processes and procedures to ensure that all work is planned and performed under controlled conditions by personnel who are knowledgeable of the work requirements, and that these individuals are capable of accomplishing the work in accordance with the requirements and guidance presented in this QAPD.

This section further establishes management involvement in the work processes through their interactions with personnel performing the work and through their review and verification of ongoing and completed work. This will help ensure that the definition of "acceptable work performance" is clearly communicated and that personnel are provided the necessary training, resources, and administrative controls to properly accomplish their tasks.

2.1.1 Work

A. Personnel performing work are responsible for the quality of their work. Because the individual worker is the first line in ensuring quality, personnel will be knowledgeable of requirements for work they perform and the capability of the tools and processes they use.

B. Line managers will ensure that personnel working under their supervision are qualified and are provided the necessary training, resources, and administrative controls to accomplish assigned tasks. Criteria describing acceptable work performance shall be defined for the worker.

C. Line managers will review work and related information to ensure that the desired quality is being achieved and to identify areas needing improvement.

D. Work shall be planned, authorized, and accomplished under controlled conditions using technical standards and implementing procedures commensurate with the complexity and risk of the work.

2.1.2 Implementing Procedures

A. Implementing procedures shall be developed, verified, and approved by technically competent personnel.

B. Implementing procedures shall include the following information as appropriate to the work to be performed:

- responsibilities of the organizations affected by the document
- technical, regulatory, or other program requirements
- sequential description of the work to be performed
- quantitative or qualitative acceptance criteria sufficient for determining that activities were satisfactorily accomplished
- prerequisites, limits, precautions, process parameters, and environmental conditions
- special qualification and training requirements
- verification points and hold points
- methods for demonstrating that the work was performed as required (such as provisions for recording inspection and test results, check-off lists, or sign-off blocks)
- identification of the permanent or nonpermanent classification of quality assurance records generated by the implementing procedure

C. Implementing procedures shall also be reviewed, approved, and controlled.

D. Individuals performing work will comply with implementing procedures; however, when work cannot be accomplished as described in the implementing procedure or accomplishment of such work would result in an undesirable situation, condition adverse to quality, or an unacceptable safety risk, the work shall be suspended or procedures for expedited changes shall be invoked.

2.1.3 Item Identification

To ensure that only correct and accepted items are used or installed, records of items shall be maintained in a manner that ensures identification is established and maintained.

A. Items shall be identified and traced from the time of initial fabrication or receipt, up to and including, installation or end use. Documentation shall ensure that the item can be traced at all times from its source through the item's installation or end use.

B. Item identification methods shall include physical markings. If physical markings are either impractical or insufficient, other appropriate means shall be employed (such as physical separation, labels or tags attached to containers, or procedural control). When used, physical markings shall:

- be applied using materials and methods that provide a clear, permanent, and legible identification
- not be detrimental to the function or service life of the item
- be transferred to each part of an identified item when the item is subdivided
- not be obliterated or hidden by surface treatments, or coatings, or installation unless other means of identification are substituted

C. If codes, standards, or specifications include specific identification or traceability requirements (such as identification or traceability of the item to applicable specification or grade of material; heat, batch, lot, part, or serial number; or specified inspection, test, or other records), then identification and traceability methods shall be implemented to ensure meeting the special requirements.

D. Item identification control system records shall provide the inspection, test, and operating status of items. Items that have satisfactorily passed the required inspections and tests shall be identified. The identification methods shall preclude the inadvertent installation, use, or operation of items that have not passed required inspections and tests.

E. The status of inspections and tests shall be identified either on the items or in documents traceable to the items. Status shall be maintained through the use of status indicators (such as tags, markings, labels, and stamps), or other means (such as travelers, inspection or test records) and the authority for applying and removing status indicators shall be specified.

F. If items have a limited operating or shelf life specified, then methods shall be established that preclude using the item beyond the operating or shelf life.

2.1.4 Special Processes

A. Processes shall be considered as special processes if they meet any one or combination of the following criteria:

- the results are highly dependent on the control of the process
- the results are highly dependent on the skill of the operator
- the quality of the results cannot be readily determined by inspection or test of the product

B. Implementing procedures shall be established to ensure special process parameters are controlled and specified environmental conditions are maintained. In addition to the guidance provided in the section entitled "Implementing Procedure," special process implementing procedures shall include or reference:

- requirements for qualification of personnel, process(es), and equipment
- conditions necessary for completing of the special process including equipment, statistical process control, controlled parameters of the process, and calibration requirements

2.1.5 Handling, Storage, and Shipping

Handling, storage, cleaning, shipping, and other means of preserving, transporting, and packaging of items shall be conducted in accordance with established work and inspection implementing procedures, shipping instructions, or other specified documents.

A. If required for critical, sensitive, perishable, or high-value articles, specific implementing procedures for handling, storage, cleaning, packaging, shipping, and other preservation shall be prepared and used.

B. Measures shall be established and implemented for the marking and labeling of items for packaging, shipping, handling, and storage as necessary to adequately identify, maintain, and preserve the item. Markings and labels shall indicate the presence of special environments or the need for special controls as necessary.

If required for protection or maintenance of particular items, special equipment (such as containers, shock absorbers, and accelerometers) and special protective environments (such as inert gas and specific moisture and temperature levels) shall be specified, planned for, and provided.

A. If special protective equipment and environments are used, provisions shall be made for verifying their adequacy.

B. Special handling tools and equipment shall be used and controlled as necessary to ensure safe and adequate handling.

C. Special handling tools and equipment shall be inspected and tested at specified intervals and in accordance with implementing procedures to verify that the tools and equipment are adequately maintained.

D. Operators of special handling and lifting equipment shall be sufficiently experienced and trained to use the equipment.

If storage of items is required, then methods shall be established for the control of item identification records that are commensurate with the planned duration and conditions of storage. These methods shall provide for, as applicable:

- maintenance or replacement of markings and identification tags damaged during handling or aging
- protection of identification markings that are subject to excessive deterioration resulting from environmental exposure
- update of related identification records and documentation

Status indicators, such as tagging valves and switches to prevent inadvertent operation, shall be used to indicate operating status of items. Status indicators, such as lockout tagging, shall also be used where appropriate.

2.2 DESIGN CONTROL

Items and processes shall be designed using sound engineering/scientific principles and appropriate standards. Design work, including changes, shall incorporate appropriate requirements such as general design criteria and design bases. Design interfaces shall be identified and controlled. The adequacy of design products shall be verified by individuals or groups other than those who performed the work. Verification work shall be completed before approval and implementation of the design.

This section provides requirements to ensure that designs (from conceptual through final) are defined, controlled, and verified. In establishing design controls, management is responsible to ensure that design inputs are technically correct; that design interfaces are identified; that authorities, responsibilities, and lines of communication are clearly defined; and that the design processes clearly define the acceptance criteria for the product.

2.2.1 Design Input

Applicable design inputs (such as design bases, conceptual design reports, performance requirements, regulatory requirements, codes, and standards) will be controlled by those responsible for the design in accordance with the following requirements:

A. Design inputs will be identified and documented, and their selection reviewed and approved by those responsible for the design.

B. Design inputs shall be specified and approved on a timely basis and to the level of detail necessary to permit the design work to be carried out correctly in a manner that provides a consistent basis for making design decisions, accomplishing design verification, and evaluating design changes.

C. Changes from approved design inputs and reasons for the changes shall be identified, approved, documented, and controlled.

2.2.2 Design Process

The design process shall be controlled according to the following requirements:

A. Appropriate standards shall be identified and documented, and their selection reviewed and approved. Changes from specified standards, including the reasons for the change, shall be identified, approved, documented, and controlled.

B. Design work shall be prescribed and documented on a timely basis and to the level of detail necessary to permit the design process to be carried out correctly.

C. Design documents shall be adequate to support design, fabrication, construction, and operation.

D. Design documents shall be sufficiently detailed as to purpose, method, assumptions, design input, references, and units such that a person technically qualified in the subject can understand the documents and verify their adequacy without recourse to the originator.

E. Controls for identifying assemblies or components that are part of the item being designed shall be established. If a commercial grade assembly or component is modified or selected by special inspection or testing to meet requirements that are more restrictive than the supplier's published product description, then the assembly or component shall be represented as different from the commercial grade item in a manner traceable to a documented definition of the difference.

F. Controls for selecting and reviewing design methods, materials, parts, equipment, and processes essential to the function of an item shall be established.

G. Drawings, specifications, and other design output documents shall contain appropriate inspection and testing acceptance criteria.

2.2.3 Design Analyses

A. Design analyses shall be planned, controlled, and documented.

B. Documentation of design analyses shall include:

- definition of the objective of the analyses
- definition of design inputs and their sources
- results of literature searches or other applicable background data

- identification of assumptions and designation of those assumptions which shall be verified as the design proceeds

- identification of any computer calculations, including computer type, computer software name, revision identification, inputs, outputs, and the bases (or reference thereto) supporting application of the software to the specific physical problem

- identification of the reviewer and approver

C. Calculations shall be identifiable by subject (including structure, system, or component to which the calculation applies), originator, reviewer, and date, or by other designator such that the calculations are traceable.

D. Computer software used to perform design analyses shall be developed, qualified, and used according to the requirements of the section entitled, "Software Quality Assurance Requirements."

2.2.4 Design Interface

Design interfaces shall be identified and controlled so that efforts are coordinated among participating organizations.

A. Design interface controls shall include the assignment of responsibility and the establishment of implementing procedures among participating design organizations for the review, approval, release, distribution, and revision of documents involving design interfaces.

B. Design information transmitted across interfaces shall be documented and controlled.

C. The status of the design information or issued design documents shall be identified in transmittals. Where necessary, incomplete designs that require further evaluation, review, or approval shall be identified.

2.2.5 Design Verification

The acceptability of design work and documents, including design inputs, processes, outputs, and changes, shall be verified. The following design control requirements shall be applied to verify the adequacy of design.

A. Design verification shall be performed using one or a combination of the following methods:

- design review

- alternate calculations

- qualification testing

B. The particular design verification method shall be identified.

C. The results of design verification shall be documented, including the identification of the verifier.

D. Design verification shall be performed by competent individuals or groups other than those who performed the original design (but they may be from the same organization). If necessary, this verification may be performed by the originator's supervisor provided that:

1. The supervisor did not specify a singular design approach or rule out certain design considerations and did not establish the design inputs used in the design, or

2. The supervisor is the only individual in the organization competent to perform the verification, and

3. The determination to use the supervisor is documented and approved in advance.

E. Design verification shall be performed at appropriate times during the design process.

1. Verification shall be performed before release for procurement, manufacture, construction, or release to another organization for use in other design work.

2. Design verification shall be completed before relying on the item to perform its function.

F. The extent of the design verification required shall be based on the complexity, risk, uniqueness of the design, complexity of design, degree of standardization, state of the art, and similarity with previously proven designs.

G. Use of previously proven designs shall be controlled according to the following requirements:

1. The applicability of standardized or previously proven designs shall be verified with respect to meeting pertinent design inputs for each application.

2. Known problems affecting standard or previously proven designs and their effects on other features shall be considered.

3. The original design and associated verification measures shall be adequately documented and referenced in the files of subsequent application of the design.

4. Changes in previously verified designs shall require reverification. Such reverifications shall include the evaluation of the effects of those changes on the overall previously verified design and on any design analyses upon which the design is based.

2.2.5.1 Design Reviews

Design reviews shall be controlled, documented, and performed. Design reviews shall consider the following:

A. The design inputs were correctly selected and incorporated.

B. Assumptions necessary to perform the design work were adequately described, reasonable, and reverified as necessary.

C. An appropriate design method was used.

D. The design output is reasonable compared to design inputs.

E. The necessary design input and verification requirements for interfacing organizations were specified in the design documents or in supporting implementing procedures.

Disposition of review comments shall be documented.

2.2.5.2 Alternative Calculations

These are calculations or analyses that are made with alternate methods to verify correctness of the original calculations or analyses. The appropriateness of assumptions, input data used, computer programs, or other calculation methods used shall be evaluated.

2.2.5.3 Qualification Testing

Qualification testing requirements are listed below:

A. The test configuration shall be defined and documented.

B. Testing shall demonstrate the adequacy of performance under conditions that simulate the most adverse design conditions. Operating modes and environmental conditions in which the item shall perform satisfactorily shall be considered in determining the most adverse conditions.

C. If the tests verify only specific design features, then the other features of the design shall be verified by other means.

D. Test results shall be documented, and evaluated by the responsible design organization, to ensure that test requirements have been met.

E. If qualification testing indicates that a modification to an item is necessary to obtain acceptable performance, then the modification shall be documented and the item modified and retested or otherwise verified to ensure satisfactory performance.

F. Scaling laws shall be established and verified when tests are being performed on models or mockups.

G. The results of model test work shall be subject to error analysis, where applicable, before using the results in final design work.

2.2.6 Design Change

Design changes shall be controlled according to the following requirements:

A. Changes to final designs, field changes, and nonconforming items dispositioned "use as is" or "repair" shall be justified and shall be subject to design control measures commensurate with those applied to the original design.

B. Design control measures for changes shall include provisions to ensure that the design analyses for the item are still valid.

C. Changes shall be approved by the same groups or organizations that reviewed and approved the original design documents.

   1. If an organization that originally was responsible for approving a particular design document is no longer responsible, then a new responsible organization shall be designated.

   2. The cognizant design organization shall have demonstrated competence in the specific design area of interest and have an adequate understanding of the requirements and intent of the original design.

D. If a significant design change becomes necessary because of an incorrect original design, the design process and design verification methods and implementing procedures shall be reviewed and modified as appropriate. These design deficiencies shall be documented according to the requirements provided in the subsection entitled "Conditions Adverse to Quality and Significant Conditions Adverse to Quality."

E. Field changes shall be incorporated into the applicable design documents.

F. Design changes that impact related implementing procedures or training programs shall be communicated to appropriate organizations.

2.3 PROCUREMENT

CAO shall ensure that procured items and services meet established technical and quality assurance requirements and that they perform as specified. Prospective suppliers shall be evaluated and selected on the basis of documented criteria. CAO shall ensure that approved suppliers continue to provide acceptable items and services.

2.3.1 Procurement Planning Requirements

The procurement of items and services shall be planned and controlled to ensure that participating organizations' requirements are accurate, complete, and clearly understood by their suppliers.

2.3.1.1 Procurement Planning

Procurement activities shall be planned and documented to ensure a systematic approach to the procurement process. Planning shall be accomplished as early as possible. Procurement planning shall:

A. Identify procurement methods and organizational responsibilities, which includes the quality assurance organization.

B. Identify and document the sequence of actions and milestones needed to effectively complete the procurement. Provide for the integration of the following activities:

- procurement document preparation, review, and change control
- selection of procurement sources
- proposal/bid evaluation and award
- purchaser evaluation of supplier performance
- purchaser verifications including any hold-point and witness-point notifications
- control of nonconformances
- corrective action
- acceptance of the item or service
- identification of quality assurance records

2.3.1.2 Supplier Selection

Supplier selection shall be based on an evaluation of the supplier's capability to provide items or services in accordance with procurement document requirements.

A. Organizations responsible for supplier source selection shall be identified and shall include the quality assurance organization.

B. Measures for selecting procurement sources shall include the following elements:

- evaluation of the supplier's history for providing an identical or similar product that performs satisfactorily in actual use
- evaluation of supplier's current quality assurance records supported by any documented qualitative and quantitative information
- evaluation of the supplier's technical and quality assurance capability based on an evaluation of the supplier's facilities, personnel, and quality program implementation

C. The results of procurement source selection shall be documented.

2.3.1.3 Proposal/Bid Evaluation

A. The proposal/bid evaluation process shall include a determination of the extent of conformance to the procurement document requirements. This evaluation shall be performed by designated, technically qualified personnel and shall include, at a minimum, the following:

- technical considerations
- quality assurance program
- supplier personnel
- supplier production capability
- supplier past performance
- alternatives
- exceptions

B. Before the contract is awarded, the purchaser shall resolve, or obtain commitments to resolve, deficient quality conditions identified during the proposal/bid evaluation.

C. Supplier quality assurance programs shall be accepted by the purchaser before the supplier starts work.

2.3.2 Procurement Document Requirements

The following requirements are established to ensure that procurement documents, and any changes thereto, contain appropriate technical and quality assurance requirements.

2.3.2.1 Procurement Document Preparation

Procurement documents shall include the following provisions, as applicable to the item or service being procured:

A. The scope of work shall be defined.

B. Technical requirements shall be specified, including:

1. Design bases shall be identified or referenced.

2. Specific documents (such as drawings, codes, standards, regulations, procedures, or instructions) that describe the technical requirements of the items or services to be furnished shall be identified. The revision level or change status of these documents shall also be identified.

3. Tests, inspections, hold points or acceptance criteria that the purchaser shall use to monitor and evaluate the performance of the supplier shall be specified.

C. Quality assurance program requirements shall be specified, including:

1. The supplier shall have a documented quality assurance program that implements quality program requirements of the next higher level CAO organization prior to the initiation of work. The level of detail of the quality assurance program plan and subsequent implementing procedures shall depend on the scope, nature, or complexity of the item or service being procured.

2. The supplier shall incorporate the appropriate technical and quality assurance program requirements into any subtier supplier-issued procurement document.

3. When deemed appropriate, the purchaser may permit some or all supplier work to be performed under the purchaser's quality assurance program, provided that the requirements are adequately implemented. In these cases, procurement documents shall specify that the purchaser's quality assurance implementing procedures are applicable to the supplier and that the purchaser shall provide these applicable documents to the supplier.

D. Right of access to supplier facilities and records for inspection or audit by the purchaser, CAO, or other designee authorized by the purchaser shall be established.

E. If the purchaser requires the supplier to maintain documentation that will become quality assurance records, the retention classification and disposition requirements shall be identified.

F. Purchaser requirements for the supplier to report nonconformances and requirements for purchaser approval of the disposition of nonconformances shall be established.

G. Spare and replacement parts or assemblies and the appropriate technical and quality assurance data required for ordering shall be identified.

2.3.2.2 Procurement Document Review and Approval

A. A review of the procurement documents and any changes thereto shall be made to verify that documents include appropriate provisions to ensure that items or services shall meet the prescribed requirements. Procurement document reviews shall be performed and documented prior to issuance to the supplier of the procurement documents or changes thereto.

B. Reviews shall be performed by personnel who have access to pertinent information and who have an adequate understanding of the requirements and scope of the procurement.

C. Procurement document reviews shall include representatives from the technical and quality assurance organizations.

D. Procurement documents shall be approved by appropriate management.

2.3.3 Supplier Performance Evaluation Requirements

The purchaser of items and services shall establish measures to interface with the supplier and to verify supplier's performance. The measures shall include:

- establishing an understanding between the purchaser and supplier of the requirements and specifications identified in the procurement documents
- requiring the supplier to identify planning techniques and processes to be used in fulfilling procurement document requirements
- reviewing supplier documents that are prepared or processed during work performed to fulfill procurement requirements
- identifying and processing necessary change information

- establishing the method to be used to document information exchanges between purchaser and supplier
- establishing the extent of assessment activities and inspection

2.3.3.1 Source Verification

The purchaser may accept an item or service by monitoring, auditing, surveillance, witnessing, or observing activities performed by the supplier. This method of acceptance is called source verification.

The extent of source verifications shall be a function of the relative importance, complexity, and quantity of items or services being procured, as well as the supplier's quality of performance. Source verifications shall be accomplished as early as possible, but in any case prior to the start of those activities that are required to be controlled and shall include the active involvement of the purchaser's quality assurance organization. In addition:

A. Source verification shall be accomplished consistent with the supplier's planned inspections, examinations, or tests, and performed at intervals consistent with the importance and complexity of the item.

B. Documented evidence of acceptance of source verified items or services shall be furnished to the party receiving the item, to the purchaser, and to the supplier.

C. Source verification shall be performed by qualified personnel.

2.3.3.2 Receiving Inspection

When a receiving inspection is used to accept an item:

A. The inspection shall include consideration of source assessments, verifications and audits, and the demonstrated performance quality of the supplier.

B. The inspection shall be performed in accordance with established inspection procedures or instructions.

C. The inspection shall verify, as applicable, proper configuration; identification; dimensional, physical, and other characteristics; freedom from shipping damage; and cleanliness.

D. The inspection shall be planned and executed according to the requirements stated in the subsection entitled "Inspection Planning."

E. Receiving inspection shall include a review of adequacy and completeness of any required supplier documentation submittal.

2.3.3.3 Post-Installation Testing

When post-installation testing is used as a method of acceptance, then post-installation test requirements and acceptance documentation shall be mutually established and agreed upon by the purchaser and supplier.

2.3.3.4 Supplier Certificate of Conformance

When a Certificate of Conformance is used the minimum criteria below shall be met:

A. The certificate shall identify the purchased material or equipment, such as by the purchase order number.

B. The certificate shall identify the specific procurement requirements met by the purchased material or equipment, such as codes, standards, and other specifications. This may be accomplished by including a list of the specific requirements or by providing, on-site, a copy of the purchase order and the procurement specifications or drawings, together with a suitable certificate. The procurement requirements identified shall include any approved changes, waivers, or deviations applicable to the subject material or equipment.

C. The certificate shall identify any procurement requirements that have not been met, together with an explanation and the means for resolving the nonconformances.

D. The certificate shall be signed or otherwise authenticated by a person who is responsible for this quality assurance function and whose function and position are described in the purchaser's or supplier's quality assurance program.

E. The certification system, including the procedures to be followed in filling out a certificate and the administrative procedures for review and approval of the certificates, shall be described in the purchaser's or supplier's quality assurance program.

F. Means shall be provided to verify the validity of supplier certificates and the effectiveness of the certification system, such as during the performance of audits of the supplier or independent inspection or test of the items. Such verification shall be conducted by the purchaser at intervals commensurate with the supplier's past quality performance.

2.3.3.5 Control of Supplier Nonconformances

The purchaser and supplier shall establish and document the process for disposition of items that do not meet procurement document requirements according to the following:

A. The supplier shall submit a report of nonconformance to the purchaser that includes supplier-recommended disposition (for example, "use as is" or "repair") and provide technical justification for such disposition.

Reports of nonconformances to procurement document requirements or documents approved by the purchaser shall be submitted to the purchaser for approval. Examples of conditions requiring a report of nonconformance include:

1. Technical or material requirements are violated.

2. A requirement in supplier documents that have been approved by the purchaser is violated.

3. The nonconformance cannot be corrected by continuation of the original manufacturing process or by rework.

4. The item does not conform to the original requirement even though the item can be restored to a condition such that the item's capability to function is unimpaired.

B. The purchaser shall disposition the supplier's recommendation.

C. The purchaser shall verify implementation of the disposition.

2.3.4 Commercial Grade Items

Where design specifies the use of commercial grade items, the following requirements are an acceptable alternative to other requirements of this section.

A. The commercial grade item shall be identified in an approved design output document. An alternative commercial grade item may be applied, as long as the responsible design organization provides verification that the alternative commercial grade item performs the intended function and meets design requirements applicable to both the replaced item and its application.

B. Supplier selection shall be in accordance with source selection requirements.

C. Commercial grade items shall be identified in the procurement document by the manufacturer's published product description.

D. After receipt of a commercial grade item, the purchaser shall ensure that:

1. Damage was not sustained during shipment.

2. The item received was the item ordered.

3. Inspection or testing is accomplished, to the extent determined by the purchaser, to ensure conformance with the manufacturer's published requirements.

4. Documentation, as applicable to the item, was received and is acceptable.

2.4 INSPECTION AND TESTING

An essential part of the work planning process is to identify the items and processes to be inspected or tested, parameters or characteristics to be evaluated, techniques to be used, acceptance criteria, hold points, and the organizations responsible for performing the tests and inspections. Inspection and testing of specified items and processes shall be conducted using established criteria. The acceptance of an item shall be documented and approved by qualified and authorized personnel. Equipment used for inspections and tests shall be calibrated and maintained.

2.4.1 Selecting Inspection Personnel

The individual who performs an inspection to verify conformance of an item to specified acceptance criteria shall be qualified. Inspection team members who are supervised by a qualified inspector are not required to be qualified inspectors.

The job performance of inspection personnel will be reevaluated for capability at periodic intervals not to exceed three years. The person who has not performed inspection or testing activities in his or her qualified area for a period of one year will be reevaluated for required capability.

The inspection shall be performed by personnel other than those who performed or directly supervised the work being performed.

2.4.2 Inspection Requirements

2.4.2.1 Inspection Planning

Inspection planning shall be performed and documented to include:

- identification of work operations where inspections are necessary
- identification of the characteristics to be inspected and the identification of when, during the work process, inspections are to be performed
- identification of inspection or process monitoring methods to be employed
- identification of acceptance criteria
- identification of sampling requirements
- methods to record inspection results

- selection and identification of the measuring and test equipment to be used to perform the inspection to ensure that the equipment being utilized for inspection or testing is calibrated and is of the proper type, range, accuracy, and tolerance to accomplish the intended function

2.4.2.2 Inspection Hold Points

When mandatory hold points are used to control work that is not to proceed without the specific consent of the organization placing the hold point, then the specific hold points shall be indicated in implementing procedures. Only the organization responsible for the hold point may waive the hold point. Approval to waive specified hold points shall be documented before continuing work beyond the designated hold point.

2.4.2.3 In-Process Inspections and Monitoring

A. Items in process shall be inspected as necessary to verify quality. If inspection of processed items is impossible or disadvantageous, indirect control by monitoring of processing methods, equipment, and personnel shall be provided. Both inspection and process monitoring shall be conducted when control is deemed inadequate using only one method.

B. When a combination of inspection and process monitoring methods is used, monitoring shall be performed systematically to ensure that the specified requirements for control of the process and the quality of the item are met throughout the duration of the process.

C. Controls shall be established and documented for the coordination and sequencing of the work at established inspection points during successive stages of the process.

2.4.2.4 Final Inspections

A. Final inspections shall include a review of the results and verification of resolution of all nonconformances identified by earlier inspections.

B. Finished items shall be inspected for completeness, markings, calibration, protection from damage, or other characteristics as required to verify the quality and conformance of the item to the applicable requirements.

C. Records review shall be undertaken for adequacy and completeness.

D. Modifications, repairs, or replacements of items performed subsequent to final inspection shall require reinspection or retest, as appropriate, to verify acceptability.

2.4.2.5 Inspection Documentation

Inspection documentation shall identify:

- the item inspected and date of inspection
- the inspector's unique identifier or name of the inspector who documented, evaluated, and determined acceptability
- method of inspection
- the inspection criteria, sampling plan, or reference documents (including revision designation) used to determine acceptance
- results or acceptability
- measuring and test equipment used during the inspection, including the identification number and the calibration due date
- reference to information on actions taken in connection with nonconformances, as applicable.

2.4.3 Test Requirements

The following are testing requirements that shall be used to validate conformance of an item to specific requirements or to demonstrate satisfactory performance for service.

Examples of such tests include prototype qualification tests, production tests, proof tests prior to installation, construction tests, and pre operational tests.

2.4.3.1 Test Planning

Test planning shall include:

- identification of the implementing procedures to be developed to control and perform tests
- in lieu of specially prepared written test procedures appropriate sections of related documents such as ASTM methods can be used. If used, they shall incorporate the information directly into the approved test implementing procedure, or shall be incorporated by reference in the approved test implementing procedure
- identification of item to be tested and the test requirements and acceptance limits, including required levels of precision and accuracy

- test prerequisites that address calibrated instrumentation, appropriate and adequate test equipment and instrumentation, trained personnel, and suitably controlled environmental conditions
- mandatory hold points
- methods to record data and results
- provisions for ensuring that prerequisites for the given test have been met

2.4.3.2 Test Documentation

Test documentation shall identify:

- the item or work product tested
- date of test
- name of the tester and data recorders
- type of observation and method of testing
- identification of test criteria or reference documents used to determine acceptance
- results and acceptability of the test
- actions taken in connection with the nonconformances noted
- name of the person evaluating the test results
- identification of the measuring and test equipment used during the test (including the identification number and calibration due date)

2.4.3.3 Test Results

Test results will be documented and their conformance with acceptance criteria will be evaluated by a qualified individual within the responsible organization to ensure that test requirements have been satisfied.

2.4.4 Monitoring, Measuring, Testing, and Data Collection Equipment

The following sections establish requirements to ensure equipment used for inspection and testing is properly controlled, calibrated and maintained. For the purposes of these requirements, equipment discussed in the following sections includes measuring and test equipment, measuring and data collection equipment, equipment (either hand held or installed) used for data indication, and other equipment used for data indication and/or collection.

2.4.4.1 Calibration

Monitoring, measuring, testing, and data collection equipment shall be calibrated, adjusted, and maintained at prescribed intervals or, prior to use, against certified equipment having known valid relationships to nationally recognized standards. If no nationally recognized standards exist, the bases for calibration shall be documented.

A. Calibration standards shall have a greater accuracy than the required accuracy of the monitoring, measuring, testing, and data collection equipment being calibrated. The participant shall ensure that the calibration uncertainties are sufficiently small so that the adequacy of the measurement is not affected. Well defined and documented measurement assurance techniques or uncertainty analyses may be used to verify the adequacy of a measurement process. If such techniques or analyses are not used, then the uncertainty of calibration or verification shall not exceed 25% of the acceptable tolerance (e.g., manufacturer's specification) for each characteristic of the measuring and test equipment being calibrated or verified.

B. The method and interval of calibration for each device shall be defined based on the type of equipment, stability characteristics, required accuracy, intended use, and other conditions affecting measurement control. For monitoring, measuring, testing, and data collection equipment used in one-time-only applications, the calibration shall be done both before and after use.

C. A calibration shall be performed when the accuracy of calibrated monitoring, measuring, testing, and data collection equipment is suspect.

D. Calibrated monitoring, measuring, testing, and data collection equipment shall be labeled, tagged, or otherwise suitably marked to indicate calibration due date.

E. Calibrated monitoring, measuring, testing, and data collection equipment shall be uniquely identified to provide traceability to its calibration data.

F. All calibrations performed shall be traceable, through auditable documentation, to NIST standards, international standards or intrinsic standards.

G. When applicable, all calibrations shall be performed in controlled environmental conditions.

H. Calibration and control measure may not be required for rulers, tape measures, levels, and other such devices, if normal commercial equipment provides adequate accuracy.

2.4.4.1.1 Control of Out-of-Calibration Equipment

A. Monitoring, measuring, testing, and data collection equipment shall be considered to be out-of-calibration and shall not be used until calibrated if any of the following conditions exist:

1. The calibration due date has passed without recalibration.

2. The device produces results known or suspected to be in error.

3. Equipment has been damaged.

B. Out-of-calibration monitoring, measuring, testing, and data collection equipment shall be controlled. The controls shall include the following requirements:

1. Out-of-calibration monitoring, measuring, testing, and data collection equipment shall be tagged, segregated, or otherwise controlled to prevent use until they have been recalibrated.

2. When measuring and test equipment is found to be out-of-calibration during recalibration, the validity of results obtained using that equipment since its last valid calibration shall be evaluated.

a. The evaluation shall include the determination of acceptability of previously collected data, processes monitored, or items previously inspected or tested.

b. The evaluation shall be documented.

c. Corrective actions will be taken.

C. Recall intervals shall be established and re-evaluated based on instrument calibration history.

D. If any monitoring, measuring, testing, and data collection equipment is consistently found to be out-of-calibration during the recalibration process, it shall be repaired or replaced.

2.4.4.1.2 Documenting Calibration of Monitoring, Measuring, Testing, and Data Collection

Equipment monitoring, measuring, testing, and data collection equipment calibration documentation shall include the following information:

- description and unambiguous identification of the item calibrated
- physical condition of the calibrated item
- date(s) of performance of calibration, where appropriate
- identification of the calibration procedure used, or unambiguous description of any non-standard method used

- "as found" and "as left" data
- a signature and title, or an equivalent identification of the person(s) accepting responsibility for the content of the certificate or report (however produced), and date of issue
- special limitations of use

SECTION 3 – QUALITY ASSURANCE ASSESSMENT REQUIREMENTS

Planned and periodic assessments shall be conducted to measure management effectiveness, item quality and process effectiveness, and to promote improvement. The organization performing assessments shall have sufficient authority and freedom from the line organization to carry out its responsibilities. Persons conducting assessments shall be technically qualified and knowledgeable in their assigned roles.

3.1 MANAGEMENT ASSESSMENT

Managers at every level shall periodically assess the performance of their organization to determine how well leadership is being provided to enable the organization to continuously meet the customer's requirements and expectations. This assessment shall place emphasis on the use of human and material resources to achieve the organization's goals and objectives. The management assessment should include an introspective evaluation to determine if the entire integrated management system effectively focuses on meeting strategic goals.

Managers should retain overall responsibility for management assessments. Direct participation by Senior Management is essential to the success of the process because management is in the position to view the organization as a total system.

Management assessments should focus on the identification and resolution of both systemic and cultural management issues and problems. Strengths and weaknesses affecting the achievement of organizational objectives should be identified so that meaningful action can be taken to improve quality.

Processes being assessed should include strategic planning, organizational interfaces, cost control, use of performance indicators, staff training and qualifications, and supervisory oversight and support. Effective management assessments should evaluate such conditions as the state of employee knowledge, motivation, and morale; the amount of mutual trust and communication among workers and organizations; the existence of an atmosphere of creativity and improvement; and the adequacy of human and material resources.

Management assessment results should be used as input to the organization's continuous improvement process.

3.2 INDEPENDENT ASSESSMENT

A process of planned periodic independent assessments shall be established and implemented. Independent assessments shall focus on improving items and processes by emphasizing line organization's achievement of quality. The types and frequencies of independent assessments shall be scheduled, based on the status, risk, complexity, and importance of the processes and activities being conducted.

3.2.1 Planning Independent Assessments

The organization performing the independent assessment shall develop and document an assessment plan for each independent assessment. This plan shall include the scope, purpose, assessment personnel, work to be assessed, organizations to be notified, schedule and checklists to be used. Assessments shall include technical evaluations of the applicable procedures, instructions, activities and items. The scope shall include the corrective actions taken since the previous assessment.

3.2.2 Scheduling Independent Assessments

A. CAO will maintain a schedule of independent assessments. The assessment schedule shall be developed annually and revised as necessary.

B. Independent assessments shall be scheduled to begin as early in the life of the work as practicable and shall be scheduled to continue at intervals consistent with the schedule for accomplishing the work. Internal independent assessments of work to verify quality assurance compliance shall be performed annually or at least once during the life of the work, whichever is shorter.

C. Regularly scheduled independent assessments may be supplemented by additional assessments (i.e., performance based audits) of selected work products and/or work processes.

D. External assessments for compliance shall be performed annually. The need to schedule additional external assessments shall also be evaluated when a major change in the contract scope or work methodology occurs. Pre-award surveys, if applicable, shall serve as the first external independent assessment if the affected organization is implementing the same quality program for other contracts that is proposed for the purchaser's contract.

E. Annual performance evaluations shall be performed on contractors to determine the need to schedule additional external independent assessments. This evaluation shall be documented and based on:

- review of documentation furnished by the contractor's organization (such as certificates of conformance, nonconformance notices, and corrective action documentation)
- results of previous assessments, source verifications, audits, management assessments, and receiving inspections (including assessments from other sources)
- experience of identical or similar products or services furnished by the same participant organization

3.2.3 Independent Assessment Team Selection

A qualified team shall be identified before beginning each independent assessment. The organization performing the assessment shall select and assign assessors who are independent of any direct responsibility for performing the work being assessed. Assessment personnel shall have sufficient authority and organizational freedom to objectively identify problems and verify that adequate corrective action has been completed and performed.

A. An assessment team leader shall be appointed to indoctrinate and supervise the team, organize and direct the assessment and coordinate the preparation and issuance of the assessment report.

B. Before starting the assessment, the assessment team leader shall ensure that the assigned personnel collectively have experience and training commensurate with the scope, complexity, or special nature of the work to be assessed.

C. Technical specialists shall be used when assessing the adequacy of technical processes.

3.2.4 Assessment Personnel Qualification

3.2.4.1 Lead Auditor Qualification

A lead auditor shall be capable of organizing and directing assessments, reporting assessment observations, and evaluating planned and implemented corrective action. A lead auditor also shall be certified as meeting the requirements provided in this section for education and experience, communication skills, training, audit participation, and passing the lead auditor examination.

3.2.4.1.1 Lead Auditor Education and Experience

The prospective lead auditor shall have verifiable evidence that a minimum of 10 credits have been accumulated under the following scoring system:

A. Education (four credits maximum)

1. An associate's degree from an accredited institution scores one credit. If the degree is in engineering, physical sciences, mathematics, or quality assurance, it scores two credits.

2. A bachelor's degree from an accredited institution scores two credits. If the degree is in engineering, physical sciences, mathematics, or quality assurance, it scores three credits. In addition, score one more credit for a master's degree (or higher) in engineering, physical sciences, business management, or quality assurance from an accredited institution.

B. Experience (nine credits maximum)

The prospective lead auditor shall have participated in a minimum of five quality assurance audits or assessments or equivalent verifications (such as management assessments, pre-award surveys, or comprehensive surveillance, as long as the parameters of the audit process are met) within a period of time not to exceed three years prior to the date of certification. One audit of which shall be a nuclear quality assurance audit within the year prior to qualification. In addition, for technical experience in such areas as scientific investigation, site characterization, nuclear waste management, production, transportation, engineering, manufacturing, construction, operation, maintenance, or experience applicable to the auditing or assessing the organization's area of responsibility scores one credit for each full year, with a maximum of five credits for this aspect of experience.

1. If two years of this experience have been in a nuclear field, score one additional credit; or

2. If two years of this experience have been in quality assurance, score two additional credits; or

3. If two years of this experience have been in auditing or assessment, score three additional credits; or

4. If two years of this experience have been in nuclear-related quality assurance, score three additional credits; or

5. If two years of this experience have been in nuclear-related quality assurance auditing or assessment, score four additional credits.

C. Professional Competence (two credits maximum)

For certification of competency in engineering science or quality assurance specialties issued and approved by a state agency or national professional or technical society, score two credits.

D. Rights of Management (two credits maximum)

When determined appropriate, the organization performing the qualification may grant up to two credits for other performance factors applicable to auditing or assessing that are not explicitly called out in this section (such as leadership, sound judgment, maturity, analytical ability, tenacity, past performance, and completed quality assurance training courses).

3.2.4.1.2 Communication Skills

The prospective lead auditor shall have the capability to communicate effectively, both in writing and orally. These skills shall be attested to in writing by the candidate's supervisor.

3.2.4.1.3 Lead Auditor Training

Prospective lead auditors shall be trained to the extent necessary to ensure their competence in skills as established by the organization responsible for performing audits and assessments. Training in the following areas shall be accomplished and its completion verified based upon management evaluation of the particular needs of each prospective lead auditor:

- knowledge and understanding of this QAPD and other program related procedures, codes, standards, regulations, and regulatory guides
- general structure of quality assurance plans and implementation procedures, as a whole, and as related to specific elements of this QAPD
- auditing or assessment techniques of examining, questioning, evaluating, reporting, methods of identifying, following up on, and closing corrective action items
- audit planning in functional areas of nuclear quality assurance
- on-the-job training to include applicable elements of the assessment program

3.2.4.1.4 Lead Auditor Examination

A. The prospective lead auditor shall pass an examination that evaluates the comprehension of and ability to apply the audit knowledge described in this section. The test shall be oral, written, practical, or any combination of these methods.

B. The development and administration of the examination for a lead auditor is the responsibility of the assessing organization. The auditing organization shall:

1. Maintain the integrity of the examination through confidentiality of files and, where applicable, proctoring of examinations.
2. Develop and maintain objective evidence regarding the type and content of the examination.

3.2.4.1.5 Lead Auditor Certification

The lead auditors will be certified by the auditing organization as being qualified to lead audits and assessments. This certification will document the:

- name of the organization performing the certification
- name of the lead auditor
- date of certification or recertification
- basis of certification (such as education, experience, communication skills, and training)

- signature of the designated representative of the organization responsible for certification

3.2.4.1.6 Lead Auditor Proficiency Maintenance

A. Lead auditors shall maintain their proficiency through one or a combination of the following:

- regular and active participation in the audit process
- review and study of codes, standards, quality assurance implementation procedures, instructions, and other documents related to quality assurance program auditing or assessment
- participation in training programs

B. Management of the auditing organization shall evaluate the proficiency of lead auditors annually. Based on the evaluation, management shall choose to extend the qualification, require retraining, or require requalification. Management evaluations shall be documented.

C. Lead auditors who fail to maintain their proficiency for a two-year period shall require requalification to the requirements for a lead auditor of this section.

3.2.4.2 Technical Specialist Qualification

Technical specialists selected for independent assessment assignments shall be indoctrinated commensurate with the scope, complexity, or special nature of the work being assessed. In addition they shall be trained to the requirements of the assessment process associated with their duties.

3.2.4.3 Independent Assessor Qualification

Independent assessors shall be technically qualified in their assigned roles. In addition, they shall have appropriate training or orientation to develop their competence for performing assessments. Competence of personnel performing various assessment functions shall be developed by the following methods:

A. Orientation to provide a working knowledge and understanding of the program quality assurance requirements and implementing procedures used to perform assessments and report assessment results.

B. Training that provides fundamentals, objectives, and techniques of performing assessments. Training shall include methods of examining, questioning, evaluating, and documenting specific assessment items and methods of closing out conditions adverse to quality.

C. On-the-job training, guidance, and counseling under the direct supervision of a lead auditor may be substituted for the training above. Such training shall include planning, performing, reporting, and follow-up action involved in conducting assessments.

3.2.5 Performing Independent Assessments

A. All independent assessments shall be performed in accordance with written procedures or checklists.

B. Elements that have been selected for independent assessment shall be evaluated against specified requirements. Objective evidence related to the planning and technical aspects of the work performance shall be examined to the depth necessary to determine if these elements are being implemented effectively.

C. Independent assessment results shall be documented by assessment personnel and reported to and reviewed by management having responsibility for the area assessed. Conditions requiring prompt corrective action shall be reported immediately to management of the assessed organization.

D. Conditions adverse to quality shall be documented and corrected according to the requirements of the subsections entitled "Conditions Adverse to Quality and Significant Conditions Adverse to Quality."

3.2.6 Reporting Independent Assessment Results

A. The independent assessment report shall be prepared by the assessment team leader, and issued to the management of the assessed organization and any affected organizations. The assessment team leader shall consider inclusion of the following information in the report:

- a description of the assessment scope
- identification of the assessors
- identification of persons contacted during the assessment
- a summary of the documents reviewed, persons interviewed, and the specific results of the reviews and interviews (i.e., a summary of the checklist contents)
- statement of the quality assurance program effectiveness
- a description of each reported condition adverse to quality in sufficient detail to enable corrective action to be taken by the assessed organization
- commendable quality practices

3.2.7 Assessment Response and Follow Up

A. Management of the assessed organization will investigate conditions adverse to quality; determine and schedule corrective action, including measures to prevent recurrence; and notify the assessing organization in writing of the actions planned or taken.

B. The adequacy of corrective actions taken for conditions adverse to quality shall be evaluated and approved by the assessing organization.

C. Follow-up action shall be taken by the assessing organization to verify that corrective action is accomplished as scheduled.

SECTION 4 – SAMPLE CONTROL QUALITY ASSURANCE REQUIREMENTS

This section defines the requirements for the control of material samples, including identification, handling and shipping, and archiving. This section also defines requirements for the disposition of nonconforming samples. The following general control requirements apply to samples:

A. Samples shall be controlled and identified in a manner consistent with their intended use.

B. Sample controls shall define responsibilities such as interfaces between organizations for documenting and tracking sample possession from sample collection and identification through handling, preservation, shipment, transfer, analysis, storage, and final disposition.

C. Sample controls shall include specifics on orientation relative to the location that was sampled, as appropriate.

4.1 SAMPLE CONTROL

The controls for samples shall address the following requirements, as applicable:

A. A chain of custody record shall be maintained which records all persons that have custody of samples from the time a sample is taken until its final disposition.

B. If samples have limited shelf life, then methods shall be established that preclude using the sample beyond its intended shelf life.

C. If sample storage is required, then methods shall be established for the control of sample identification that are commensurate with the planned duration and conditions of storage. These methods shall provide for, as applicable,

- maintenance or replacement of markings and identification tags damaged during handling or aging
- protection of identification markings subject to excessive deterioration resulting from environmental exposure

4.2 SAMPLE IDENTIFICATION

A. Samples shall be identified from their initial collection through final disposition.

B. Sample identification shall be documented and verified before released for disposition.

C. Identification shall be maintained physically on the samples wherever possible or in a

manner that ensures that identification is possible. If physical markings are either impractical or insufficient, other appropriate means shall be employed (such as physical separation, labels or tags attached to containers, or procedural control). When used, physical markings shall be such that:

1. They are applied using materials and methods that provide a clear and legible identification.

2. They do not detrimentally affect the sample content or form.

3. They are transferrable to each identified sample part when the sample is subdivided.

D. Sample traceability shall ensure that the sample can be traced at all times from its collection through final disposition.

F. Implementation procedures shall specify the representative samples to be archived if the need to archive samples is identified.

4.3 HANDLING, STORING, AND SHIPPING SAMPLES

Handling, storing, cleaning, packaging, shipping, and preservation of samples shall be conducted in accordance with established work and inspection implementation procedures or other specified documents. These measures include:

A. If required for critical, sensitive, perishable, or high-value samples, specific measures for handling, storage, cleaning, packaging, shipping, and preservation shall be identified and used.

B. Measures shall be established for marking and labeling samples for packaging, shipping, handling, and storage as necessary to adequately identify, maintain, and preserve the sample. Markings and labels shall indicate the presence of special environments or the need for special controls if necessary.

C. If required for particular samples, special protective equipment (such as containers) and special protective environments (such as inert gas, and moisture and temperature limits) shall be specified and provided.

4.4 DISPOSITION OF NONCONFORMING SAMPLES

A. Samples that do not meet requirements specified in work controlling documents (such as job packages, travelers, or work requests) shall be documented, evaluated, identified, and segregated in accordance with the subsection entitled "Identifying and Classifying Conditions Adverse to Quality."

B. The disposition for nonconforming samples shall be identified and documented and shall be limited to "use-as-is," "limited use," or "discard."

SECTION 5 – SCIENTIFIC INVESTIGATION QUALITY ASSURANCE REQUIREMENTS

Scientific investigations shall be defined, controlled, verified, and documented. Process variables affecting scientific investigations shall be measured and controlled.

5.1 PLANNING SCIENTIFIC INVESTIGATIONS

A. Variables that affect interrelated scientific investigations shall be identified and controlled appropriately in each investigation to assure comparability.

B. The technical adequacy of procedures for conducting scientific investigations and their implementation shall be reviewed and approved by qualified persons other than those who prepared the procedures.

C. The results of developmental testing shall be reviewed for adequacy and approved by qualified persons prior to implementation of the procedures for data collection.

D. Planning shall be coordinated with organizations providing input to or using the results of the investigation.

E. Planning shall address provisions for determining the precision, accuracy, representativeness, comparability, and completeness of results.

5.2 PERFORMING SCIENTIFIC INVESTIGATIONS

A. Scientific investigations shall be performed using scientific notebooks, technical implementation documents, or a combination of both.

B. Scientific notebooks shall contain:

- a statement of the objective and description of work performed or reference to an approved plan that describes the work
- the method(s) used
- identification of the samples
- measuring and test equipment used
- description of the work performed and results obtained, names of individuals performing the work, and dated initials or signature, as appropriate, of individuals making the entries
- description of changes made to methods used, as appropriate

C. Scientific results will be periodically reviewed by a qualified individual to verify there is sufficient detail to retrace the investigation and confirm the results, if feasible, or repeat the investigation and achieve comparable results without recourse to the original investigator.

D. Scientific notebooks shall be considered QA records.

5.3 DATA DOCUMENTATION, CONTROL, AND VALIDATION

5.3.1 Data Identification and Usage

A. Identification and traceability shall be maintained throughout the lifetime of the data.

B. Data reduction and transfer will be controlled to permit independent reproductibility by another qualified individual.

5.3.2 Data Validation

Data validation is a systematic effort to review data, on an individual data package basis, to assure the required data quality level is obtained. Results of the review may require that data qualifiers be assigned and/or the results may be used in customer-supplier continuous improvement efforts.

A. Validation methods shall be planned and documented. The documentation shall include the acceptance criteria used to determine if the data is valid.

B. Data collected shall be subject to validation, including:

- A review of relevant documentation conducted to establish technical adequacy, suitability for intended usage, and the satisfaction of quality assurance and documentation requirements
- The results of the data review shall be documented.
- The reviewer will be independent from the collector.

C. Data considered as established fact by the scientific and engineering community, such as engineering handbook data, critical tables, and the CRC Handbook, do not require validation.

5.4 POST QUALIFICATION OF EXISTING DATA

This section contains requirements unique to the post qualification of existing data.

Post qualification of existing data relied upon to address safety and waste isolation issues shall be qualified using one or a combination of the following methods:

A. Determination that the data were collected under an approved QA program which has been revised to meet any changes in DOE standards.

B. The use of corroborating data with inferences drawn to corroborate the existing data shall have relationships that are clearly identified and justified.

C. Confirmatory testing that is performed and documented.

D Peer review performed and documented in accordance with the subsection entitled "Peer Reviews."

SECTION 6 — SOFTWARE QUALITY ASSURANCE REQUIREMENTS

This section of the QAPD establishes software quality assurance requirements applicable to the CAO and specifies the requirements for the development, procurement, maintenance, and use of software, as applied to the engineering, analysis, and operations functions of the CAO.

6.1 APPLICABILITY

This section applies to software used to process, gather, or generate information that may be used in design, analysis or operational decisions. It also applies to both supplier-developed software and procured services prior to release for production use by the CAO.

6.2 GRADATION OF QUALITY MEASURES

The extent to which specific programmatic controls are implemented shall be appropriate to the application and sufficient to ensure the quality of the software for its intended use. The implementation of specific requirements shall be prescribed in written plan(s) and procedures, when and to the extent specified by the organization invoking this section.

Each organization shall make a determination concerning each software application that delineates the methods of compliance with this section appropriate for use of the software; this determination shall be based upon a documented evaluation of the software to:

a) determine the adequacy to support software operation and maintenance, and
b) identify the activities to be performed and the documentation that is needed to meet the requirements of this section.

6.3 SOFTWARE QUALITY ASSURANCE PLANS AND PROCEDURES

Each organization invoking this section shall develop organization-specific plans that prescribe the establishment of permanent software standards and procedures. Both plans and procedures shall be developed to specify methods, techniques, and responsibilities required to implement the requirements of this section of the QAPD. Plans shall be forwarded to the QA Manager for review and concurrence.

Software quality assurance principles and practices utilized in the establishment of permanent software procedures shall meet regulatory and other statutory requirements and shall consist of generally accepted industry good practices, such as those provided in ASME NQA-2, Part 2.7, NUREG/BR-0167, and ANS/IEEE-7-4.3.2.

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6.4 INVENTORY OF SOFTWARE

Each organization invoking this section of the QAPD shall inventory the software for which they maintain responsibility that is subject to this section of the QAPD. This inventory shall be maintained current.

6.5 CLASSIFICATION OF SOFTWARE

Each organization invoking this section of the QAPD shall classify software for which they maintain responsibility. This classification shall address the old use of the software relative to its application to engineering, design, analysis and operations activities and to its importance to regulatory compliance and/or significance in managing information or augmenting decisions.

6.6 PROCURED OR OTHERWISE ACQUIRED SOFTWARE

The procurement of software and software-related services shall be in accordance with the section entitled "Procurement." Upon delivery to the requesting organization, the software shall be placed under configuration control. Once the software has been installed, the sponsoring organization shall perform user acceptance of the software to verify the software's functional capability and the vendor-supplied supporting documentation.

6.7 SOFTWARE DEVELOPMENT AND MAINTENANCE

The development and maintenance of software shall employ a systematic approach that transforms the problem analysis results into design, the implementation of the design into validated software, and sufficient documentation (which may constitute records) to objectively demonstrate that the requirements have been successfully implemented into validated software.

Changes made to software shall be formally documented to describe the nature and scope of the change and an identification to allow traceability of the change to the affected configuration item. Changes in software shall be indicated in the reworked, revised/replaced version.

Changes made to the operating environment (e.g., operating system update) of previously accepted software shall be evaluated for impact. This evaluation shall be performed by an individual competent in the technical subject area. The evaluation shall be documented and corrective actions performed, as appropriate, to assure the quality of the affected application(s).

6.8 SOFTWARE DOCUMENTATION AND RECORDS

Software shall be described in one or more documents which detail user instructions, technical basis, functional requirements and maintenance-related information sufficient to be understood by an independent technically competent individual and allow maintenance of the software and its documentation. The documentation shall be reviewed by an individual technically competent in the area for which the use of the application is intended; this review shall verify that the documentation adequately and accurately reflects the software that comprise the application, and verify that the application is adequate and correct for the stated use(s) and acceptable to the requesting organization.

This documentation shall be made available to all primary users in a controlled manner in accordance with the section entitled "Document Control and Distribution." Documentation shall be kept in a form to permit retrievability, maintenance and retention in order to maintain the accepted quality of the application.

Methods shall be established in accordance with the section entitled "Records" to assure that contractors and vendors establish quality records concerning software applications. These methods, at a minimum, shall address record quality, access controls and retention periods. Quality records shall be stored in facilities that provide an environment suitable for the particular media.

6.9 SOFTWARE VALIDATION

6.9.1 Software Verification

Verification of software shall include reviews that ensure that requirements are complete and correct and shall include appropriate testing. Verification of software and software related activities shall be clearly documented and approved and performed by any competent individual(s) or group(s) other than those who performed the software design, but who may be from the same organization. This verification may be performed by the designer's supervisor when the supervisor is the only individual in the organization competent to perform the verification , provided the supervisor did not specify a singular design approach or rule out certain design considerations and did not establish the design inputs used.

6.9.2 Software Validation

Software shall be validated by comparing test results of software execution with objective evidence obtained by other acceptable means (e.g., hand calculations, manual processing, accepted empirical results, other validated software of similar purpose, or direct observation). The results of this evaluation shall be of sufficient scope and depth to prove the capabilities and limitations delineated in the software documentation.

The methods, test data, software-generated results, and conclusions shall be documented in a form that can be understood by an independent individual competent in the application of the software for the particular problem under study, The documentation shall be reviewed by a competent individual; this review shall address the adequacy and correctness of the documentation in meeting the requirements of this section and overall acceptability of the software applicability of the software application for its use.

The validation of modifications shall be subject to selective regression testing to detect errors introduced during the modification of systems components, to verify the modifications have not caused unintended adverse effects, or to verify that a modified system(s) or system component(s) still meets specified requirements.

6.10 SOFTWARE TRACEABILITY AND VERSION CONTROL

Configuration items, such as source code, executable software, documentation, validation proofs, and software-generated output, shall be traceable to one another by some means, manual or automatic. This traceability shall be sufficient to allow verification that the version of the software being used corresponds with that which has been documented, validated and accepted.

6.11 INSTALLATION AND CHECKOUT

Software shall be placed under configuration control and then accepted by its designed user prior to use. User acceptance shall consist of integrating the software with other components essential to its performance such as installing hardware and other software, reformatting or creating databases and performing tests to ensure that the software performs according to stated requirements in its target environment.

At minimum, installation and checkout of software shall consist of both

a) the execution of tests for installation and integration; and
b) the document approval of the software for operational use.

6.12 SOFTWARE ERRORS

Specific methods shall be established to handle software application errors. When errors are discovered in software or software results the sponsoring organization shall determine the effect on previous uses(s) and the need for corrective action based on sufficient input from affected users. Errors which could significantly impact decisions that were based upon prior use or that require significant modification to the application shall be identified to all affected users and shall be controlled. Errors that have been determined as a material attribute to a nonconformance or may represent a condition adverse to quality shall be controlled in accordance with the subsection entitled" Conditions Adverse to Quality."

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6.13 SOFTWARE RETIREMENT

Criteria shall be developed to determine if software can be retired from practical use and methods shall be developed to ensure that retired software are thereafter restricted from use and are no longer subject to the requirements of this section of the QAPD.

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Alternative Calculations: Calculations that are made with alternative methods to verify correctness of the original calculation.

Approval: The documented determination by a responsible internal and/or external organization that a work product is suitable for the intended purpose and shall be used as required.

Assessment/Verification: The act of reviewing, inspecting, testing, checking, conducting surveillances, auditing, or otherwise determining and documenting whether items, processes, or services meet specified requirements. The terms assessment and verification, as used in DOE 5700.6C, are synonymous; their use is determined by who is performing the work. Assessments are performed by or for senior management. Verifications are performed by the line organizations.

Assessor: An individual who is qualified to perform assigned portions of an assessment.

Audit: A planned and documented quality assurance program assessment performed to determine by investigation of objective evidence the adequacy of and compliance with established quality assurance implementation procedures and the effectiveness of implementation.

Auditor: An individual who is qualified to perform assigned portions of an audit.

Certificate of Conformance: A document signed or otherwise authenticated by an authorized individual certifying the degree to which items or services meet specified requirements.

Certification: The act of determining, verifying, and attesting (in writing) to the achievement of or compliance with specified requirements.

Change Control: A process of formally documenting and approving significant changes to the project or fiscal baseline.

Characteristic: A property of a work product that is distinct, describable, and measurable.

Commercial Grade Item: An item that is: (1) not subject to design or specification criteria unique to the WIPP Program or nuclear facilities, (2) used in applications other than the nuclear industry, and (3) ordered from the manufacturer or supplier on the basis of specifications set forth in the manufacturer's published product description.

Condition Adverse to Quality: An all-inclusive term used in reference to any of the following: failures, malfunctions, deficiencies, defective items, and nonconformances.

Configuration Control: The process of identifying and defining the configuration items in a system, controlling the release and change of these items throughout the system life cycle, recording and reporting the status of configuration items and change requests.

Configuration Item: A collection of hardware or software elements treated as a unit for the purpose of configuration control.

Controlled Document: A document that is prepared, reviewed, approved, and distributed in accordance with established implementation procedures. Controlled documents are subject to controlled distribution and to a defined and controlled change process.

Corrective Action: Measures taken to rectify conditions adverse to quality and, where necessary, to preclude repetition.

Design Basis: Information that identifies the specific functions to be performed by items and the specific values or ranges of values chosen for controlling parameters as reference bounds for design.

Design Input: Those criteria, parameters, bases, or other design requirements upon which detailed final design is based.

Design Output: Drawings, specifications, and other documents used to define technical requirements of structures, systems, components and computer programs.

Design Process: Technical process that commences with identification of design input and ends with the issuance of design output documents.

Design Review: A documented evaluation of design output during the design process to determine design adequacy and conformance to specified acceptance criteria.

Document: Recorded information that describes, specifies, reports, certifies, requires, or provides data or results. A document is not considered a record until it meets the definition of record.

Document Control: The process for controlling documents that provides for adequacy review, approval for release by authorized personnel, and distribution for use at the prescribed work locations.

Error: A discrepancy between a computed, observed or measured value or condition and the true, specified, or theoretically correct value or condition.

Expedited Change: An abbreviated and interim method of revising a document at the work location where the document is used when the normal change process would cause unnecessary delays. The management responsible for the work makes the expedited change and follows up with appropriate standard procedures for undertaking an expedited change.

Graded Approach: A process by which the level of analysis, documentation, and actions necessary to comply with an established requirement are commensurate with:

(a) The relative importance to safety and waste isolation;

(b) The magnitude of any hazard involved;

(c) The life cycle stage of facility;

(d) The programmatic mission of a facility;

(e) The particular characteristics of a facility; and

(f) Any other relevant factor.

Independent Assessment: An assessment that is conducted by an independent group or organization, having authority and freedom from the line organization, to evaluate the scope, status, adequacy, programmatic compliance, or effectiveness of a program or activity.

Item: An all-inclusive term used in place of any of the following: appurtenance, assembly, component, equipment, material, module, part, structure, subassembly, subsystem, system, unit, or support systems.

Lead Auditor: An individual trained, qualified, and certified to organize and direct an audit, report audit findings, and evaluate corrective actions.

Line Management: Those management positions below senior management that are directly responsible for work task products and services.

Measuring and Test Equipment (M&TE): All devices used to measure, gage, test, inspect, or otherwise determine compliance with prescribed technical requirements. Measuring instruments used in taking quantitative and/or qualitative measurements.

Metrology: The science of precision measurement.

Monitoring and Data Collection Equipment (M&DC): A subcategory of M&TE that is used in the collection of measurement data for the establishment of test conditions and general information and the collection of general measurement data not utilized to verify the conformance of an item or equipment to specified criteria.

Nonconformance: A deficiency in characteristic or record that renders the quality of an item or sample unacceptable or indeterminate.

Non-Permanent Records: Records having value for a specific, limited time and authorized by National Archives and Records Administration to be destroyed after that time.

Participant: Those organizations and individuals that perform work in support of the CAO mission.

Peer: A person having technical expertise in the subject matter to be reviewed to a degree at least equivalent to that needed for the original work.

Peer Review: A documented critical review of work generally beyond the state of the art or characterized by the existence of potential uncertainty.

Permanent QA Record: A QA record which is maintained for the life of the Republic.

Permanent Records: Records that have been determined by National Archives and Records Administration to have historical or other value warranting permanent preservation in the National Archives.

Procedure: A document that specifies or describes how an activity is to be performed. The term "procedure" is also inclusive of instructions and drawings.

Process: A series of actions that achieves an end or result.

Procurement Document: Purchase orders, contracts, specifications, or other documents used to define technical and quality assurance requirements for the procurement of items or services.

Qualification (Personnel): The capabilities gained through education, training, or experience that qualify an individual to perform a required function.

Qualification Testing: A test that is intended to provide a desired level of confidence that an item meets specified criteria.

Quality: The condition achieved when an item, service, or process meets or exceeds the user's requirements and expectations.

Quality Assurance: All those actions that provide confidence that quality is achieved.

Quality Assurance Implementing Procedure: A document that prescribes an approved process for accomplishing work in compliance with CAO QAPD requirements.

Quality Assurance Program (QAP): The overall program established to assign responsibilities and authorities, define policies and requirements, and provide for the performance and assessment of work.

Quality Assurance Record: A completed document (regardless of medium) that furnishes evidence of the quality of items and/or activities affecting safety or waste isolation.

Quality Management Plan: A document which describes the responsibilities, activities, and methods of implementation, that are applicable to a project and the relationship of the plan to the Quality Assurance Program.

Quality System: See *Quality Assurance Program.*

Record: A completed document or other media that provide objective evidence of an item, service, or process.

Remedial Action: The actions taken to correct specifically identified conditions adverse to quality.

Repair: The process of restoring an item to a condition such that the capability of an item to function reliably and safely is unimpaired even though that item still does not conform to the original requirement.

Rework: The process by which an item is restored to original specifications by completion or correction.

Root Cause: The identified cause of a condition adverse to quality that, if corrected, will preclude recurrence or greatly reduce the probability of recurrence of the same or a similar condition adverse to quality.

Sample (Material): A physical part of a whole whose properties are sampled to gain information about the whole.

Scientific and Engineering Software: Software that uses numerical methods to complete scientific, engineering, and mathematical calculations.

Scientific Investigation: Any research, experiment, test, study, or activity that is performed for the purpose of investigating a natural system or man-made aspects of a geologic repository, including the investigations that support design of the facilities and the waste package.

Scientific Notebook: A record of the methods and results of scientific investigations that is used when the work involves a high degree of professional judgment or trial and error methods or both.

Senior Management: The manager or managers responsible for mission accomplishment and overall operations. For CAO, senior management is the CAO Manager, Deputy Manager, the QA Manager and the Branch Chiefs.

Service: The performance of work, such as design, construction, fabrication, inspection, nondestructive examination/testing, environmental qualification, equipment qualification, repair, installation, or the like.

Significant Condition Adverse to Quality: A significant condition adverse to quality is one that, if uncorrected, could lead to a serious affect on safety/operability or the ability to isolate waste.

Site Characterization: The program of exploration and research both in the laboratory and the field that is undertaken to establish the natural conditions and the ranges of parameters of a particular site.

Software: Computer programs, procedures, rules, and associated documentation and data pertaining to the operation of a computer system.

Software Verification and Validation (V&V): The process of determining whether the requirements for a system or component are complete and correct, the products of each development phase fulfill the requirements or conditions imposed by the previous phase, and the final system or component complies with specified requirements. See *Validation* and *Verification.*

Special Process: A process, the results of which are highly dependent on the control of the process or the skill of the operators, or both, and in which the specified quality cannot be readily determined by inspection or test of the product.

Stop Work Order: A formal directive issued by management that work must be stopped until resolution of the related significant condition adverse to quality or nonconformance.

Supplier: Any individual or organization who furnishes items or services in accordance with a contract. An all-inclusive term used in place of any of the following: vendor, seller, source, participant, contractor, or subcontractor.

Surveillance: The act of observing real-time activities and/or reviewing documentation to verify conformance with specified requirements and to evaluate their adequacy and effectiveness.

System Software: Software which is used exclusively in the preparation, installation, or operation of executable software applications. Examples of such software include Operating Systems, Compilers, Assemblers, Translators, Interpreters, Automated Protocols, Utilities and Tools, Teleprocessing Managers, and Query Languages.

Technical Review: A documented critical review of work that has been performed within the state of the art. The review is accomplished by one or more qualified reviewers who are collectively equivalent in technical expertise to those who performed the original work. The review is an in-depth analysis and evaluation of documents, activities, material, data, or items that require technical verification or validation for applicability, correctness, adequacy, completeness, and assurance that established requirements are satisfied.

Technical Specialist: An individual who is assigned to an assessment team when the scope, complexity, or special nature of the work to be audited warrants assistance from a technical standpoint.

Testing: An element of verification for the determination of the capability of an item to meet specified requirements by subjecting the item to a set of physical, chemical, environmental, or operating conditions.

Traceability: The ability to trace the history, application, and location of an item, data, or sample using recorded documentation.

As related to metrology, traceability means, the ability to relate individual measurement results through an unbroken chain of calibrations to one or more of the following

(a) U.S. national standards maintained by NIST or the U.S. Naval Observatory

(b) Fundamental or natural physical constants with values assigned or accepted by NIST

(c) National Standards of other countries which are correlated with NIST

Use As Is: A disposition permitted for a nonconforming item when it can be established that the item is satisfactory for its intended use.

Validation: An activity that demonstrates or confirms that a process, item, data set, or service satisfies the requirements defined by the user. See *Software Verification and Validation.*

Verification: See *Assessment* and *Software Verification and Validation.*

Work: The process of performing a defined task or activity, for example, research and development, operations, maintenance and repair, administration, software development and use, inspection, safeguards and security, data collection, and analysis.

STATISTICAL SUMMARY OF THE RADIOLOGICAL BASELINE PROGRAM FOR THE WASTE ISOLATION PILOT PLANT

DOE/WIPP 92-037

March 1992

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Executive Summary

The report presents summary statistics and probability models for data collected during the Radiological Baseline Program (RBP) at the Waste Isolation Pilot Plant (WIPP). This program was designed to provide preoperational measurements of radioactivity in environmental samples that will serve as a basis for evaluating similar data collected during the WIPP Operational Environmental Monitoring Program. The RBP data analyzed in this report cover the period from 1985 through 1989. Sample types included in this report are airborne particulates, soil, surface water, groundwater, sediments, and six types of biotic tissue sample.

Airborne particulate samples were measured for gross beta activity, gross alpha activity, and concentrations of 22 individual radionuclides. Soil samples were analyzed for 19 radionuclides. Surface and groundwater samples were analyzed for 18 radionuclides. Sediment and biotic tissue samples were analyzed for 17 radionuclides.

Statistical summaries for these data bases include estimation of the mean, standard deviation, standard error, and coefficient of variation. Probability modeling was conducted on those data sets that exhibited random behavior. The normal and 2- or 3-parameter lognormal distributions were found to provide good models for most data bases. Critical values at the 0.80, 0.90, 0.95, and 0.99 probability levels were estimated for each data base. These values are appropriate for establishing warning and action levels for control charts during the Operational Environmental Monitoring Program.

1.0 Introduction

The Waste Isolation Pilot Plant (WIPP) is a U.S. Department of Energy (DOE) research and development project to demonstrate the safe disposal of waste materials contaminated with transuranic (TRU) radionuclides from defense programs. From 1986 through 1989, the WIPP Radiological Baseline Program (RBP) was dedicated to characterizing the radiological environment in the vicinity of WIPP prior to the start of waste handling operations. The preoperational data collected during the RBP, along with operational data collected at control locations, will serve as a basis for evaluating the results of the WIPP Operational Environmental Monitoring Program (OEMP). This report presents statistical summaries of the RBP data bases in a form that will facilitate their use in the OEMP.

1.1 WIPP Site Description

The WIPP Site is in a remote location in southeastern New Mexico, approximately 40 kilometers east southeast of Carlsbad, New Mexico. This area, called Los Medanos ("the dunes"), is a flat, sandy plain on the western edge of the Llano Estacado. The site is underlain with thick beds of Permian-aged sediments and evaporites. The halite-dominated Salado Formation, which is approximately 600 meters thick at the WIPP Site, will be the medium for isolating the waste material.

The climate of the Los Medanos area is warm-temperate and semiarid. Weather parameters have been monitored at the WIPP facility since 1985 and have been summarized yearly in the WIPP Annual Site Environmental Monitoring Reports (Reith et al., 1986; Banz et al., 1987; Flynn, 1988 and 1989; DOE, 1990). Summer high and winter low extremes in temperature are typically near 40 degrees and -10 degrees centigrade, respectively. Annual precipitation averages about 30 centimeters, with most falling in the summer. The prevailing wind in the area is from the southeast. Due to the midcontinental location of the site, however, most weather parameters are prone to extremes and rapid change.

The soils of the Los Medanos area are dominated by eolian sand of the Berino and Kermit Series (Soil Conservation Service, 1971). These soils are susceptible to wind erosion but are typically stabilized by vegetation. Shrubs, especially shinnery oak (*Quercus havardii*) and mesquite (*Prosopis glandulosus*), form coppice dunes that dominate the area. Perennial grasses, such as giant dropseed (*Sporobolus giganteus*), sand dropseed (*S. cryptandrus*), and fall witchgrass

(*Leptoloma cognata*), and sandbur (*Cenchrus insertus*), are important elements in the vegetation and aid in stabilizing the soil.

Due to the sandy nature of the soil and the undulating surface created by the coppice dunes, surface runoff is minimal, and effective precipitation is high. The soils are underlain (typically at a depth of about 2 meters) by a well-developed, Pleistocene-aged caliche (the Mescalero caliche), which impedes the percolation of water and leaves it available to evapotranspiration.

Wildlife in the area shows influences from both the Great Plains and the Chihuahuan desert. High densities of breeding birds of prey, especially Swainson's hawks (*Buteo swainsoni*), Harris's hawks (*Parabuteo unicinctus*), and great horned owls (*Bubo virginianus*), have been recorded in the Los Medanos (Bednarz and Hayden, 1988). These populations are supported by a small-mammal prey-base of cottontail rabbit (*Sylvilagus* sp.), ground squirrel (*Spermophilus* sp.), and nocturnal rodents, chiefly Ord's kangaroo rat (*Dipodomys ordii*). Game animals in the area include scaled quail (*Callipepla squamata*), northern bobwhite (*Colinus virginianus*), and mule deer (*Odocoileus hemionus*).

The principal land uses in the Los Medanos area are livestock (cattle) grazing and hydrocarbon (oil and gas) production. The three nearest residences to the WIPP Site are the Mill's ranch, approximately 6 kilometers south of the facility; the Smith ranch, approximately 9 kilometers west of the facility; and the Mobley Ranch, approximately 10 kilometers southwest of the facility.

Seven kilometers to the northwest of WIPP, the Los Medanos surface abruptly drops approximately 30 meters into Nash Draw, a wide depression containing several playa lakes, the largest of which is Laguna Grande de la Sal. Several potash mines and associated refining plants and outlying shaft facilities are located in Nash Draw.

The Pecos River is approximately 22 kilometers southwest of the WIPP Site at its nearest point. The Pecos flows from north to south through the city of Carlsbad. Several other municipalities in southeastern New Mexico, including Artesia and Loving, border its west bank. The river is used primarily for irrigation and recreation (fishing and boating) and has several flood-control and diversion dams along its course, the largest of which is Brantley Dam (constructed during the course of the RBP), McMillan Dam (replaced by Brantley and

now breached), Avalon Dam, and Red Bluff Dam (immediately south of the New Mexico-Texas border).

An important event in the radiological history of the WIPP area is Project Gnome (see Mercer et al., 1989). In 1961, the U.S. Atomic Energy Commission detonated a 3-kiloton nuclear device in the Salado Formation approximately 12 kilometers southwest of the present WIPP Site. This test, which was part of the Plowshares Project, and subsequent experiments in radionuclide mobility resulted in radioactive surface and groundwater contamination in that area. Decontamination efforts have since reduced the surface radioactivity to approximately background levels (DOE, 1981; EG&G, 1988), although local groundwater radioactivity is still elevated (AEC, 1973).

1.2 WIPP Project Description

The WIPP repository is being mined at a level of 655 meters below the ground surface in the Salado Formation. The repository is accessed through four shafts: the Waste Handling Shaft, which is covered at the surface by the Waste Handling Building; the Salt Handling Shaft, through which mined salt is brought to the surface for placement and storage on a stockpile; the Air Intake Shaft, which provides a supplemental source of surface air to ventilate the repository; and the Exhaust Shaft, through which outgoing air is conducted and, if necessary, diverted through high-efficiency particulate air (HEPA) filters contained in the Exhaust Filter Building.

The projected 25-year operational period of the WIPP Project will be preceded by a 5-year Test Phase in which limited quantities of Contact-Handled (CH) TRU waste will be emplaced within instrumented bins and alcoves to test repository performance parameters. Based on the results of these tests, a decision will be made as to whether the operational phase will proceed. If it does, waste emplacement will proceed for both CH and Remote-Handled (RH) TRU waste. If the repository is found to be unsuitable, the experimental waste will be retrieved and the facility closed.

The CH waste will be shipped to WIPP in specially designed Transuranic Package Transporters, called TRUPACT-IIs. The RH waste will be transported in shielded casks. Transport containers will only be opened inside of the Waste Handling Building, where air flow is controlled through HEPA filter systems. A variety of on-site systems are in place that will monitor personnel and work areas for airborne radioactive contamination.

1.3 Environmental Monitoring Programs

The goal of the WIPP environmental monitoring programs is to verify that the waste handling operations are not contaminating the surrounding accessible environment. The design of the monitoring programs follows the two-phase approach described by Green (1979). In this approach, the existing (unimpacted) environment is characterized in a baseline study (the RBP). During the time of potential impact, an environmental monitoring program (the OEMP) is directed at detecting the impact, should it occur. The baseline data provide the standards against which the changes are detected. Non-WIPP-related changes in environmental parameters during the operational period will be accounted for through the use of control sites.

The designs of the RBP and OEMP are described in detail in Mercer et al. (1989). The RBP is divided into five subprograms, as follows:

- The Airborne Particulate Baseline (air sampling)
- The Ambient Radiation Baseline (penetrating radiation monitoring)
- The Terrestrial Baseline (soil sampling)
- The Hydrologic Baseline (groundwater and surface water sampling)
- The Biotic Tissue Baseline (animal and vegetation sampling).

The ambient radiation baseline, which consists of three elements (environmental dosimetry, aerial gamma survey, and high-pressure ionization chamber [HPIC] gamma radiation monitoring), are not summarized in this report. Environmental dosimetry will not be continued in the OEMP, while the aerial gamma survey, which represents continuous spatial coverage at a single point in time, and HPIC monitoring, which represents continuous temporal coverage at a single point in space, are not amenable to the type of statistical summarization presented here. The HPIC data are presented in the Annual Site Environmental Monitoring Reports (Banz et al., 1987; Flynn, 1988 and 1989; DOE, 1990). Descriptions of the other RBP subprograms are presented in the respective summary sections of this report (Sections 3.0 through 7.0).

1.4 RBP Data Collection and Quality Assurance

All data summarized in this report are from samples of environmental media collected in accordance with the WIPP Environmental Procedures Manual, WP02-3. Sample preparation, such as preservation, weighing, drying, ashing, and packaging, was conducted either in the field or at the WIPP Sample Preparation Laboratory, as required. Chain-of-custody documentation was maintained for all samples.

Sample analysis was contracted to the Waltz Mill laboratory of the Westinghouse Advanced Energy Systems Division (WAESD). Laboratory quality control was maintained through routine calibration of instruments, routine yield determinations for radiochemical procedures, frequent source and background counts, reagent purity checks, routine duplicate analyses, and participation in inter-laboratory cross-checks (Flynn, 1989). The minimum detection limits (MDL) presented in this report are from Flynn (1989), with units converted to match the data analyses.

Analytical results that are less than the MDL (including negative results) are reported by the laboratory and have been included in these analyses as reported. Due to analytical methods, some radionuclides are commonly reported as being less than a maximum value. When such maximum values represent a small proportion of the data set, or when they are themselves random in behavior, statistical analyses may be performed on them (Gilbert, 1987). In this report, data sets with more than 10 percent "less than" values were not statistically analyzed unless the maxima were found to simulate a random process.

The Environmental Evaluation Group (EEG) conducts parallel and independent environmental monitoring at WIPP, including air, soil, water (surface, groundwater, and public drinking water), sediment, and biotic tissues. Splits of some RBP samples (soil, water, sediment, and tissues) have been provided to the EEG for independent analysis. The results and summary of the EEG preoperation environmental monitoring program are reported in Kenney et al. (1990). In general, the measurements of radioactivity and radionuclide concentrations in the EEG program are consistent with those of the RBP.

2.0 Methods

The purpose of this analysis is to derive probability models of the analytical results of the RBP that can be used for the future evaluation of similar data derived from the OEMP. This purpose is distinct from presenting a radiological characterization of the environment at and about the WIPP Site. The distinction between these two sampling objectives, i.e., descriptive sampling versus sampling for modeling (Eberhardt and Gilbert, 1980), must be clearly understood. The reader is cautioned that assumptions about the underlying precision and accuracy of the data and decisions about the statistical methodology used to analyze the data are not based on the goal of finding the most accurate single approximation of each parameter (e.g., the mean or a confidence range for the mean) as would be the case for a descriptive study. Rather, they are based on the goal of finding predictive probability models for evaluating each individual datapoint as it is generated during the OEMP.

Statistical analyses in this report were performed using Lotus® 1-2-3® Version 2.1 and Statgraphics®* Version 2.6. The methodology followed five steps:

- The individual RBP data bases were compiled from laboratory data reports onto Lotus 1-2-3 spreadsheets. Where appropriate, the data were scaled to minimize the use of large (positive or negative) exponents. The Lotus 1-2-3 spreadsheets were imported into Statgraphics file format.

- The data bases were evaluated, both subjectively (based on observable patterns or site knowledge) and statistically, for homogeneous subgroups. The data were stratified in accordance with these evaluations.

- Summary statistics were calculated for each subgroup.

- Where possible, probability distribution models were fitted to the data in each group.

- Critical values were estimated for each subgroup for four probability levels, 0.80, 0.90, 0.95, and 0.99.

The following sections describe the statistical methods used in these analyses.

*Lotus and 1-2-3 are registered trademarks of the Lotus Development Corporation. Statgraphics is a registered trademark of the Statistical Graphics Corporation.

2.1 Probability Model

In its simplest form, the probabilistic model that describes each RBP parameter is:

$$x_{ij} = E(X) + r_{ij} \tag{2.1}$$

where x_{ij} is the measured value of the parameter X at location i and at time j, E(X) is the expected value of the parameter, and r_{ij} is an element of the random variable R, with mean zero. Both the value of E(X) and the shape of the probability distribution of R are determined by number of factors related to sampling. For the purposes of discussion, these are classified into two groups, environmental factors and procedural factors.

The environmental factors consist of three basic elements—the regional expected value of the parameter as it exists in the environment (not its measured value), the spatial variability of the parameter over the region, and the temporal variability of the parameter over a specified time. This may be written:

$$u_{ij} = E(U) + s_i + t_{ij} \tag{2.2}$$

where u_{ij} is the actual value (e.g., concentration of a radionuclide) of the parameter at location i and time j. E(U) is the expected value of the random variable U over all locations and times in the study. s_i and t_{ij} are random variables with mean zero that describe the spatial and temporal variability of the parameter. The variability with time is considered to be location-dependent, although this dependence may be weak in many cases.

The procedural factors consist of all sources of sampling and measurement error, whether systematic or random. Depending upon the degree of scrutiny with which the sampling and measurement activities are assessed, the number of identifiable factors can be large or small. Some of the more important general factors include counting error associated with both sample and background counts, self-shielding, error due to extraction processes, sample-handling techniques, and sample-collection techniques, including variability in sampling equipment.

Each factor may be seen as contributing two quantities to the final measurement of x_{ij} —a constant, or bias quantity, and a random quantity with mean zero. Thus, assuming that these factors are independent, the total effect of the procedural factors is:

$$p = \sum_{i=1}^{n} (b_i + e_i) \tag{2.3}$$

where p is the total error associated with the n procedural factors, b_i is the bias contributed by the i^{th} factor, and e_i is the random contribution of the i^{th} factor. This may be rewritten:

$$p = \sum_{i=1}^{n} b_i + \sum_{i=1}^{n} e_i$$

or,

$$p = b_p + e_p \tag{2.4}$$

where

$$b_p = \sum_{i=1}^{n} b_i$$

and

$$e_p = \sum_{i=1}^{n} e_i$$

Thus, b_p is the total amount of procedural bias expected in each measurement. Insufficient data are available to accurately quantify b_p, although some elements of bias, such as background counts within the sample count, have been estimated and corrected for in the data. In this report, it is assumed that bias is minimized and/or controlled through adherence to sample-collection procedures, analytical procedures, quality control procedures, and the participation in interlaboratory cross-checking (Flynn, 1989). The gross alpha counts on

airborne particulate samples provides an example where a known change in analytical instrumentation resulted in a significant change in bias and required special consideration in the evaluation of the data (see Section 3.2).

The random element of the procedural factors, e_p, is independent of bias and will remain even if bias is completely eliminated or corrected for. As a sum of random variables with mean zero, e_p is also a random variable with mean zero. If all e_i's are independent, the variance of e_p will be the sum of their variances; however, the probability distribution of e_p will be a convolution of the probability distributions of the e_i's and thus is not readily predictable, although the Central Limit Theorem dictates that e_p will converge on a normal distribution as n increases (Mood et al., 1974).

The measured value of the parameter is composed of the actual value of the parameter in the environment (or the sampled environmental medium) at the time and location of sample collection plus the total effect (precision and bias) of sampling and measurement on that value, or:

$$x_{ij} = u_{ij} + p = E(U) + s_i + t_{ij} + b_p + e_p \qquad (2.5)$$

This is equivalent to Equation 2.1 when:

$$E(X) = E(U) + b_p$$

and

$$r_{ij} = s_i + t_{ij} + e_p$$

In this model, p is assumed to be independent of sample location and time. In the following analyses, b_p and e_p are considered inseparable parts of E(X) and r_{ij}, respectively. The emphasis of the data analyses in this report is the characterization of E(X) and r_{ij} through the probabilistic assessment of x_{ij}'s. As discussed in the following section, data stratification has been used to account for the effects of s_i and t_{ij}. Correlation analysis is used to quantify precision on replicate samples and duplicate counts of gross alpha and beta activities in airborne particulate samples.

2.2 Data Stratification

In the probability model described above, the random nature of r_{ij} is dependent on location i and time j being randomly selected from their respective domains, which are continuous. In reality, this is not the case. Sampling locations are fixed and strategically sited to maximize the probability of detecting radionuclide releases from the WIPP facility. Further, sampling times are usually at (approximately) regular intervals. Thus, s_i may in fact be considered a discrete random variable, with the domain of i being limited to the set of sample locations, and t_{ij} and r_{ij} are definable as finite mixtures (Titterington et al., 1985). The resulting complexity in the probability model is ameliorated by *a posteriori* stratification of the data into approximately homogeneous spatial and temporal groups (Gilbert, 1987; Eberhardt and Thomas, 1991).

The data within each individual data base were classified on spatial or temporal criteria specific to that data set. These are described separately in the subsequent sections. Depending on the distribution of sampling locations, the objective of the spatial classification is to either identify nonoverlapping geographic areas (e.g., Los Medanos, Nash Draw, and the Pecos River valley) that exhibit distinct probability characteristics for the parameter in question or to analyze the data for varying geographic scales. The surface water data base is an example of the former case. The airborne particulate data base and soil data base are examples of the latter.

In addition to spatial classification according to surface location, the soil and groundwater data bases were also stratigraphically divided. The three depths from which soil samples were collected were analyzed for differences in means. The groundwater samples collected from three geologic strata were also analyzed for differences in means.

Temporal divisions within each data base, where applicable, are limited to quarters within the calendar year. Differences between quarters in the probabilistic behavior of some parameters are assumed to be predictable, and separate modeling of the quarters would be of value to the operational monitoring program. Differences between years, on the other hand, are not considered to be predictable; thus, year was not used as a criterion for temporal classification.

Differences between means of the data groups were analyzed using one-way analysis-of-variance (ANOVA) or, for more than one classification factor, multifactor ANOVA (MANOVA). Differences in means were considered significant at the 0.05 probability level. Where differences were found, Tukey's Honestly Significant Difference (HSD) multiple range

test was used to identify homogeneous groups at the 95 percent confidence level. This is an *a posteriori* test with experimentwise significance (Steel and Torrie, 1960). Prior to performance of ANOVA or MANOVA, the data were inspected for normality through normal probability plots. Where the data were found to be right-skewed, they were log-transformed to improve symmetry. Based on the results of these analyses, stratified data sets were either combined into homogeneous groups or modeled independently.

2.3 Summary Statistics

Four statistics are calculated for most data bases. The sample mean and standard deviation are calculated using the maximum likelihood estimators. The standard error is estimated as the standard deviation divided by the square root of the sample size and is, by definition, the maximum likelihood estimator of the standard deviation of the mean. The coefficient of variation is the ratio of the standard deviation and the mean.

Data sets in which more than 10 percent of the data points are reported as being less than a maximum value are not summarized with these four statistics. Instead, only the mean is estimated for these data sets. Since maximum values were included in the calculation, this will overestimate the true value. Therefore, these estimates are presented with "less than" symbols.

The coefficient of variation provides a way of assessing the magnitude of variability within the data set with respect to its mean (Sokal and Rohlf, 1981). Conversely, it is also way of assessing the nearness of the mean to zero with respect to the standard deviation. A high coefficient of variation value (e.g., greater than 3.0) indicates that the mean is small relative to its variability. Measurements of transuranics in environmental media typically exhibit high coefficients of variation (Pinder and Paine, 1980).

2.4 Probability Distribution Modeling

Probability distribution modeling on the final data sets followed a sequence of model testing. In all cases, the normal distribution was tested first, followed by the two-parameter lognormal distribution. These two families of probability distributions will provide the most accessible basis for evaluating the operational data due to the ready availability of tables, tests, and parametric procedures based on the normal distribution and the simple transformation of data from the lognormal to the normal distribution.

Data were initially evaluated for normality or lognormality by the use of normal probability plots of the raw and log-transformed data (Gilbert, 1987). If a reasonable fit to a straight line was observed on this plot, the model was tested using the maximum likelihood estimates of the mean and standard deviation as model parameters. The Kolmogorov-Smirnov goodness-of-fit test on the Statgraphics software package was used to test the null hypothesis that the model fits the data. Statgraphics calculates the D statistic and returns its significance level based on the sample size. A significance of 0.05 or less was used as the criterion for rejecting the null hypothesis and proceeding to the next model. In some cases, no model was found to produce an acceptable D value. In these cases, the data model is presented as the normal distribution with the mean and standard deviation as parameters.

When the data were observed to be right-skewed, but a good fit to the two-parameter lognormal was not found, or more important, some of the data were less than or equal to zero and therefore invalid for log-transformation, a scalar constant, t, was added to the data points and the lognormal distribution was retested. The resulting model is a three-parameter lognormal distribution. The application of this family of distributions to environmental monitoring data is discussed in detail by Gilbert (1987). The value of the constant was estimated by an iterative process by which the Kolmogorov-Smirnov D statistic was minimized.

Data sets with high proportions of "less than" values were not modeled. In rare cases, neither the normal nor the lognormal distributions were found to satisfy the Kolnogorov-Smirnov goodness-of-fit test. Other distributions were also tested (gamma, Weibull, beta), but in no case was this successful. In these cases, a close visual fit of the normal or lognormal distribution is presented.

2.5 Critical Values

A critical value, X_p, is the upper limit of the p^{th} quantile of the random variable X. Based on the probability distribution model determined for each RBP data set, four critical values were determined: p = 0.80, 0.90, 0.95, and 0.99. In the cases where no model was determined, the critical values were determined directly from the order statistics of the data set. These are reported with "less than" symbols when more than 10 percent of the data are reported as being less than a maximum value.

3.0 Airborne Particulate Samples

3.1 Gross Beta Activity

Weekly samples of airborne particulates were counted for gross beta radioactivity. Duplicate counts were performed on 191 filters to assess error resulting from counting technique. Total error resulting from sample collection, handling, and analysis was assessed through the collection of replicate samples, i.e., samples collected at the same location over the same time period but by different samplers. Eighty-three replicate samples were collected at the WIPP East location by two side-by-side samplers on the same base. Twenty-two replicate samples were collected at the WIPP Northwest location with the second sampler elevated approximately 1.5 meters above the primary sampler.

Correlation analysis on the duplicate counts indicated a high degree of precision in the gross beta counts (r^2 = 93.7 percent). The total sample precision, as indicated by the correlation of replicate samples from the WIPP East location, was only slightly less than that of the duplicate counts (r^2 = 93.2 percent). The correlation between the parallel samplers at WIPP Northwest, where the second sampler was elevated above the first, was further reduced (r^2 = 82.3 percent). A t-test on the log-transform of the WIPP Northwest data indicated no difference in the means at 95 percent confidence.

The Chernobyl accident caused significant increases in gross beta activity on all filter samples collected during weeks 19, 20, and 21 of 1986. These weeks were deleted from the data base prior to statistical analysis, since they represent known artificially induced elevations in activity over the natural background. The question of a long-term effect of Chernobyl on the background levels was explored through an ANOVA on the first 18 weeks of (log-transformed) data from each of the four years.

The means of the first 18 weeks of beta activity increase sequentially with year, from the low in 1986 of 8.1 x 10^{-10} Becquerels per milliliter to a high in 1989 of 1.0 x 10^{-9} Becquerels per milliliter, with the ANOVA indicating significant differences existing between means at 95 percent confidence. However, Tukey's HSD multiple range test showed 1986 and 1987 formed a homogeneous group, with 1988 and 1989 being significantly greater than their respective previous years. These results refute the hypothesis that the Chernobyl accident produced a sudden, statistically significant shift in background beta activity.

Prior to statistical analysis, the large data base (1506 data points) was stratified into two geographical groups to avert biasing the analyses by the greater concentration of sampling locations near the WIPP facility. Due to a right-skew of the data, the data were also log-transformed before analyses that assume normally distributed data were performed.

The first sampler group, the Regional Transect, consists of the four off-site sampler locations—Carlsbad, Smith Ranch, Mills Ranch, and Eunice. These locations comprise a west-east cross-section of southeastern New Mexico with representation of the Pecos River valley, Nash Draw, Los Medanos, and the Llano Estacado, respectively. The group also consists of two urban locations and two rural residences.

The second sampler group, the WIPP Site, consists of the four WIPP locations—WIPP East, WIPP South, WIPP Northwest, and WIPP Far Field. The latter sampler was installed in week 38 of 1986 to eventually replace the WIPP Northwest sampler, which was located too close to the air intake shaft for downwind monitoring during the operational period. The WIPP Northwest sampler was removed after week 50 of 1988. All samplers in the WIPP Site group are within one kilometer of the WIPP facility.

A MANOVA was applied to each of the transformed data sets, with location and quarter as the independent factors. Where significant differences were found between groups (with p less than or equal to 0.05), Tukey's HSD multiple range test was used to identify homogeneous groups.

No significant differences were found between the means of the Regional Transect locations. Among the WIPP Site locations, WIPP Northwest was found to be significantly different from WIPP South and WIPP East, while WIPP Far Field was homogeneous with all WIPP locations. This result substantiated the comparability of the WIPP Northwest and Far-Field locations but also dictated the deletion of the WIPP Northwest data over the period of parallel sample collection so as not to bias the results toward that direction.

For both the Regional Transect and the WIPP Site, the same pattern of differences was observed between quarters: fourth quarter greater than first quarter greater than second and third quarters, which are equal. The data were subdivided temporally to reflect this pattern prior to the analysis of distributions.

Tables 3-1 through 3-3 present the results of the statistical characterization of the six temporal/spatial groups identified within the gross beta activity data base. All except one group (fourth quarter of the Regional Transect) were fitted to the lognormal distribution. The exception was fitted to the normal distribution. For all three temporal groups, the mean of the WIPP group is approximately 6 percent less than that of the Regional Transect. The coefficients of variation are small and relatively uniform across all groups, indicating good control of random error in this data base.

3.2 Gross Alpha Activity

Weekly airborne particulate samples were counted for gross alpha radioactivity. As with the gross beta counts, duplicate counts on individual samples and replicate counts on samples collected in parallel were performed to quantify error resulting from sample collection, handling, and analysis. An important aspect of the statistical analysis of the gross alpha data base is a change in the configuration of the counter at the start of 1989 that reduced the amount of shielding and, consequentially, improved the precision and accuracy of the data. The 1989 data are therefore analyzed separately.

Correlation analysis of the 141 duplicate gross alpha counts performed prior to 1989 and the 52 duplicate counts performed during 1989 showed a large improvement in precision, with r^2 increasing from 27.3 to 83.7 percent. Correlation between replicate samples also improved, with r^2 increasing from 42.8 prior to 1989 (n = 36) to 78.3 percent in 1989 (n = 49). The set of parallel samplers at the WIPP Northwest location (pre-1989) showed very poor correlation for gross alpha counts (r^2 = 23.7 percent, n = 25).

The Chernobyl accident caused no discernible effect on the gross alpha activity, although it is acknowledged that a small effect would have been masked by the poor precision in the data during that time period.

As with the gross beta data base, the gross alpha data base was stratified into two geographic groups, the Regional Transect and the WIPP Site (see previous section for descriptions). A MANOVA of the (log-transformed) 1989 data did not reveal significant differences between locations within either group (at 95 percent confidence), although differences were found between quarters. For this data set, the third quarter had the lowest mean alpha activity and the first quarter had the highest. The second and fourth quarters were intermediate and indistinguishable from each other at this confidence level. The data base was further subdivided into three temporal groups based on this result.

Table 3-1

Gross Beta Activity in Air Samples:
Summary Statistics

Quarter	Group	n	Mean	s.e.	s	c.v.
1	REGION	206	0.97 +/-	0.02	0.29	0.30
1	WIPP	150	0.91 +/-	0.02	0.27	0.30
2 & 3	REGION	399	0.82 +/-	0.01	0.22	0.27
2 & 3	WIPP	291	0.77 +/-	0.01	0.25	0.33
4	REGION	198	1.21 +/-	0.02	0.34	0.28
4	WIPP	147	1.15 +/-	0.03	0.38	0.33

Abbreviations:
- n - Sample size
- s.e. - Standard error
- s - Standard deviation
- c.v. - Coefficient of variation

Units are in Becquerels per milliliter x 10^{-9}

Table 3-2

Gross Beta Activity in Air Samples:
Probability Distribution Functions

Quarter	Group	Type	Mean	s	K-S Signif.
1	REGION	LOGNORM.	0.97	0.28	0.28
1	WIPP	LOGNORM.	0.91	0.27	0.06
2 & 3	REGION	LOGNORM.	0.82	0.22	0.10
2 & 3	WIPP	LOGNORM.	0.77	0.23	0.18
4	REGION	NORMAL	1.21	0.34	1.00
4	WIPP	LOGNORM.	1.15	0.38	1.00

Abbreviations:
s - Standard deviation
K-S Signif.- Kolmogorov-Smirnov significance level

Units are in Becquerels per milliliter x 10^{-9}

Table 3-3

Gross Beta Activity in Air Samples:
Critical Values

Quarter	Group	Probability			
		0.80	0.90	0.95	0.99
1	REGION	1.18	1.34	1.48	1.80
1	WIPP	1.11	1.26	1.40	1.71
2 & 3	REGION	0.99	1.11	1.22	1.46
2 & 3	WIPP	0.94	1.07	1.19	1.46
4	REGION	1.50	1.64	1.77	2.00
4	WIPP	1.43	1.65	1.85	2.31

Units are in Becquerels per milliliter x 10^{-9}

Tables 3-4 through 3-6 present the results of the statistical characterization of the six temporal/spatial groups of the 1989 gross alpha data. An interesting pattern of distribution models emerge from these results. The maximum and minimum quarters (first and third quarters, respectively) showed symmetrical distributions about the mean and were fitted to the normal distribution for both the Regional Transect and the WIPP Site. The combined second and fourth quarter data were right-skewed and fit the lognormal distribution, perhaps reflecting an intermediate distribution between the two extremes.

As with the gross beta activity, the 1989 gross alpha means of the WIPP Site are consistently about 10 percent less than the Regional Transect. Coefficients of variation have a wider range and are typically larger than those of the gross beta data, indicating less precision in the analyses.

An attempt was made to find a linear transformation function to apply to the pre-1989 data in order to bring it to a level comparable to the 1989 data. The pre-1989 data were stratified geographically and temporally to match the subdivisions of the 1989 data base. It was noted that the third quarter again had the lowest gross alpha activity and that the third quarter WIPP Site data was also normally distributed. Assuming that the data group with the lowest mean activity and the smallest geographic range will be most comparable between years and therefore reflect the differences resulting from analytical methods most accurately, a transformation function was derived to give the pre-1989 third quarter WIPP data the same mean and standard deviation as the 1989 third quarter WIPP data.

The resulting transformation function is:

$$y = \frac{x + 0.03}{0.22} \tag{3.1}$$

where x is the pre-1989 datum and y is the transformed datum.

Tables 3-7 through 3-9 present the results of the statistical analysis of the transformed data. The MANOVA and Tukey's multiple range test verify the third quarter data set as being significantly less than the other quarters at 95 percent confidence but failed to find a

Table 3-4

1989 Gross Alpha Activity in Air Samples:
Summary Statistics

Quarter	Group	n	Mean		s.e.	s	c.v.
1	REGION	50	0.82	+/-	0.04	0.27	0.33
1	WIPP	38	0.75	+/-	0.04	0.25	0.33
2 & 4	REGION	102	0.54	+/-	0.01	0.14	0.26
2 & 4	WIPP	75	0.49	+/-	0.02	0.14	0.28
3	REGION	50	0.44	+/-	0.02	0.13	0.30
3	WIPP	38	0.38	+/-	0.02	0.14	0.37

Abbreviations:
- n - Sample size
- s.e. - Standard error
- s - Standard deviation
- c.v. - Coefficient of variation

Units are in Becquerels per milliliter x 10^{-9}

Table 3-5

1989 Gross Alpha Activity in Air Samples:
Probability Distribution Functions

Quarter	Group	Type	Mean	s	K-S Signif.
1	REGION	NORMAL	0.82	0.27	0.50
1	WIPP	NORMAL	0.75	0.25	0.37
2 & 4	REGION	LOGNORM.	0.54	0.14	1.00
2 & 4	WIPP	LOGNORM.	0.49	0.15	0.41
3	REGION	NORMAL	0.44	0.13	0.14
3	WIPP	NORMAL	0.37	0.14	1.00

Abbreviations:
s - Standard deviation
K-S Signif.- Kolmogorov-Smirnov significance level

Units are in Becquerels per milliliter x 10^{-9}

Table 3-6

1989 Gross Alpha Activity in Air Samples:
Critical Values

Quarter	Group	Probability			
		0.80	0.90	0.95	0.99
1	REGION	1.05	1.17	1.26	1.45
1	WIPP	0.96	1.07	1.16	1.33
2 & 4	REGION	0.65	0.72	0.80	0.95
2 & 4	WIPP	0.60	0.69	0.77	0.94
3	REGION	0.55	0.61	0.65	0.74
3	WIPP	0.49	0.55	0.60	0.70

Units are in Becquerels per milliliter x 10^{-9}

Table 3-7

Pre-1989 Gross Alpha Activity in Air Samples:
Summary Statistics

Quarter	Group	n	Mean		s.e.	s	c.v.
1	REGION	156	0.42	+/-	0.01	0.15	0.36
1	WIPP	138	0.41	+/-	0.01	0.15	0.36
2 & 4	REGION	312	0.45	+/-	0.01	0.17	0.38
2 & 4	WIPP	283	0.42	+/-	0.01	0.17	0.40
3	REGION	153	0.40	+/-	0.02	0.23	0.58
3	WIPP	145	0.37	+/-	0.01	0.14	0.38

Original data have been linearly transformed by the function:
$y = (x + 0.03)/0.22$

Abbreviations:
- n - Sample size
- s.e. - Standard error
- s - Standard deviation
- c.v. - Coefficient of variation

Units are in Becquerels per milliliter x 10^{-9}

Table 3-8

Pre-1989 Gross Alpha Activity in Air Samples: Probability Distribution Functions

Quarter	Group	Type	Mean	s	K-S Signif.
1	REGION	NORMAL	0.42	0.15	1.00
1	WIPP	LOGNORM.	0.41	0.16	1.00
2 & 4	REGION	LOGNORM.	0.46	0.17	0.37
2 & 4	WIPP	LOGNORM.	0.43	0.17	0.37
3	REGION	LOGNORM.	0.40	0.18	0.54
3	WIPP	NORMAL	0.36	0.14	0.40

Original data have been linearly transformed by the function:

$$y = (x + 0.03)/0.22$$

Abbreviations:

s - Standard deviation

K-S Signif.- Kolmogorov-Smirnov significance level

Units are in Becquerels per milliliter x 10^{-9}

Table 3-9

Pre-1989 Gross Alpha Activity in Air Samples: Critical Values

Quarter	Group	Probability			
		0.80	0.90	0.95	0.99
1	REGION	0.55	0.61	0.67	0.77
1	WIPP	0.52	0.62	0.71	0.92
2 & 4	REGION	0.58	0.68	0.78	0.99
2 & 4	WIPP	0.55	0.65	0.75	0.97
3	REGION	0.52	0.63	0.74	0.99
3	WIPP	0.48	0.54	0.59	0.68

Original data have been linearly transformed by the function:

$$y = (x + 0.03)/0.22$$

Units are in Becquerels per milliliter x 10^{-9}

difference between the other three quarters. Again, the means of the WIPP Site are about 6 percent less those of the Regional Transect. The coefficients of variation are greater than those of the 1989 data.

3.3 Quarterly Radionuclide Analysis

Weekly samples of airborne particulates from each sampler location were composited over each quarter and analyzed for specific radionuclides. Statistical analysis of these data consisted of a normal probability plotting to determine symmetry and normality (or lognormality) of the data sets, ANOVA to determine homogeneity of the data across sampler locations and quarters, and statistical distribution fitting.

The latter analysis was not performed on five radionuclides (^{60}Co, ^{137}Cs, ^{226}Ra, ^{228}Ra, and ^{228}Th), since more than 10 percent of these data sets are reported as being less than a maximum value. Although this type of data is an unavoidable consequence of the analytical method for these radionuclides and unfortunately precludes the identification of the underlying probability distribution function through parametric techniques, maximum critical percentiles were estimated directly from the cumulative distribution of the raw data.

No radionuclides were found to differ significantly (95 percent confidence level) between sampler locations. Only ^{230}Th was found to differ between quarters. The data for this radionuclide were divided between two temporal groups, accordingly (quarters 1 and 4; quarters 2 and 3). This grouping reflects the temporal pattern found in the gross beta activity.

Tables 3-10 through 3-12 present the results of the statistical analyses performed on these data. Because the MDL for the quarterly composited samples are determined in Becquerels (Bq)/composite sample, they are not directly comparable to the mean radionuclide concentrations, which are expressed in Bq/mL of air. A minimum detectable average (MDA) was therefore calculated from each MDL, which expresses the minimum average concentration (in Bq/mL) that would have to be maintained over the entire quarter to obtain the MDL on the quarterly sample. The MDA calculation is based on the assumptions of a quarter equaling a 91-day sampling period and an average sampling rate of 2 cubic feet per minute. This gives a total of 262,080 cubic feet of air sampled per composite, or 7.42×10^9 milliliters per composite sample. Therefore, the MDA, in Bq/mL, is the MDL multiplied by the inverse of 7.42×10^9 mL/composite sample.

Table 3-10

Quarterly Airborne Particulate Samples:
Summary Statistics

Radio-nuclide	Group	MDA	n	Mean		s.e.	s	c.v.
^{7}Be	ALL	---	106	5700	+/-	100	900	0.16
^{40}K	ALL	---	106	160	+/-	10	70	0.44
^{60}Co	ALL	0.015	106	< 12		N/A	N/A	N/A
^{90}Sr	ALL	0.150	92	6	+/-	4	35	5.83
^{137}Cs	ALL	0.010	100	< 5.8		N/A	N/A	N/A
^{210}Pb	ALL	0.100	99	760	+/-	28	280	0.37
^{210}Po	ALL	---	53	700	+/-	28	210	0.30
^{226}Ra	ALL	0.025	107	< 16		N/A	N/A	N/A
^{228}Ra	ALL	---	107	< 30		N/A	N/A	N/A
^{228}Th	ALL	0.015	107	< 11		N/A	N/A	N/A
^{230}Th	Q1&4	0.010	43	9.6	+/-	1.4	9.2	0.96
	Q2&3	0.010	40	5.4	+/-	1.0	6.7	1.24
^{232}Th	ALL	0.010	83	5.3	+/-	0.7	6.7	1.26
^{233}U	ALL	0.005	98	-1.0	+/-	0.5	4.6	4.60
^{234}U	ALL	0.005	98	3.2	+/-	0.3	2.8	0.88
^{235}U	ALL	---	98	0.2	+/-	0.1	1.0	5.00
^{238}U	ALL	0.005	98	2.4	+/-	0.2	1.5	0.62
^{237}Np	ALL	0.010	79	-0.3	+/-	0.2	1.4	4.67
^{238}Pu	ALL	0.020	100	-1.5	+/-	0.8	7.7	5.13
$^{239/240}Pu$	ALL	0.010	100	0.3	+/-	0.3	3.3	11.00
^{241}Pu	ALL	0.499	100	900	+/-	600	6100	6.78
^{241}Am	ALL	0.005	37	2.6	+/-	1.6	9.7	3.73
^{244}Cm	ALL	0.005	37	-0.6	+/-	1.4	8.2	13.67

Abbreviations:

MDA - Minimum Detectable Average
s - Standard deviation
c.v. - Coefficient of variation
Q1&4 - Quarters 1 and 4
n - Sample size
s.e. - Standard error
N/A - Not Applicable
Q2&3 - Quarters 2 and 3

Units are in Becquerels per milliliter x 10^{-12}

Table 3-11

Quarterly Airborne Particulate Samples: Probability Distribution Functions

Radio-nuclide	Group	Type	Parameter			K-S Signif.
			Mean	s	t	
^{7}Be	ALL	LOGNORM.	5660	930	--	0.16
^{40}K	ALL	NORMAL	155	70	--	1.00
^{60}Co	ALL	N/A	N/A	N/A	N/A	N/A
^{90}Sr	ALL	NORMAL	6.5	35	--	1.00
^{137}Cs	ALL	N/A	N/A	N/A	N/A	N/A
^{210}Pb	ALL	LOGNORM.	750	270	--	1.00
^{210}Po	ALL	LOGNORM.	703	207	--	0.41
^{226}Ra	ALL	N/A	N/A	N/A	N/A	N/A
^{228}Ra	ALL	N/A	N/A	N/A	N/A	N/A
^{228}Th	ALL	N/A	N/A	N/A	N/A	N/A
^{230}Th	Q1&4	LOGNORM.	20.8	9.1	11.1	1.00
	Q2&3	NORMAL	5.4	6.7	--	0.40
^{232}Th	ALL	LOGNORM.	12	6.4	6.7	0.35
^{233}U	ALL	NORMAL	-1.0	4.6	--	0.00
^{234}U	ALL	LOGNORM.	8.4	1.7	5.2	0.50
^{235}U	ALL	NORMAL	0.25	1.0	--	0.23
^{238}U	ALL	NORMAL	2.4	1.5	--	1.00
^{237}Np	ALL	NORMAL	-0.3	1.4	--	0.38
^{238}Pu	ALL	NORMAL	-1.5	7.7	--	0.00
$^{239/240}Pu$	ALL	NORMAL	0.29	3.3	--	0.00
^{241}Pu	ALL	NORMAL	910	6100	--	0.00
^{241}Am	ALL	LOGNORM.	19.4	9.9	16.7	1.00
^{244}Cm	ALL	NORMAL	-0.6	8.2	--	0.00

Abbreviations:

s - Standard Deviation
t - Scalar Constant (3-Parameter Lognormal)
K-S Signif. - Kolmogorov-Smirnov significance level
N/A - Not Applicable
Q1&4 - Quarters 1 and 4 Q2&3 - Quarters 2 and 3

Units are in Becquerels per milliliter x 10^{-12}

Table 3-12

Quarterly Airborne Particulate Samples: Critical Values

Radio-nuclide	Group	Probability 0.80	0.90	0.95	0.99
^{7}Be	ALL	6400	6900	7300	8200
^{40}K	ALL	210	240	270	320
^{60}Co	ALL	< 14	< 16	< 24	< 27
^{90}Sr	ALL	36	51	64	88
^{137}Cs	ALL	< 8	< 10	< 11	< 17
^{210}Pb	ALL	950	1100	1200	1600
^{210}Po	ALL	860	980	1100	1300
^{226}Ra	ALL	< 20	< 30	< 40	< 120
^{228}Ra	ALL	< 41	< 56	< 63	< 74
^{228}Th	ALL	< 19	< 27	< 30	< 44
^{230}Th	Q1&4	16	21	27	39
	Q2&3	11	14	16	21
^{232}Th	ALL	9	13	17	27
^{233}U	ALL	2.9	4.9	6.6	9.7
^{234}U	ALL	4.5	5.4	6.2	7.9
^{235}U	ALL	1.1	1.5	1.9	2.6
^{238}U	ALL	3.7	4.3	4.9	5.9
^{237}Np	ALL	0.8	1.4	2.0	2.9
^{238}Pu	ALL	5	8	11	16
$^{239/240}Pu$	ALL	3.1	4.5	5.7	8.0
^{241}Pu	ALL	6000	9000	11000	15000
^{241}Am	ALL	26	32	38	53
^{244}Cm	ALL	6	10	13	18

Abbreviations:
Q1&4 - Quarters 1 and 4
Q2&3 - Quarters 2 and 3

Units are in Becquerels per milliliter x 10^{-12}

4.0 Soil Samples

Soil samples were collected and analyzed from a total of 37 locations within an 80-kilometer radius of the WIPP facility. At each location, samples from three depths were collected, although not all depths were analyzed from every location. The three depths are denoted as surface (0 to 2 centimeters), intermediate (2 to 5 centimeters), and deep (5 to 10 centimeters). Two sampling times are represented in the data base—December 1985 and July 1987. These were considered replicate samples from each location and were not distinguished in the statistical analysis. The samples were analyzed for 19 radionuclides.

Due to the wide geographic scope of the soil sampling program, the data base was divided into three geographic groups, each representing a different regional scale. The WIPP Site group, which has the smallest scale (covering the smallest area), consists of the eight locations at the cardinal compass directions from the center of the WIPP facility along the Secured Area Boundary fence. All sampling locations in this group are within 1 kilometer of the Waste Handling Building and Exhaust Shaft.

The next group in increasing scale is the Five-Mile Ring, which consists of 16 locations forming a ring with a radius of approximately 5 miles (8 kilometers) and centered at the WIPP facility. The sampling locations are at the 16 principal compass directions around the ring. All are within the Los Medanos region and represent an area of approximately 200 square kilometers.

The third group, the Outer Sites, consists of 13 locations, representing a variety of habitats, soil types, and land uses in southeastern New Mexico, from Artesia and Loving on the west to Hobbs and Jal on the east and including the Gnome Site, a potash mine, and an oil production area. The area of coverage of approximately 10,000 square kilometers.

The data for each parameter were graphically checked for normal and lognormal distribution using a normal probability plot. When the latter was indicated, the data were log-transformed prior to analysis. ANOVA, with a 95 percent confidence limit, was used to test each parameter for homogeneity between geographic groups and between depths. Only those sampling locations with all three depths represented in the data base were used for the latter. Where differences were found, Tukey's multiple range test was used to identify homogeneous groups at 95 percent confidence.

^{40}K, ^{234}U, ^{235}U, and ^{238}U exhibited significant differences between all three geographic groups, while ^{137}Cs, ^{226}Ra, ^{228}Th, and ^{230}Th exhibited differences between the Outer Sites and the other two groups, which were indistinguishable. No significant differences were found between depths.

The data base was subdivided according to the result of the ANOVAs. Each of the subsequent data sets was tested and fit to a probability distribution model. The results are presented in Tables 4-1 through 4-3. ^{60}Co and ^{228}Ra were not fitted to probability models, because more than 10 percent of the data were reported as being less than a maximum value. Data fits to either the normal or lognormal distributions were generally good. ^{241}Am, ^{230}Th, ^{232}Th, and ^{235}U were fitted to three-parameter lognormal distributions.

^{233}U, ^{237}Np, and all isotopes of plutonium exhibited poor fits to all models tested. These data sets generally shared a pattern of being symmetrical about zero, with a high frequency of data points near zero, but with a relatively wide spread of data points on either side. In these cases, the critical values were derived from the normal distribution, with parameters equal to the maximum-likelihood estimators of the mean and standard deviation calculated from the data.

Table 4-1

Soil Samples: Summary Statistics

Radio-nuclide	Group	MDL	n	Mean		s.e.	s	c.v.
^{40}K	O	---	35	340	+/-	20	130	0.38
	R	---	79	180	+/-	10	60	0.33
	W	---	33	200	+/-	10	30	0.15
^{60}Co	ALL	3.7	114	< 2.4		N/A	N/A	N/A
^{90}Sr	ALL	74	145	0.06	+/-	0.06	0.78	13
^{137}Cs	O	3.7	24	8.1	+/-	1.3	6.3	0.78
	R/W	3.7	121	4.7	+/-	0.4	4.9	1.04
^{226}Ra	O	7.4	35	20	+/-	2	10	0.50
	R/W	7.4	111	9.6	+/-	0.2	2.2	0.23
^{228}Ra	ALL	---	144	< 80		N/A	N/A	N/A
^{228}Th	O	3.7	35	18	+/-	2	9	0.50
	R/W	3.7	112	7.8	+/-	0.2	2.5	0.32
^{230}Th	O	3.7	24	19	+/-	5	26	1.37
	R/W	3.7	129	9.1	+/-	0.8	9.1	1.00
^{232}Th	ALL	3.7	154	11	+/-	1	13	1.18
^{233}U	ALL	3.7	145	0.02	+/-	0.04	0.55	27.50
^{234}U	O	3.7	25	12	+/-	1	7	0.58
	R	3.7	96	6.8	+/-	0.5	5.3	0.78
	W	3.7	32	5.4	+/-	0.2	1.4	0.26
^{235}U	O	---	17	0.63	+/-	0.17	0.70	1.11
	R	---	96	0.40	+/-	0.04	0.41	1.02
	W	---	32	0.16	+/-	0.06	0.34	2.12
^{238}U	O	3.7	25	11	+/-	1	6	0.54
	R	3.7	96	5.9	+/-	0.2	2.4	0.41
	W	3.7	33	5.7	+/-	0.3	1.6	0.28
^{237}Np	ALL	3.7	154	-0.03	+/-	0.03	0.35	11.67

Table 4-1

(Continued)

Radio-nuclide	Group	MDL	n	Mean		s.e.	s	c.v.
^{238}Pu	ALL	15	145	-0.1	+/-	0.1	1.1	11.00
$^{239/240}Pu$	ALL	7.4	145	0.20	+/-	0.06	0.73	3.65
^{241}Pu	ALL	370	145	160	+/-	50	560	3.50
^{241}Am	ALL	3.7	58	1.7	+/-	0.3	2.0	1.18
^{244}Cm	ALL	3.7	58	0.21	+/-	0.11	0.83	3.95

Abbreviations:
Groups: O - Outer Sites; R - Five-mile Ring; W - WIPP Site
MDL - Minimum Detection Limit
n - Sample size
s.e. - Standard error
s - Standard deviation
c.v. - Coefficient of variation
N/A - Not Applicable

Units are in Becquerels per gram x 10^{-3}

Table 4-2

Soil Samples: Probability Distribution Functions

Radio-nuclide	Group	Type	Parameter			K-S Signif.
			Mean	s	t	
^{40}K	O	LOGNORM.	340	140	---	1.00
	R	LOGNORM.	180	50	---	0.39
	W	NORMAL	200	30	---	1.00
^{60}Co	ALL	N/A	N/A	N/A	N/A	N/A
^{90}Sr	ALL	NORMAL	0.06	0.78	---	0.38
^{137}Cs	O	LOGNORM.	8.4	8.2	---	1.00
	R/W	LOGNORM.	4.8	4.8	---	0.52
^{226}Ra	O	LOGNORM.	20	12	---	1.00
	R/W	LOGNORM.	9.6	2.1	---	0.36
^{228}Ra	ALL	N/A	N/A	N/A	N/A	N/A
^{228}Th	O	LOGNORM.	18	9.7	---	1.00
	R/W	LOGNORM.	7.7	2.4	---	0.47
^{230}Th	O	LOGNORM.	32	120	2.2	1.00
	R/W	LOGNORM.	12	12	2.2	1.00
^{232}Th	ALL	LOGNORM.	13	18	1.0	1.00
^{233}U	ALL	NORMAL	0.02	0.54	---	0.00
^{234}U	O	LOGNORM.	12	7.1	---	1.00
	R	LOGNORM.	6.7	4.2	---	0.16
	W	NORMAL	5.4	1.4	---	1.00
^{235}U	O	LOGNORM.	1.2	0.83	0.5	1.00
	R	LOGNORM.	0.91	0.40	0.5	1.00
	W	NORMAL	0.16	0.34	---	1.00
^{238}U	O	LOGNORM.	11	6	---	1.00
	R	LOGNORM.	5.9	2.3	---	0.51
	W	LOGNORM.	5.8	1.7	---	1.00
^{237}Np	ALL	NORMAL	-0.03	0.35	---	0.02

Table 4-2

(Continued)

Radio-nuclide	Group	Type	Parameter			K-S Signif.
			Mean	s	t	
^{238}Pu	ALL	NORMAL	-0.1	1.1	---	0.00
$^{239/240}Pu$	ALL	NORMAL	0.20	0.73	---	0.01
^{241}Pu	ALL	NORMAL	160	560	---	0.00
^{241}Am	ALL	LOGNORM.	6.7	2.1	5.0	0.32
^{244}Cm	ALL	NORMAL	0.21	0.83	---	0.35

Abbreviations:
s - Standard Deviation
t - Scalar Constant (3-Parameter Lognormal)
Groups: O - Outer Sites; R - Five-mile Ring; W - WIPP Site
K-S Signif. - Kolmogorov-Smirnov significance level
N/A - Not Applicable

Units are in Becquerels per gram x 10^{-3}

Table 4-3

Soil Samples: Critical Values

Radio-nuclide	Group	MDL	Probability 0.80	0.90	0.95	0.99
^{40}K	O	---	430	520	600	780
	R	---	220	250	280	340
	W	---	230	240	260	280
^{60}Co	ALL	3.7	< 3.3	< 3.7	< 4.4	< 5.2
^{90}Sr	ALL	74	0.7	1.0	1.3	1.9
^{137}Cs	O	3.7	12	17	23	40
	R/W	3.7	7	10	13	24
^{226}Ra	O	7.4	28	35	42	61
	R/W	7.4	11	12	13	16
^{228}Ra	ALL	---	< 120	< 170	< 180	< 400
^{228}Th	O	3.7	24	30	36	51
	R/W	3.7	9	11	12	15
^{230}Th	O	3.7	30	70	120	380
	R/W	3.7	15	22	31	57
^{232}Th	ALL	3.7	17	28	41	83
^{233}U	ALL	3.7	0.5	0.7	0.9	1.3
^{234}U	O	3.7	16	21	25	37
	R	3.7	9	12	15	22
	W	3.7	6.6	7.2	7.7	8.6
^{235}U	O	---	1.2	1.7	2.3	3.7
	R	---	0.7	0.9	1.2	1.7
	W	---	0.45	0.60	0.72	0.95
^{238}U	O	3.7	15	18	22	32
	R	3.7	8	9	10	13
	W	3.7	7	8	9	11
^{237}Np	ALL	3.7	0.26	0.42	0.54	0.78

Table 4-3

(Continued)

Radio-nuclide	Group	MDL	Probability 0.80	0.90	0.95	0.99
^{238}Pu	ALL	15	0.8	1.3	1.7	2.4
$^{239/240}Pu$	ALL	7.4	0.8	1.1	1.4	1.9
^{241}Pu	ALL	370	600	900	1100	1500
^{241}Am	ALL	3.7	3.3	4.5	5.6	8.0
^{244}Cm	ALL	3.7	0.9	1.2	1.5	2.1

Abbreviations:
Groups: O - Outer Sites; R - Five-mile Ring; W - WIPP Site
MDL - Minimum Detection Limit

Units are in Becquerels per gram x 10^{-3}

5.0 Water Samples

Both surface-water and groundwater samples were collected during the RBP. These samples were analyzed for 18 radionuclides, including tritium (^3H). The resulting data from the surface-water and groundwater sampling programs were analyzed independently.

5.1 Surface Water Samples

Samples of surface water were collected from 12 locations over the course of the RBP. A total of five sampling rounds were performed. The separate rounds are considered replicate samples for the statistical analyses. Not all locations were sampled during each round, giving a maximum sample size of 44 data points for each parameter.

Sampling locations were divided into three groups for an initial analysis of geographic variability. Stock tanks represented the largest group, with five locations, and they are the locations closest to the WIPP facility. Stock tanks in this area are typically man-made earthen catchment basins with no surface outflow, except by rare overflow events. Three of the tank samples are within the Los Medanos area and two are in Nash Draw, to the west. Also included in this group is a single sample of WIPP influent water and a single sample of water from the WIPP primary wastewater treatment lagoon.

The Pecos River represents the next major surface water group. Four sampling locations were used along the Pecos, from a northern (up-river) point near the town of Artesia, New Mexico, to a southern (down-river) point near the town of Malaga, New Mexico. The Pecos River locations were sampled four times during the RBP.

The third group, called Laguna Grande de la Sal, represents water from a series of playa lakes at the lower (southwestern) end of Nash Draw. These lakes are fed by both surface flow and springs. The water in these lakes is highly saline, often at or near saturation level for sodium chloride and other salts. The sediments of Laguna Grande de la Sal, the largest of the lakes, are rich enough in crystalline sodium chloride that they are commercially mined.

Laguna Grande de la Sal was sampled five times during the RBP, with each sample consisting of a composite of one or two aliquots from separate locations along the lake shoreline and an aliquot from Laguna Tres, northeast of Laguna Grande. The sampling

location on the south shore of Laguna Grande was twice excluded from the composite sample due to drying of that part of the lake.

ANOVA was performed on each data base to identify significant differences between these groups (at 95 percent confidence). As a result of these analyses, ^{40}K data from Laguna Grande de la Sal were separated from the other locations, and all four isotopes of uranium were segregated among the three geographic groups prior to statistical analysis.

Summary statistics for the surface water data base are presented in Table 5-1. The means for most radionuclides are below their respective detection limit. Due to its saline nature, the concentration of ^{40}K is significantly higher in Laguna Grande than the freshwater sites. Laguna Grande also has the highest concentrations of uranium (all four radioisotopes). The concentrations of uranium are consistently higher in the Pecos River than the stock tanks near the WIPP Site.

Table 5-2 presents the results of probability distribution modeling of the various data bases. These results generally show a good fit for the normal and lognormal distributions. Three-parameter lognormal distributions were used for seven isotopes. ^{60}Co and ^{137}Cs were not modeled, due to the large proportion of data reported as less than a maximum value. Table 5-3 presents critical values for each parameter based on the probability model or, in the cases of ^{60}Co and ^{137}Cs, the actual data.

5.2 Groundwater Samples

During the RBP, samples of groundwater were collected from 37 wells, including 23 water monitoring wells in the Culebra unit of the Rustler Formation, 4 in the Magenta unit of the Rustler, and 10 privately owned wells. Replicate sampling of these wells range from one to four independent samples.

The groundwater data were initially stratified into three groups—Culebra wells, Magenta wells, and private wells—and ANOVA was applied to determine whether significant differences (at 95 percent confidence) exist among these groups for each parameter. The elevated ^{40}K concentrations are expected owing to the briny nature of the Culebra water and its proximity to the Salado Formation.

^{226}Ra was found to have a distinct geographic pattern in the Culebra. Means from individual wells show this radionuclide increases in concentration from west to east. Because this

Table 5-1

Surface Water Samples: Summary Statistics

Radio-nuclide	Group	MDL	n	Mean		s.e.	s	c.v.
^{3}H	ALL	56	41	-26	+/-	7	43	1.65
^{40}K	TANKS/PECOS	---	39	< 100	+/-	10	80	0.80
	LGS	---	5	10000	+/-	1000	2000	0.20
^{60}Co	ALL	3.0	44	< 13		N/A	N/A	N/A
^{90}Sr	ALL	7.4	43	0.28	+/-	0.08	0.52	1.86
^{137}Cs	ALL	1.9	44	< 6.9		N/A	N/A	N/A
^{226}Ra	ALL	5.6	40	< 4.8	+/-	1.1	7.2	1.5
^{228}Ra	ALL	---	40	< 8.4	+/-	0.6	3.9	0.46
^{228}Th	ALL	3.7	40	< 2.3	+/-	0.3	2.2	0.96
^{230}Th	ALL	0.37	44	0.10	+/-	0.04	0.29	2.9
^{232}Th	ALL	0.37	44	0.032	+/-	0.013	0.087	2.72
^{233}U	TANKS	0.37	23	-0.016	+/-	0.008	0.040	2.5
	LGS	0.37	5	0.07	+/-	0.06	0.12	1.71
	PECOS	0.37	16	0.001	+/-	0.013	0.053	53.00
^{234}U	TANKS	0.37	23	0.11	+/-	0.04	0.19	1.73
	LGS	0.37	5	5.7	+/-	1.5	3.3	0.58
	PECOS	0.37	16	1.2	+/-	0.2	0.7	0.58
^{235}U	TANKS	---	22	0.006	+/-	0.004	0.020	3.33
	LGS	---	5	0.13	+/-	0.04	0.09	0.69
	PECOS	---	15	0.045	+/-	0.009	0.036	0.80
^{238}U	TANKS	0.37	22	0.046	+/-	0.012	0.054	1.17
	LGS	0.37	5	2.8	+/-	0.7	1.6	0.57
	PECOS	0.37	16	0.56	+/-	0.06	0.22	0.39
^{237}Np	ALL	0.37	41	0.003	+/-	0.005	0.035	11.67
^{238}Pu	ALL	0.11	44	-0.004	+/-	0.013	0.085	21.25
$^{239/240}Pu$	ALL	0.74	44	-0.006	+/-	0.006	0.041	6.83
^{241}Pu	ALL	37	44	9	+/-	2	13	1.44

Abbreviations:
MDL - Minimum Detection Limit
s.e. - Standard error
c.v. - Coefficient of variation
N/A - Not Applicable
n - Sample size
s - Standard deviation
LGS - Laguna Grande de la Sal

Units are in Becquerels per gram x 10^{-4}

Table 5-2

Surface Water Samples: Probability Distribution Functions

Radio-nuclide	Group	Type	Parameter Mean	Parameter s	Parameter t	K-S Signif.
^{3}H	ALL	NORMAL	-26	43	---	1.00
^{40}K	TANKS/PECOS	LOGNORM.	120	160	---	1.00
	LGS	NORMAL	10000	2500	---	1.00
^{60}Co	ALL	N/A	N/A	N/A	N/A	N/A
^{90}Sr	ALL	LOGNORM.	0.91	0.65	0.60	1.00
^{137}Cs	ALL	N/A	N/A	N/A	N/A	N/A
^{226}Ra	ALL	LOGNORM.	4.5	5.0	---	1.00
^{228}Ra	ALL	NORMAL	8.4	3.9	---	0.21
^{228}Th	ALL	LOGNORM.	2.5	4.0	---	0.44
^{230}Th	ALL	LOGNORM.	0.57	0.10	0.5	1.00
^{232}Th	ALL	LOGNORM.	0.24	0.10	0.2	0.50
^{233}U	TANKS	NORMAL	-0.01	0.04	---	0.11
	LGS	LOGNORM.	0.13	0.50	0.01	1.00
	PECOS	NORMAL	0.00	0.053	---	0.27
^{234}U	TANKS	LOGNORM.	0.13	0.23	0.012	1.00
	LGS	LOGNORM.	6.1	4.4	---	1.00
	PECOS	LOGNORM.	1.2	0.61	---	1.00
^{235}U	TANKS	NORMAL	0.006	0.020	---	1.00
	LGS	LOGNORM.	0.14	0.12	---	1.00
	PECOS	LOGNORM.	0.044	0.027	---	1.00
^{238}U	TANKS	LOGNORM.	0.09	0.071	0.04	1.00
	LGS	LOGNORM.	3.0	2.1	---	1.00
	PECOS	NORMAL	0.56	0.22	---	1.00
^{237}Np	ALL	LOGNORM.	0.044	0.032	0.04	1.00
^{238}Pu	ALL	NORMAL	0.004	0.085	---	1.00
$^{239,240}Pu$	ALL	NORMAL	-0.009	0.037	---	1.00
^{241}Pu	ALL	NORMAL	8.3	13	---	1.00

Abbreviations:
s - Standard Deviation
t - Scalar Constant (3-Parameter Lognormal)
K-S Signif. - Kolmogorov-Smirnov significance level
LGS - Laguna Grande de la Sal
N/A - Not Applicable

Units are in Becquerels per gram x 10^{-4}

Table 5-3

Surface Water Samples: Critical Values

Radio-nuclide	Group	MDL	Probability 0.80	0.90	0.95	0.99
^{3}H	ALL	56	10	29	45	74
^{40}K	TANKS/PECOS	---	170	260	380	760
	LGS	---	12000	13000	14000	16000
^{60}Co	ALL	3.0	< 24	< 24	< 27	< 30
^{90}Sr	ALL	7.4	0.7	1.1	1.5	2.7
^{137}Cs	ALL	1.9	< 12	< 17	< 19	< 21
^{226}Ra	ALL	5.6	6	9	13	24
^{228}Ra	ALL	---	12	13	15	17
^{228}Th	ALL	3.7	3	6	8	18
^{230}Th	ALL	0.37	0.15	0.20	0.25	0.34
^{232}Th	ALL	0.37	0.11	0.17	0.23	0.36
^{233}U	TANKS	0.37	0.024	0.041	0.056	0.083
	LGS	0.37	0.1	0.3	0.5	1.5
	PECOS	0.37	0.04	0.07	0.09	0.12
^{234}U	TANKS	0.37	0.2	0.3	0.4	1.0
	LGS	0.37	8	11	14	22
	PECOS	0.37	1.6	2.0	2.4	3.3
^{235}U	TANKS	---	0.023	0.032	0.039	0.052
	LGS	---	0.20	0.28	0.36	0.60
	PECOS	---	0.06	0.08	0.10	0.14
^{238}U	TANKS	0.37	0.09	0.13	0.18	0.32
	LGS	0.37	4	6	7	11
	PECOS	0.37	0.7	0.8	0.9	1.1
^{237}Np	ALL	0.37	0.02	0.04	0.06	0.12
^{238}Pu	ALL	0.11	0.07	0.10	0.14	0.19
$^{239/240}Pu$	ALL	0.74	0.022	0.039	0.052	0.077
^{241}Pu	ALL	37	19	25	30	38

Abbreviations:
MDL - Minimum Detection Limit
LGS - Laguna Grande de la Sal
N/A - Not Applicable

Units are in Becquerels per gram x 10^{-4}

increase forms a continuous gradient across the landscape, criteria for subdivision of the data base were selected to optimize statistical and spatial uniformity within each group while maintaining large and comparable sample sizes.

The Culebra wells were divided into two groups based on whether the mean concentration of ^{226}Ra is greater or less than 1.66×10^{-3} Becquerels per gram, or three times the MDL. The low group, i.e., those having means less than this value, contains ten Culebra wells (all wells west of the WIPP Site boundary plus H-2A and H-9), as well as all Magenta wells and private wells. The high group, i.e., those wells having means greater than three times the MDL, contains 12 Culebra wells, all of which are east of the western boundary of the WIPP Site.

Table 5-4 presents the summary statistics for each radionuclide and subsequent well group. Table 5-5 presents the results of probability distribution modeling of these data bases. Table 5-6 presents the critical values resulting from these models. ^{40}K, ^{60}Co, ^{137}Cs, ^{228}Ra, and ^{228}Th all had more than 10 percent of their data reported as being less than a maximum value; however, for ^{40}K, ^{228}Ra, and ^{228}Th, probability models were found that provided a good fit to the data with these maximum values left in the data base. For ^{60}Co and ^{137}Cs, probability modeling was unsuccessful due to the nonrandom nature of the maximum values.

Of the remaining data bases that have reported MDL, only ^{226}Ra, ^{234}U, and ^{238}U have group means exceeding the MDL. Model fitting results are generally good using the normal or the two- or three-parameter lognormal distribution.

Table 5-4

Groundwater Samples: Summary Statistics

Radio-nuclide	Group	MDL	n	Mean		s.e.	s	c.v.
^{3}H	ALL	56	84	-38	+/-	4	33	0.87
^{40}K	M/P	---	33	< 73	+/-	11	65	0.89
	C	---	57	< 200	+/-	20	140	0.70
^{60}Co	ALL	3.0	92	< 12		N/A	N/A	N/A
^{90}Sr	ALL	7.4	83	0.30	+/-	0.08	0.69	2.30
^{137}Cs	ALL	1.9	92	< 7.2		N/A	N/A	N/A
^{226}Ra	LOW	5.6	39	6.9	+/-	0.8	4.7	0.68
	HIGH	5.6	32	52	+/-	5	26	0.50
^{228}Ra	ALL	---	84	< 9.6	+/-	0.4	4.2	0.44
^{228}Th	ALL	3.7	84	< 2.2	+/-	0.2	1.8	0.82
^{230}Th	ALL	0.37	87	0.14	+/-	0.05	0.47	3.36
^{232}Th	ALL	0.37	87	0.007	+/-	0.008	0.075	10.71
^{233}U	ALL	0.37	97	0.012	+/-	0.005	0.049	4.08
^{234}U	ALL	0.37	97	2.6	+/-	0.2	2.3	0.88
^{235}U	ALL	---	96	0.055	+/-	0.009	0.088	1.60
^{238}U	ALL	0.37	97	0.72	+/-	0.08	0.84	1.17
^{237}Np	ALL	0.37	87	0.001	+/-	0.004	0.041	41.00
^{238}Pu	ALL	0.11	91	0.03	+/-	0.02	0.18	6.00
$^{239/240}Pu$	ALL	0.74	91	0.007	+/-	0.008	0.080	11.43
^{241}Pu	ALL	37	91	9	+/-	3	32	3.56

Abbreviations:

MDL - Minimum Detection Limit
s.e. - Standard error
c.v. - Coefficient of variation
C - Culebra Formation
n - Sample size
s - Standard deviation
M/P - Magenta Formation and Private Wells
N/A - Not Applicable

Units are in Becquerels per gram x 10^{-4}

Table 5-5

Groundwater Samples: Probability Distribution Functions

Radio-nuclide	Group	Type	Parameter			K-S Signif.
			Mean	s	t	
^{3}H	ALL	NORMAL	-38	33	---	1.00
^{40}K	M/P	N/A	N/A	N/A	N/A	N/A
	C	N/A	N/A	N/A	N/A	N/A
^{60}Co	ALL	N/A	N/A	N/A	N/A	N/A
^{90}Sr	ALL	NORMAL	0.30	0.69	---	1.00
^{137}Cs	ALL	N/A	N/A	N/A	N/A	N/A
^{226}Ra	LOW	LOGNORM.	7.2	6.6	---	1.00
	HIGH	LOGNORM.	52	27	---	1.00
^{228}Ra	ALL	NORMAL	9.6	4.2	---	0.30
^{228}Th	ALL	LOGNORM.	-2.3	2.9	---	1.00
^{230}Th	ALL	NORMAL	0.06	0.09	---	1.00
^{232}Th	ALL	NORMAL	0.007	0.075	---	0.10
^{233}U	ALL	LOGNORM.	0.11	0.03	0.1	0.03
^{234}U	ALL	LOGNORM.	3.6	2.7	1.0	1.00
^{235}U	ALL	LOGNORM.	0.10	0.07	0.05	0.36
^{238}U	ALL	LOGNORM.	1.1	0.70	0.4	1.00
^{237}Np	ALL	NORMAL	0.001	0.02	---	1.00
^{238}Pu	ALL	LOGNORM.	0.53	0.14	0.5	0.07
$^{239/240}Pu$	ALL	NORMAL	0.007	0.029	---	0.29
^{241}Pu	ALL	NORMAL	6.9	18	---	0.34

Abbreviations:
- s - Standard Deviation
- t - Scalar Constant (3-Parameter Lognormal)
- K-S Signif. - Kolmogorov-Smirnov significance level
- N/A - Not Applicable
- M/P - Magenta Formation and Private Wells
- C - Culebra Formation

Units are in Becquerels per gram x 10^{-4}

Table 5-6

Groundwater Samples: Critical Values

Radio-nuclide	Group	MDL	Probability 0.80	0.90	0.95	0.99
^{3}H	ALL	56	-10	4	16	39
^{40}K	M/P	---	< 120	< 180	< 200	< 210
	C	---	< 310	< 370	< 440	< 630
^{60}Co	ALL	3.0	< 16	< 18	< 25	< 28
^{90}Sr	ALL	7.4	0.9	1.2	1.4	1.9
^{137}Cs	ALL	1.9	< 12	< 13	< 17	< 23
^{226}Ra	LOW	5.6	10	14	19	33
	HIGH	5.6	70	90	100	140
^{228}Ra	ALL	---	< 13	< 15	< 16	< 19
^{228}Th	ALL	3.7	< 3	< 5	< 7	< 14
^{230}Th	ALL	0.37	0.14	0.18	0.21	0.27
^{232}Th	ALL	0.37	0.07	0.10	0.13	0.18
^{233}U	ALL	0.37	0.03	0.05	0.06	0.10
^{234}U	ALL	0.37	4	6	8	13
^{235}U	ALL	---	0.09	0.13	0.18	0.31
^{238}U	ALL	0.37	1.1	1.6	2.0	3.2
^{237}Np	ALL	0.37	0.018	0.026	0.034	0.047
^{238}Pu	ALL	0.11	0.14	0.21	0.28	0.44
$^{239/240}Pu$	ALL	0.74	0.031	0.044	0.054	0.074
^{241}Pu	ALL	37	22	30	36	49

Abbreviations:
MDL - Minimum Detection Limit
N/A - Not Applicable
M/P - Magenta Formation and Private Wells
C - Culebra Formation

Units are in Becquerels per gram x 10^{-4}

6.0 Bottom Sediment Samples

The analysis of bottom sediments is a crucial component to the WIPP environmental monitoring programs. A recent study of the ecological distribution of radionuclides in a contaminated reservoir at the Savannah River Site (Whicker et al., 1990) found nearly 99 percent of long-lived radionuclides (^{90}Sr, ^{137}Cs, and transuranics) remaining in the system were in the bottom sediments.

For the WIPP RBP, bottom sediments were collected from six locations—Hill Tank, Indian Tank, Noye Tank, Laguna Grande de la Sal, and two sites along the Pecos River in conjunction with surface-water sampling. These samples were analyzed for 17 radionuclides. As with the surface-water samples, samples collected at different times from the same location are considered replicate samples for that location.

The data were stratified into three geographic groups—stock tanks, the Pecos River, and Laguna Grande de la Sal. The latter is separated because of the atypical nature of the sediments; however, this location is represented in the data base with only three replicate samples.

Analysis of variance was used to determine whether significant differences exist between these groups (at 95 percent confidence). Where none was found, the data were combined. Because of the small sample size for Laguna Grande de la Sal, it was not analyzed independently but rather combined with the group to which it had closest affinities. Thus, for ^{40}K and ^{137}Cs Laguna Grande de la Sal was combined with the stock tanks and for ^{226}Ra, ^{228}Ra, and ^{228}Th it was combined with the Pecos River data.

Summary statistics for this data base are presented in Table 6-1. In all five of the cases where differences were found between location groups, the stock tanks had higher concentrations of the radionuclide, possibly indicating an accumulation effect from the closed nature of the tanks. Laguna Grande de la Sal sediments were found to contain significantly higher concentrations of ^{234}U than the stock tanks and the Pecos River, which were indistinguishable. In this case, the data were analyzed with Laguna Grande included and then reanalyzed with it excluded.

Table 6-1

Bottom Sediment Samples: Summary Statistics

Radio-nuclide	Group	LGS	MDL	n	Mean		s.e.	s	c.v.
^{40}K	TANKS	+	---	12	670	+/-	60	220	0.33
	PECOS	-	---	8	210	+/-	20	60	0.28
^{60}Co	ALL	+	3.7	20	< 2.6		N/A	N/A	N/A
^{90}Sr	ALL	+	74	20	1	+/-	5	23	23.00
^{137}Cs	TANKS	-	3.7	9	16	+/-	3	8	0.50
	PECOS	+	3.7	11	1.2	+/-	0.4	1.4	1.17
^{226}Ra	TANKS	-	7.4	9	30	+/-	2	6	0.20
	PECOS	+	7.4	11	17	+/-	2	6	0.35
^{228}Ra	TANKS	-	---	9	< 39		N/A	N/A	N/A
	PECOS	+	---	11	< 12		N/A	N/A	N/A
^{228}Th	TANKS	-	3.7	9	31	+/-	2	5	0.16
	PECOS	+	3.7	11	9.0	+/-	1.3	4.5	0.50
^{230}Th	ALL	+	3.7	20	1.7	+/-	0.4	2.0	1.18
^{232}Th	ALL	+	3.7	20	2.1	+/-	0.6	2.7	1.28
^{233}U	ALL	+	3.7	20	0.39	+/-	0.22	0.98	2.51
^{234}U	ALL	+	3.7	20	22	+/-	5	22	1.00
	ALL	-	3.7	17	16	+/-	1	4	0.25
^{235}U	ALL	+	---	20	0.97	+/-	0.21	0.97	1.00
^{238}U	ALL	+	3.7	20	17	+/-	2	10	0.59
^{237}Np	ALL	+	3.7	20	-0.04	+/-	0.06	0.27	6.75
^{238}Pu	ALL	+	15	20	0.1	+/-	0.3	1.2	12.00
$^{239/240}Pu$	ALL	+	7.4	20	0.36	+/-	0.15	0.66	1.83
^{241}Pu	ALL	+	370	20	50	+/-	60	280	5.60

Abbreviations:
- LGS - Laguna Grande de la Sal, data included (+) or excluded (-)
- MDL - Minimum Detection Limit
- n - Sample size
- s.e. - Standard error
- s - Standard deviation
- c.v. - Coefficient of variation
- N/A - Not Applicable

Units are in Becquerels per gram x 10^{-3}

Fits to the normal or lognormal probability distributions were generally very high (Table 6-2). In four cases (^{40}K, ^{230}Th, ^{232}Th, and ^{233}U), the three-parameter lognormal distribution was used with good results. ^{90}Sr exhibits the poorest fit; however, these data are well below the MDL and tend to be clustered about zero. Critical values for all sediment data sets are presented in Table 6-3.

Table 6-2

Bottom Sediment Samples: Probability Distribution Functions

Radio-nuclide	Group	LGS	Type	Parameter			K-S Signif.
				Mean	s	t	
^{40}K	TANKS	+	NORMAL	660	220	---	1.00
	PECOS	-	LOGNORM.	67	71	-150	1.00
^{60}Co	ALL	+	N/A	N/A	N/A	N/A	N/A
^{90}Sr	ALL	+	NORMAL	4.7	12	---	1.00
^{137}Cs	TANKS	-	NORMAL	16	8.1	---	1.00
	PECOS	+	LOGNORM.	1.2	1.0	---	1.00
^{226}Ra	TANKS	-	NORMAL	30	5.6	---	1.00
	PECOS	+	NORMAL	17	6.1	---	1.00
^{228}Ra	TANKS	-	N/A	N/A	N/A	N/A	N/A
	PECOS	+	N/A	N/A	N/A	N/A	N/A
^{228}Th	TANKS	-	NORMAL	31	5.2	---	1.00
	PECOS	+	NORMAL	9.0	4.5	---	1.00
^{230}Th	ALL	+	LOGNORM.	2.4	3.5	0.5	1.00
^{232}Th	ALL	+	LOGNORM.	3.5	3.0	1.0	1.00
^{233}U	ALL	+	LOGNORM.	2.0	1.1	1.5	1.00
^{234}U	ALL	+	LOGNORM.	22	22	---	0.16
	ALL	-	NORMAL	16	4.3	---	1.00
^{235}U	ALL	+	NORMAL	0.97	0.97	---	1.00
^{238}U	ALL	+	LOGNORM.	17	9.6	---	1.00
^{237}Np	ALL	+	NORMAL	-0.045	0.27	---	1.00
^{238}Pu	ALL	+	NORMAL	0.12	1.2	---	1.00
$^{239/240}Pu$	ALL	+	NORMAL	0.36	0.66	---	1.00
^{241}Pu	ALL	+	NORMAL	51	280	---	1.00

Abbreviations:
s - Standard Deviation
t - Scalar Constant (3-Parameter Lognormal)
LGS - Laguna Grande de la Sal, data included (+) or excluded (-)
K-S Signif. - Kolmogorov-Smirnov significance level

Units are in Becquerels per gram x 10^{-3}

Table 6-3

Bottom Sediment Samples: Critical Values

Radio-nuclide	Group	LGS	MDL	Probability 0.80	0.90	0.95	0.99
^{40}K	TANKS	+	---	800	900	1000	1200
	PECOS	-	---	240	290	340	500
^{60}Co	ALL	+	3.7	< 3.3	< 3.4	< 4.6	< 5.9
^{90}Sr	ALL	+	74	15	20	24	33
^{137}Cs	TANKS	-	3.7	23	26	29	35
	PECOS	+	3.7	1.7	2.3	3.0	5.0
^{226}Ra	TANKS	-	7.4	35	37	39	43
	PECOS	+	7.4	22	25	27	31
^{228}Ra	TANKS	-	---	< 44	< 48	< 48	< 48
	PECOS	+	---	< 12	< 24	< 24	< 24
^{228}Th	TANKS	-	3.7	35	38	40	43
	PECOS	+	3.7	13	15	16	19
^{230}Th	ALL	+	3.7	3	5	7	16
^{232}Th	ALL	+	3.7	4	6	8	14
^{233}U	ALL	+	3.7	1.2	1.9	2.6	4.3
^{234}U	ALL	+	3.7	30	40	60	110
	ALL	-	3.7	20	22	23	26
^{235}U	ALL	+	---	1.8	2.2	2.6	3.2
^{238}U	ALL	+	3.7	23	29	35	50
^{237}Np	ALL	+	3.7	0.18	0.30	0.40	0.58
^{238}Pu	ALL	+	15	1.1	1.6	2.1	2.9
$^{239/240}Pu$	ALL	+	7.4	0.9	1.2	1.4	1.9
^{241}Pu	ALL	+	370	290	410	510	700

Abbreviations:
LGS - Laguna Grande de la Sal, data included (+) or excluded (-)
MDL - Minimum Detection Limit

Units are in Becquerels per gram x 10^{-3}

7.0 Biotic Tissue Samples

Tissue samples were collected from five components of the biological environment—vegetation, quail, rabbit, catfish, and domestic cattle. Because of the small sample sizes in this subprogram, no attempt was made to further subdivide the samples, nor was probability distribution fitting attempted.

Vegetation samples included above-ground tissues of native vegetation, with species represented in approximately the same proportions (in biomass) as they occur at the sampling site. The samples were ashed prior to analysis. Three sites were sampled twice during the RBP. Summary statistics for 14 radionuclides are presented in Table 7-1. ^{7}Be and ^{60}Co were the only vegetation parameters with values reported as being less than a maximum.

Rabbit, quail, and catfish tissue samples have been analyzed for 17 radionuclides. Initially, the samples were ashed prior to analysis. This procedure was later changed to merely drying the samples. Summary statistics for each data set are presented in Table 7-1.

Both muscle and bone were independently sampled and analyzed from two locally grown beef cattle. Dried tissue samples have been analyzed for 17 radionuclides. The results are summarized in Table 7-1. The means of the bone samples slightly exceeded the MDL for ^{230}Th and ^{232}Th. Because there are only two data points for each radionuclide in these data sets, standard deviation, standard error, and coefficient of variation were not calculated for the beef samples.

Table 7-1

Biotic Tissue Samples: Summary Statistics

Radio-nuclide	Sample Type	MDL	n	Mean		s.e.	s	c.v.
^{7}Be	VEGETATION (ASH)	---	5	< 2000		N/A	N/A	N/A
^{40}K	VEGETATION (ASH)	---	6	3200	+/-	400	900	0.28
	RABBIT (ASH)	---	1	1000		N/A	N/A	N/A
	RABBIT (DRY)	---	2	390		N/A	N/A	N/A
	QUAIL (ASH)	---	1	1100		N/A	N/A	N/A
	QUAIL (DRY)	---	2	410		N/A	N/A	N/A
	FISH (ASH)	---	1	1800		N/A	N/A	N/A
	FISH (DRY)	---	2	610		N/A	N/A	N/A
	BEEF (MUSCLE)	---	2	340		N/A	N/A	N/A
	BEEF (BONE)	---	2	25		N/A	N/A	N/A
^{60}Co	VEGETATION (ASH)	18	6	< 10		N/A	N/A	N/A
	RABBIT (ASH)	18	1	9.6		N/A	N/A	N/A
	RABBIT (DRY)	18	2	6.1		N/A	N/A	N/A
	QUAIL (ASH)	18	1	9.3		N/A	N/A	N/A
	QUAIL (DRY)	18	2	5.2		N/A	N/A	N/A
	FISH (ASH)	18	1	17		N/A	N/A	N/A
	FISH (DRY)	18	2	7.0		N/A	N/A	N/A
	BEEF (MUSCLE)	18	2	4.8		N/A	N/A	N/A
	BEEF (BONE)	18	2	3.8		N/A	N/A	N/A
^{90}Sr	RABBIT (ASH)	---	1	14		N/A	N/A	N/A
	RABBIT (DRY)	---	2	-3.5		N/A	N/A	N/A
	QUAIL (ASH)	---	1	28		N/A	N/A	N/A
	QUAIL (DRY)	---	2	16		N/A	N/A	N/A
	FISH (ASH)	---	1	26		N/A	N/A	N/A
	FISH (DRY)	---	2	-3.0		N/A	N/A	N/A
	BEEF (MUSCLE)	---	2	2.8		N/A	N/A	N/A
	BEEF (BONE)	---	2	12		N/A	N/A	N/A
^{137}Cs	VEGETATION (ASH)	7.4	6	10	+/-	3	6	0.60
	RABBIT (ASH)	7.4	1	2.1		N/A	N/A	N/A
	RABBIT (DRY)	7.4	2	2.2		N/A	N/A	N/A
	QUAIL (ASH)	7.4	1	7.4		N/A	N/A	N/A
	QUAIL (DRY)	7.4	2	2.6		N/A	N/A	N/A
	FISH (ASH)	7.4	1	10		N/A	N/A	N/A
	FISH (DRY)	7.4	2	1.2		N/A	N/A	N/A
	BEEF (MUSCLE)	7.4	2	3.1		N/A	N/A	N/A
	BEEF (BONE)	7.4	2	1.8		N/A	N/A	N/A

Table 7-1

(Continued)

Radio-nuclide	Sample Type	MDL	n	Mean		s.e.	s	c.v.
^{226}Ra	VEGETATION (ASH)	37	6	59	+/-	8	20	0.34
	RABBIT (ASH)	37	1	20		N/A	N/A	N/A
	RABBIT (DRY)	37	2	6.1		N/A	N/A	N/A
	QUAIL (ASH)	37	1	5.2		N/A	N/A	N/A
	QUAIL (DRY)	37	2	8.1		N/A	N/A	N/A
	FISH (ASH)	37	1	16		N/A	N/A	N/A
	FISH (DRY)	37	2	3.6		N/A	N/A	N/A
	BEEF (MUSCLE)	37	2	2.1		N/A	N/A	N/A
	BEEF (BONE)	37	2	12		N/A	N/A	N/A
^{228}Ra	VEGETATION (ASH)	---	6	65	+/-	12	30	0.45
	RABBIT (ASH)	---	1	16		N/A	N/A	N/A
	RABBIT (DRY)	---	2	11		N/A	N/A	N/A
	QUAIL (ASH)	---	1	36		N/A	N/A	N/A
	QUAIL (DRY)	---	2	20		N/A	N/A	N/A
	FISH (ASH)	---	1	33		N/A	N/A	N/A
	FISH (DRY)	---	2	22		N/A	N/A	N/A
	BEEF (MUSCLE)	---	2	9.1		N/A	N/A	N/A
	BEEF (BONE)	---	2	14		N/A	N/A	N/A
^{228}Th	VEGETATION (ASH)	15	6	27	+/-	4	10	0.39
	RABBIT (ASH)	15	1	9.3		N/A	N/A	N/A
	RABBIT (DRY)	15	2	1.3		N/A	N/A	N/A
	QUAIL (ASH)	15	1	17		N/A	N/A	N/A
	QUAIL (DRY)	15	2	6.8		N/A	N/A	N/A
	FISH (ASH)	15	1	9.3		N/A	N/A	N/A
	FISH (DRY)	15	2	6.0		N/A	N/A	N/A
	BEEF (MUSCLE)	15	2	2.8		N/A	N/A	N/A
	BEEF (BONE)	15	2	6.8		N/A	N/A	N/A
^{230}Th	RABBIT (ASH)	3.7	1	0.056		N/A	N/A	N/A
	RABBIT (DRY)	3.7	2	0.34		N/A	N/A	N/A
	QUAIL (ASH)	3.7	1	0.44		N/A	N/A	N/A
	QUAIL (DRY)	3.7	2	0.54		N/A	N/A	N/A
	FISH (ASH)	3.7	1	0.59		N/A	N/A	N/A
	FISH (DRY)	3.7	2	0.30		N/A	N/A	N/A
	BEEF (MUSCLE)	3.7	2	0.037		N/A	N/A	N/A
	BEEF (BONE)	3.7	2	3.84		N/A	N/A	N/A
^{232}Th	RABBIT (ASH)	3.7	1	1.5		N/A	N/A	N/A
	RABBIT (DRY)	3.7	2	0.18		N/A	N/A	N/A
	QUAIL (ASH)	3.7	1	0.56		N/A	N/A	N/A
	QUAIL (DRY)	3.7	2	0.31		N/A	N/A	N/A
	FISH (ASH)	3.7	1	0.14		N/A	N/A	N/A
	FISH (DRY)	3.7	2	0.19		N/A	N/A	N/A
	BEEF (MUSCLE)	3.7	2	1.0		N/A	N/A	N/A
	BEEF (BONE)	3.7	2	4.1		N/A	N/A	N/A

Table 7-1

(Continued)

Radio-nuclide	Sample Type	MDL	n	Mean		s.e.	s	c.v.
^{233}U	VEGETATION (ASH)	3.7	6	0.07	+/-	0.04	0.11	1.62
	RABBIT (ASH)	3.7	1	0.89		N/A	N/A	N/A
	RABBIT (DRY)	3.7	2	0.00		N/A	N/A	N/A
	QUAIL (ASH)	3.7	1	0.00		N/A	N/A	N/A
	QUAIL (DRY)	3.7	2	0.00		N/A	N/A	N/A
	FISH (ASH)	3.7	1	0.00		N/A	N/A	N/A
	FISH (DRY)	3.7	2	2.8		N/A	N/A	N/A
	BEEF (MUSCLE)	3.7	2	0.00		N/A	N/A	N/A
	BEEF (BONE)	3.7	2	0.00		N/A	N/A	N/A
^{234}U	VEGETATION (ASH)	3.7	6	0.06	+/-	0.02	0.04	0.63
	RABBIT (ASH)	3.7	1	0.059		N/A	N/A	N/A
	RABBIT (DRY)	3.7	2	0.00		N/A	N/A	N/A
	QUAIL (ASH)	3.7	1	0.28		N/A	N/A	N/A
	QUAIL (DRY)	3.7	2	0.22		N/A	N/A	N/A
	FISH (ASH)	3.7	1	5.9		N/A	N/A	N/A
	FISH (DRY)	3.7	2	-0.055		N/A	N/A	N/A
	BEEF (MUSCLE)	3.7	2	0.23		N/A	N/A	N/A
	BEEF (BONE)	3.7	2	0.58		N/A	N/A	N/A
^{235}U	VEGETATION (ASH)	---	6	0.09	+/-	0.08	0.21	2.43
	RABBIT (ASH)	---	1	0.41		N/A	N/A	N/A
	RABBIT (DRY)	---	2	-0.11		N/A	N/A	N/A
	QUAIL (ASH)	---	1	0.48		N/A	N/A	N/A
	QUAIL (DRY)	---	2	0.026		N/A	N/A	N/A
	FISH (ASH)	---	1	0.00		N/A	N/A	N/A
	FISH (DRY)	---	2	0.54		N/A	N/A	N/A
	BEEF (MUSCLE)	---	2	0.21		N/A	N/A	N/A
	BEEF (BONE)	---	2	0.22		N/A	N/A	N/A
^{238}U	VEGETATION (ASH)	3.7	6	0.69	+/-	0.21	0.51	0.74
	RABBIT (ASH)	3.7	1	0.00		N/A	N/A	N/A
	RABBIT (DRY)	3.7	2	1.7		N/A	N/A	N/A
	QUAIL (ASH)	3.7	1	0.00		N/A	N/A	N/A
	QUAIL (DRY)	3.7	2	0.35		N/A	N/A	N/A
	FISH (ASH)	3.7	1	5.6		N/A	N/A	N/A
	FISH (DRY)	3.7	2	1.2		N/A	N/A	N/A
	BEEF (MUSCLE)	3.7	2	0.56		N/A	N/A	N/A
	BEEF (BONE)	3.7	2	0.19		N/A	N/A	N/A

Table 7-1

(Continued)

Radio-nuclide	Sample Type	MDL	n	Mean		s.e.	s	c.v.
^{237}Np	RABBIT (ASH)	3.7	1	-0.67		N/A	N/A	N/A
	RABBIT (DRY)	3.7	2	0.00		N/A	N/A	N/A
	QUAIL (ASH)	3.7	1	-0.14		N/A	N/A	N/A
	QUAIL (DRY)	3.7	2	-0.020		N/A	N/A	N/A
	FISH (ASH)	3.7	1	0.44		N/A	N/A	N/A
	FISH (DRY)	3.7	2	-0.091		N/A	N/A	N/A
	BEEF (MUSCLE)	3.7	2	0.21		N/A	N/A	N/A
	BEEF (BONE)	3.7	2	2.9		N/A	N/A	N/A
^{238}Pu	VEGETATION (ASH)	15	6	0.0	+/-	0.7	1.8	---
	RABBIT (ASH)	15	1	1.3		N/A	N/A	N/A
	RABBIT (DRY)	15	2	0.49		N/A	N/A	N/A
	QUAIL (DRY)	15	2	1.1		N/A	N/A	N/A
	FISH (ASH)	15	1	-3.6		N/A	N/A	N/A
	FISH (DRY)	15	2	0.91		N/A	N/A	N/A
	BEEF (MUSCLE)	15	2	-1.7		N/A	N/A	N/A
	BEEF (BONE)	15	2	-0.52		N/A	N/A	N/A
$^{239/240}Pu$	VEGETATION (ASH)	7.4	6	0.37	+/-	0.15	0.36	0.96
	RABBIT (ASH)	7.4	1	0.63		N/A	N/A	N/A
	RABBIT (DRY)	7.4	2	-0.20		N/A	N/A	N/A
	QUAIL (DRY)	7.4	2	0.35		N/A	N/A	N/A
	FISH (ASH)	7.4	1	-0.56		N/A	N/A	N/A
	FISH (DRY)	7.4	2	0.13		N/A	N/A	N/A
	BEEF (MUSCLE)	7.4	2	-0.059		N/A	N/A	N/A
	BEEF (BONE)	7.4	2	0.11		N/A	N/A	N/A
^{241}Pu	VEGETATION (ASH)	370	6	370	+/-	130	300	0.81
	RABBIT (ASH)	370	1	320		N/A	N/A	N/A
	RABBIT (DRY)	370	2	400		N/A	N/A	N/A
	QUAIL (DRY)	370	2	350		N/A	N/A	N/A
	FISH (ASH)	370	1	1700		N/A	N/A	N/A
	FISH (DRY)	370	2	510		N/A	N/A	N/A
	BEEF (MUSCLE)	370	2	-1300		N/A	N/A	N/A
	BEEF (BONE)	370	2	350		N/A	N/A	N/A

Abbreviations:
- MDL - Minimum Detection Limit
- n - Sample size
- s.e. - Standard error
- s - Standard deviation
- c.v. - Coefficient of variation
- N/A - Not Applicable

ASH and DRY indicates whether the analysis was performed on ashed tissue or dried tissue, respectively.
Beef muscle and bone samples are analyzed as dried tissue.

Units are in Becquerels per gram of ash or dried tissue x 10^{-3}

8.0 Summary

The WIPP RBP was designed to provide preoperational measurements of radioactivity in environmental samples that will serve as a basis for evaluating similar data collected during the WIPP operational period in order for the safe performance of the facility to be determined. The RBP data analyzed in this report cover the period from 1985 through 1989. These data include radionuclide concentrations in airborne particulates, soil, surface water, groundwater, sediments, and six types of biotic tissue samples.

Gross beta and alpha activities were also measured in weekly airborne particulate samples. The Chernobyl accident resulted in significant increases in gross beta counts on these samples for a three-week period, although no long-term effect was detected. The Chernobyl accident did not affect the alpha counts. Gross beta activity, gross alpha activity, and ^{230}Th all differed significantly with season (quarter). In general, radioactivity on these samples was higher over a regional transect than at the WIPP Site itself.

Soil samples were collected at three depths. No differences between depth were found. The data were stratified to represent three regional scales about the WIPP Site. Isotopes of uranium, thorium, radium, cesium, and potassium were all found to vary with regional scale, with the mean concentrations increasing with area covered. Transuranics were below the detection limits.

In surface waters, Laguna Grande de la Sal exhibited relatively high concentrations of ^{40}K, ^{234}U, and ^{238}U. The Pecos River had detectable levels of ^{234}U and ^{238}U, although the sediments in stock tanks were higher in ^{40}K, ^{137}Cs, ^{226}Ra, ^{228}Ra, and ^{238}Th than the Pecos River sediments. ^{226}Ra was found to form an east-west gradient in concentration in groundwater samples collected from the Culebra dolomite unit.

Most radionuclides were below the detection limits in biotic tissues. Vegetation samples showed detectable levels of ^{7}Be, ^{40}K, ^{137}Cs, ^{226}Ra, ^{228}Ra, ^{228}Th, and ^{241}Pu. The latter, however, exhibits wide ranges in measured values resulting from low precision in its measurement on tissue samples. Animal tissues showed detectable levels of ^{40}K. Beef bone samples exhibited detectable levels of ^{230}Th and ^{232}Th. Catfish exhibited ^{234}U in ashed samples.

The normal and two- or three-parameter lognormal distributions were found to provide good models for most data bases. Critical values at the 0.80, 0.90, 0.95, and 0.99 probability levels were estimated for each data base. These values are appropriate for establishing warning and action levels for control charts during the operational environmental monitoring program.

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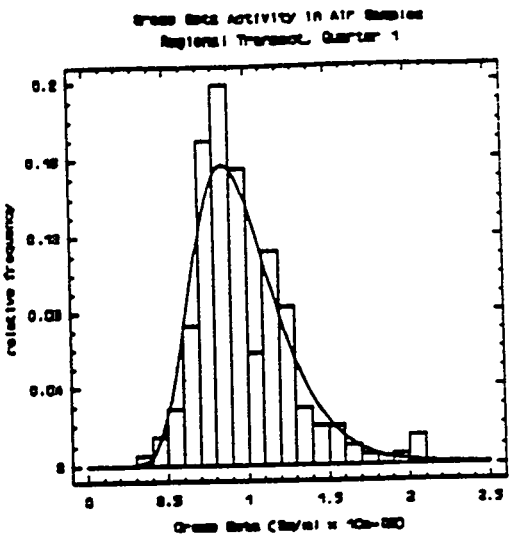
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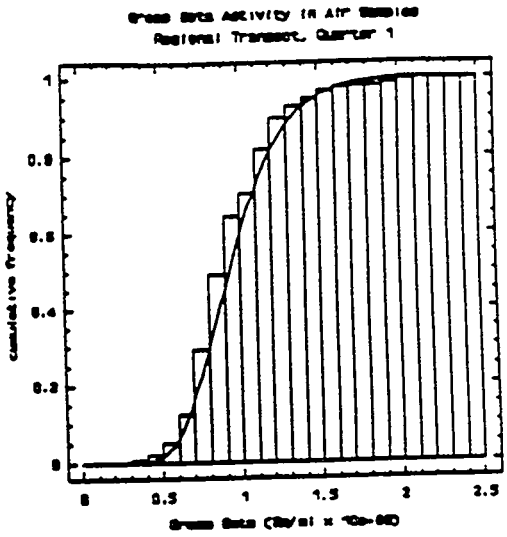
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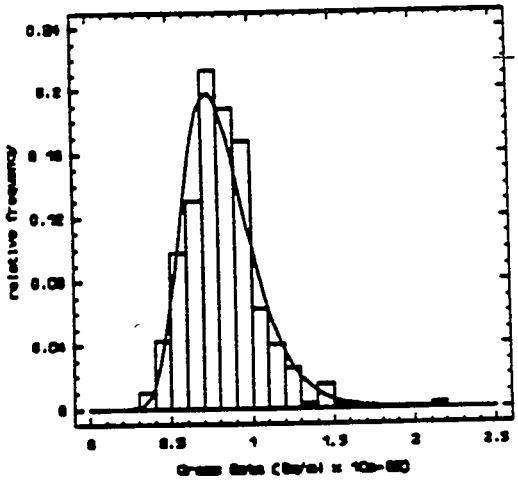
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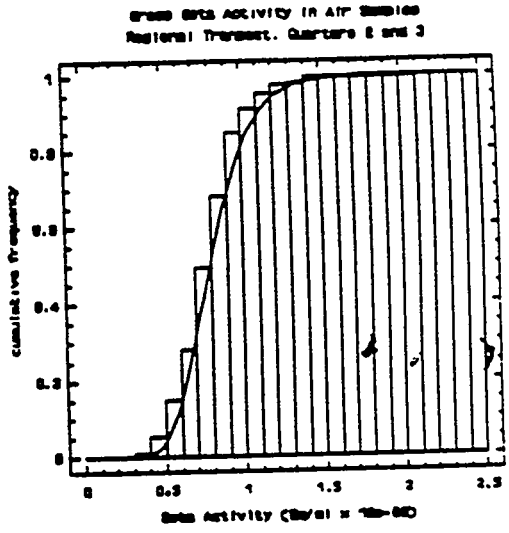
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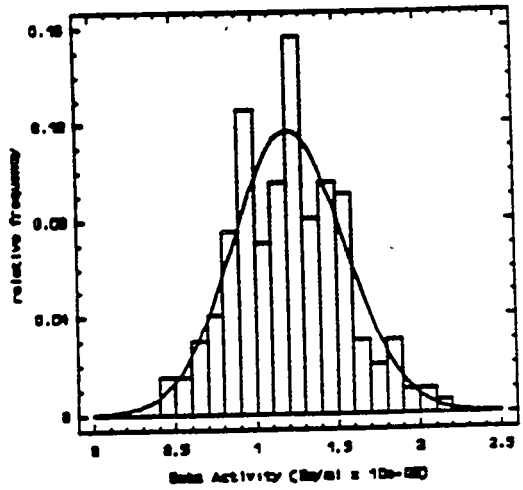
APPENDIX
DATA HISTOGRAMS AND PROBABILITY DISTRIBUTION MODELS

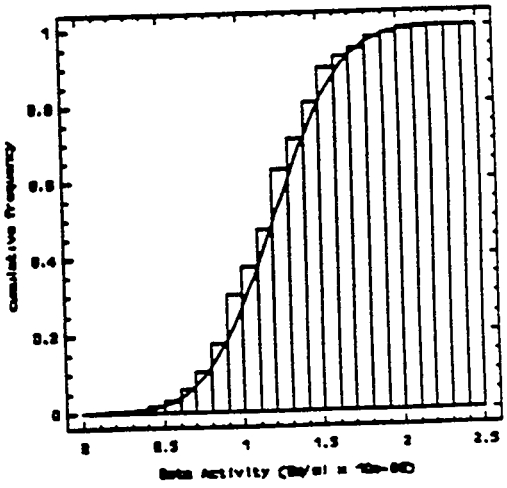

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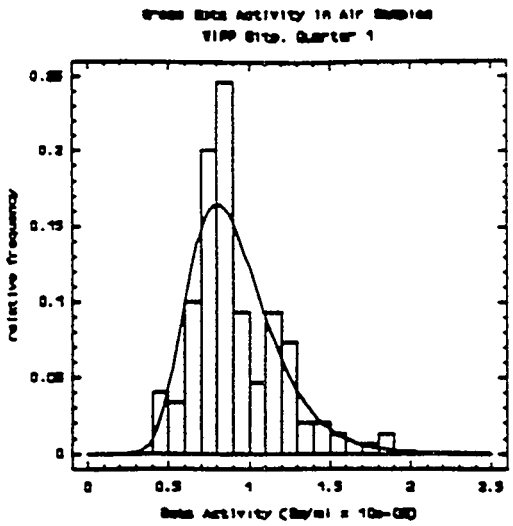

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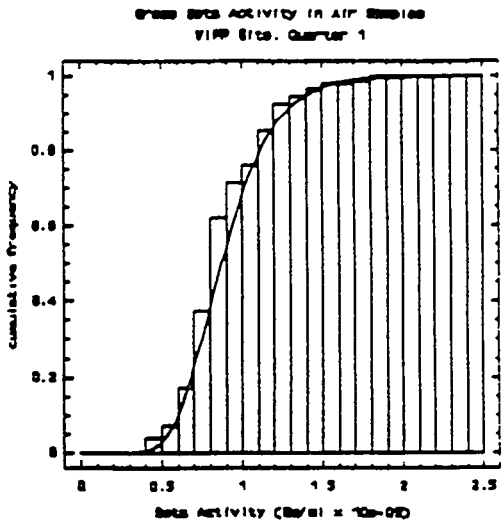

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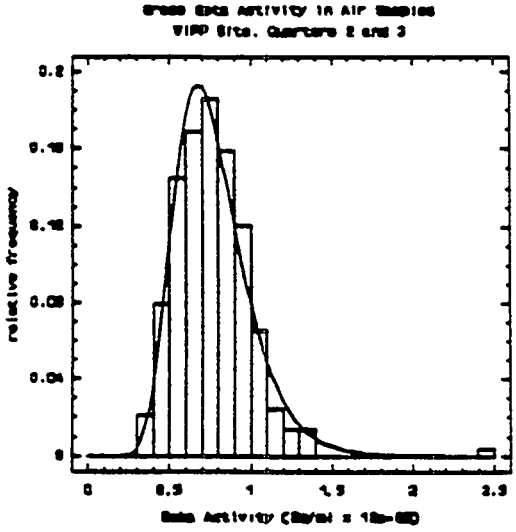

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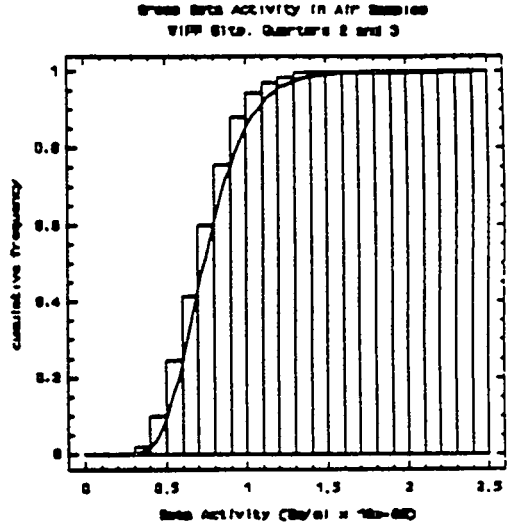

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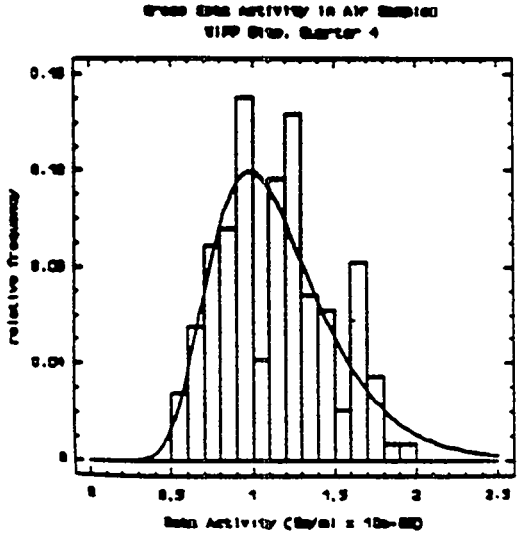

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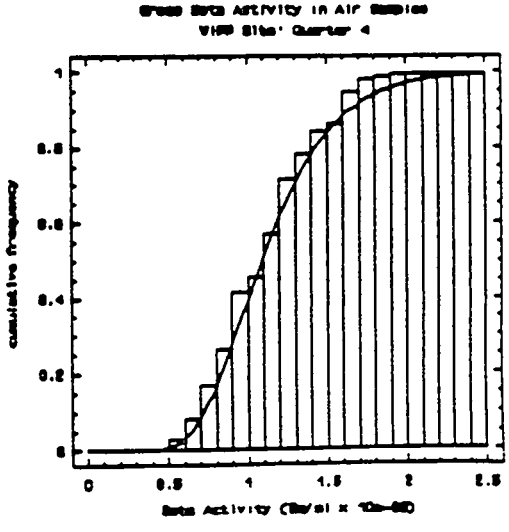

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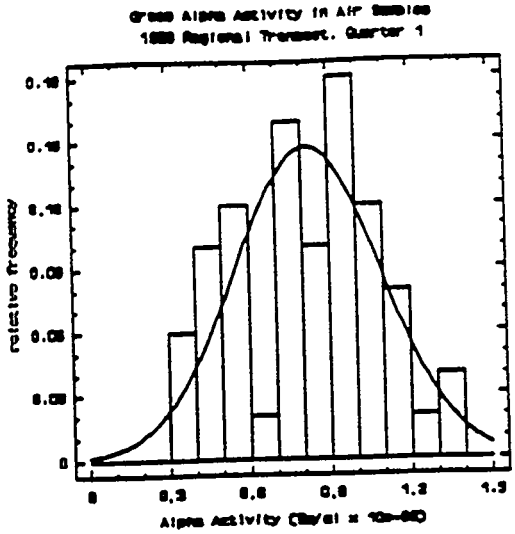

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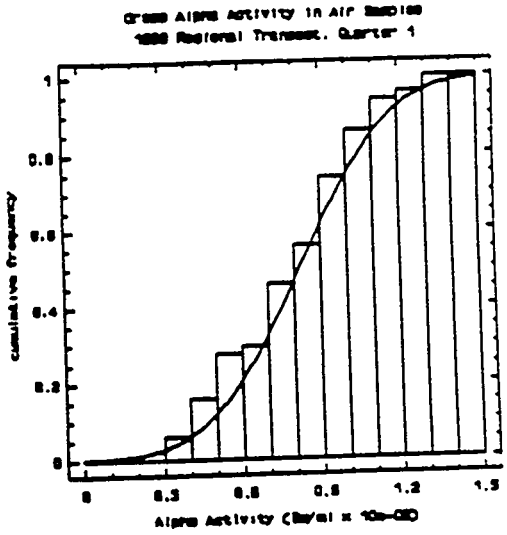

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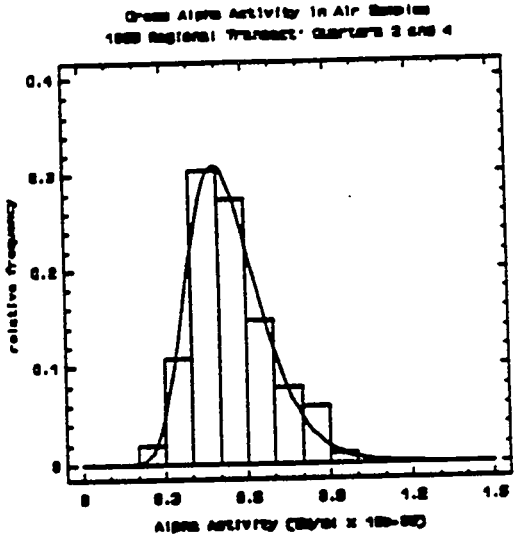

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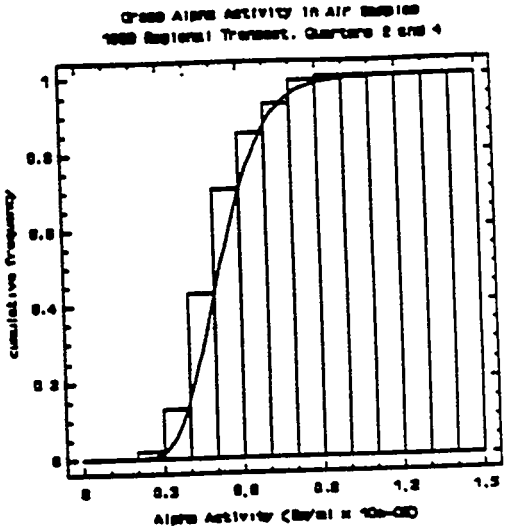

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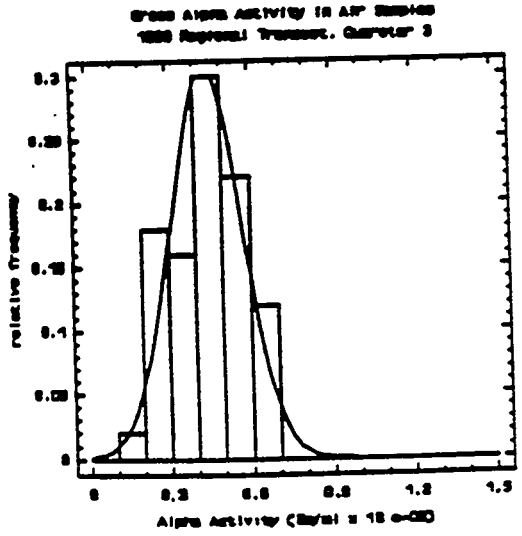

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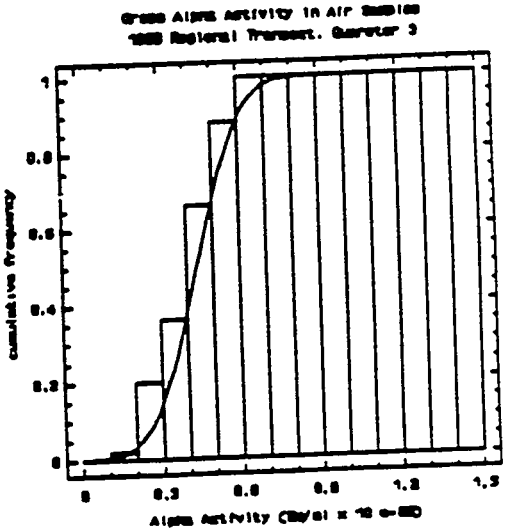

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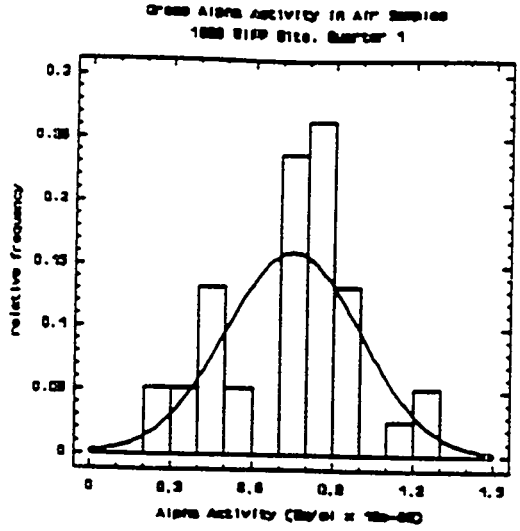

cumulative frequency
Alpha Activity (Bq/ml x 10e-06)

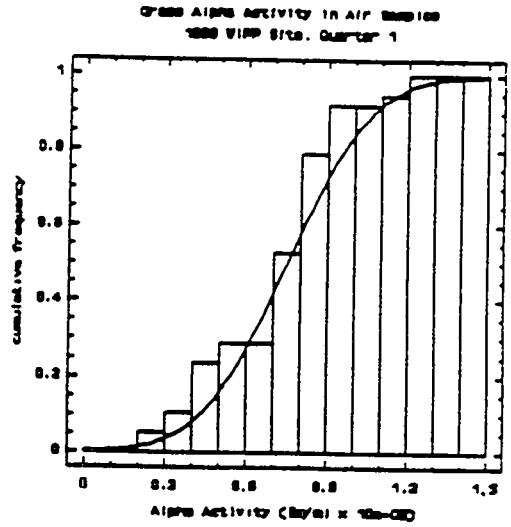

relative frequency

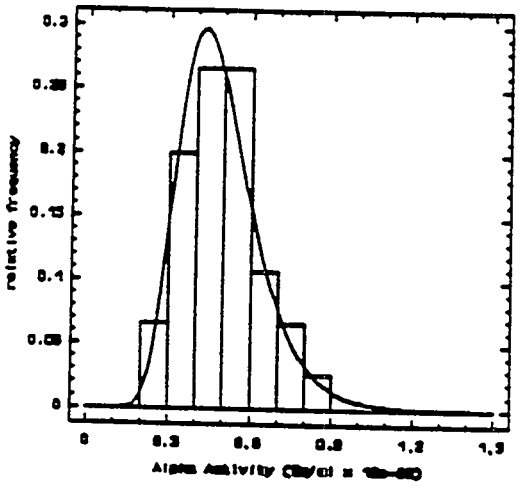

cumulative frequency
Alpha Activity (Bq/ml x 10e-06)

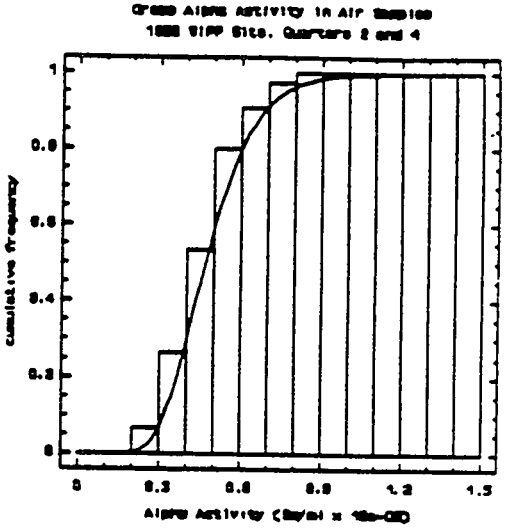

relative frequency
Alpha Activity (Bq/ml x 10 e-06)

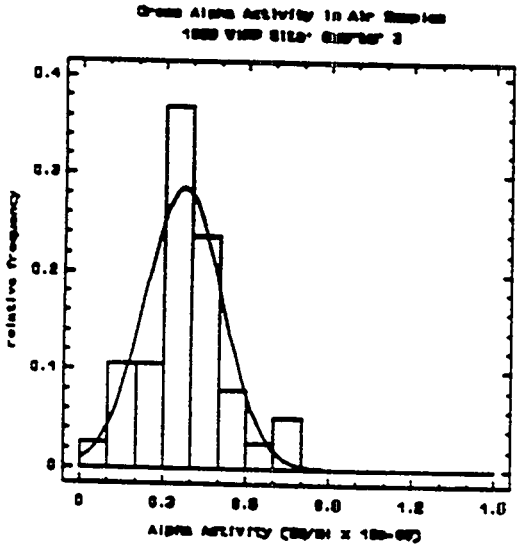

cumulative frequency

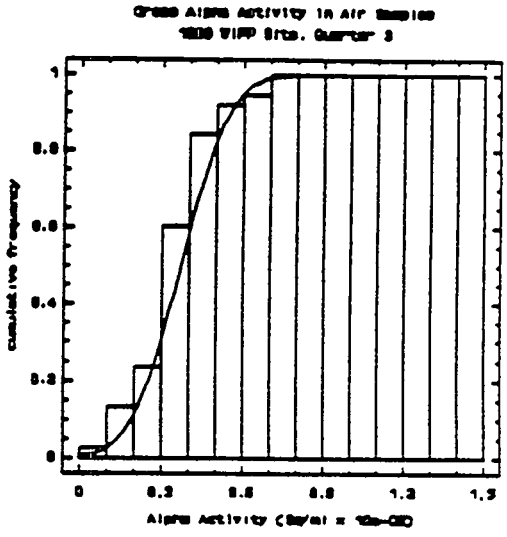

relative frequency
0.3
0.2
0.1
0
0
0.3
0.6
0.9
1.2
1.5

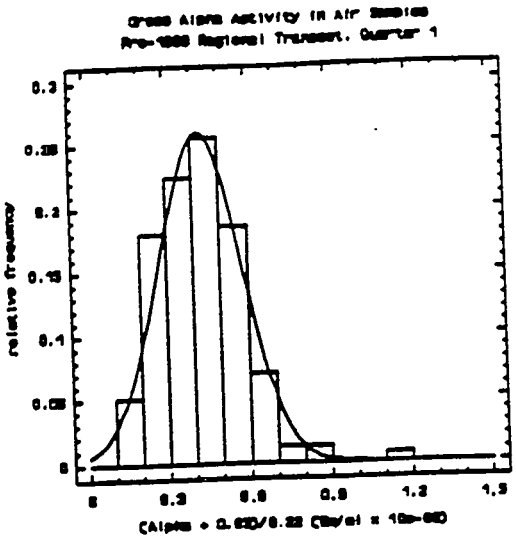

cumulative frequency
1
0.8
0.6
0.4
0.2
0
0
0.3
0.6
0.9
1.2
1.5

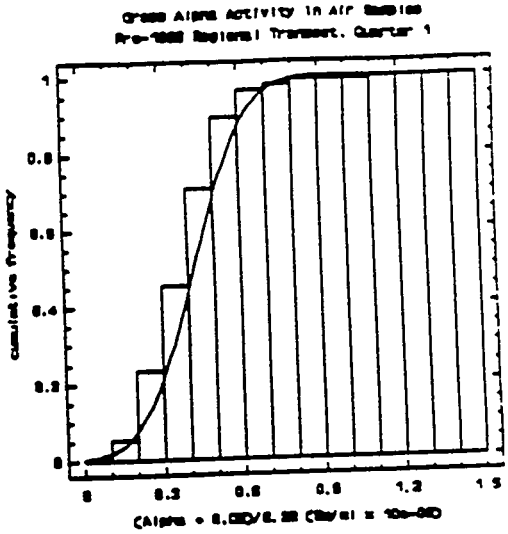

relative frequency
0.3
0.2
0.1
0
0
0.3
0.6
0.9
1.2
1.5

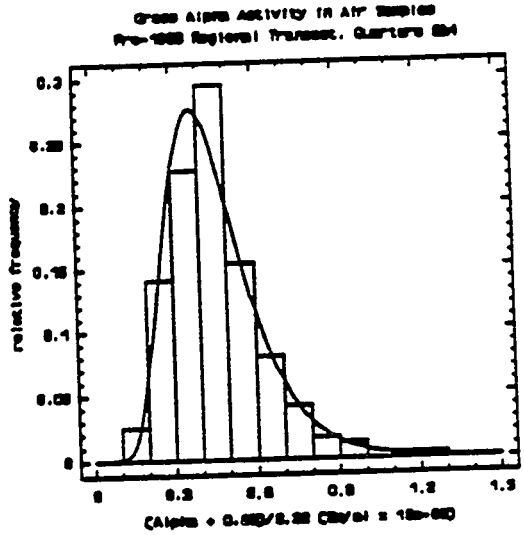

cumulative frequency
1
0.8
0.6
0.4
0.2
0
0
0.3
0.6
0.9
1.2
1.5

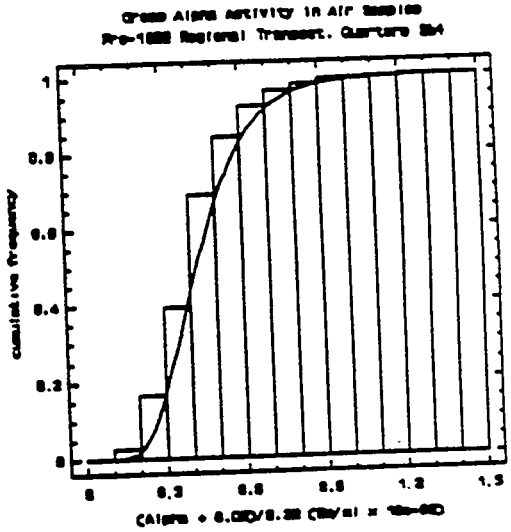

relative frequency
0.4
0.3
0.2
0.1
0
0
0.3
0.6
0.9
1.2
1.5

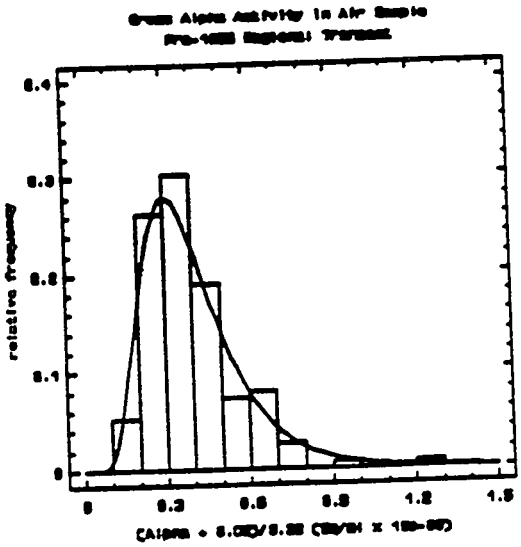

cumulative frequency
1
0.8
0.6
0.4
0.2
0
0
0.3
0.6
0.9
1.2
1.5

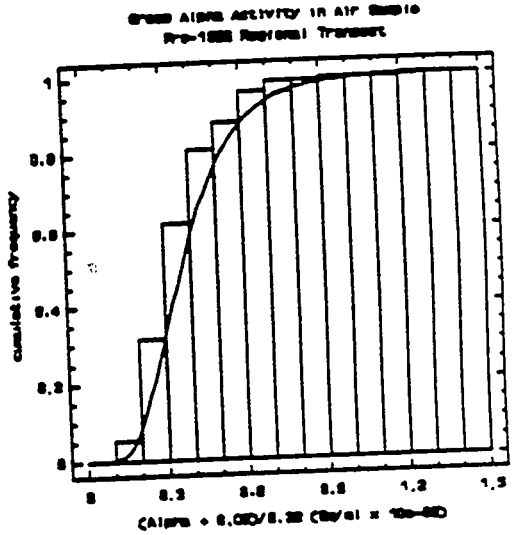

relative frequency

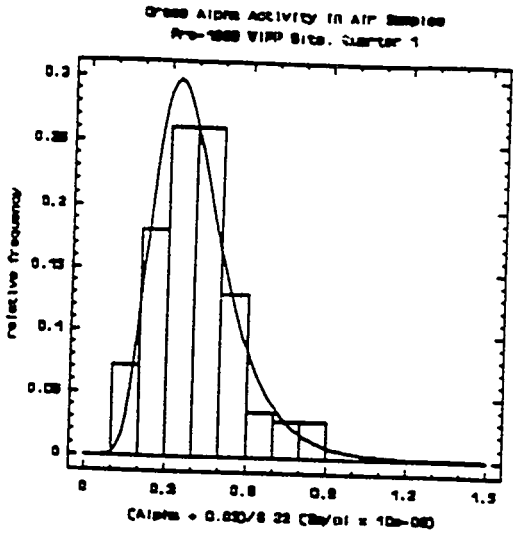

cumulative frequency

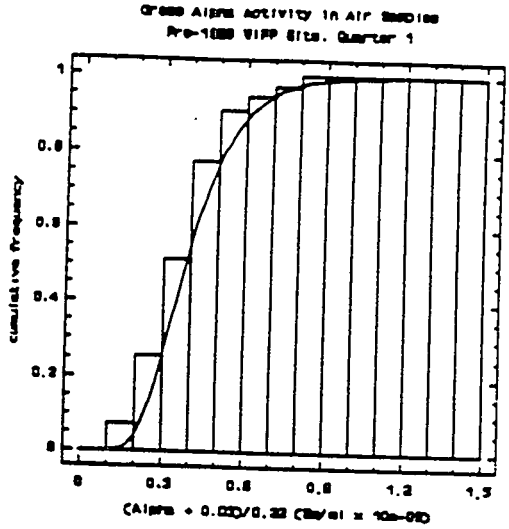

relative frequency

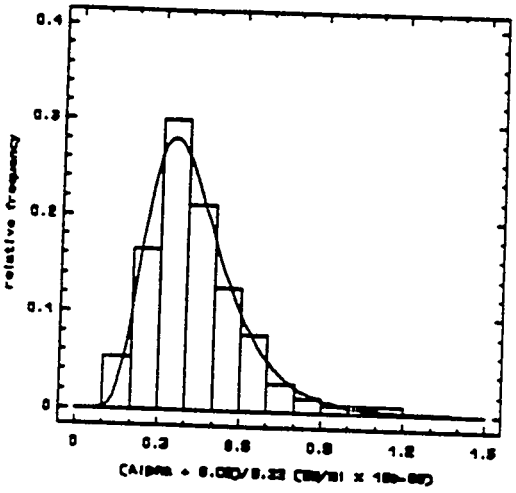

cumulative frequency

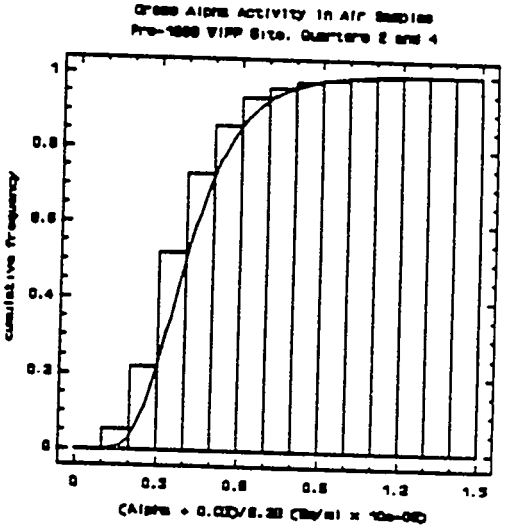

relative frequency

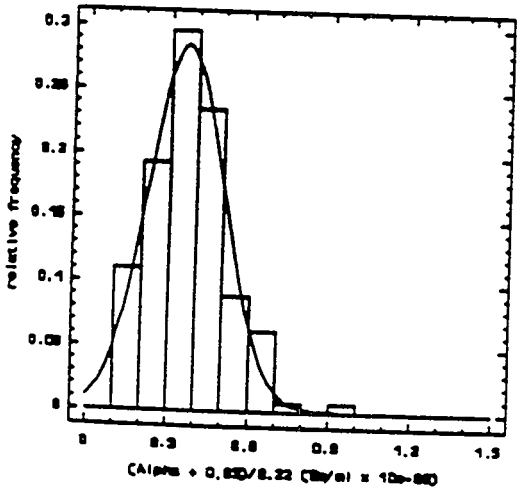

cumulative frequency

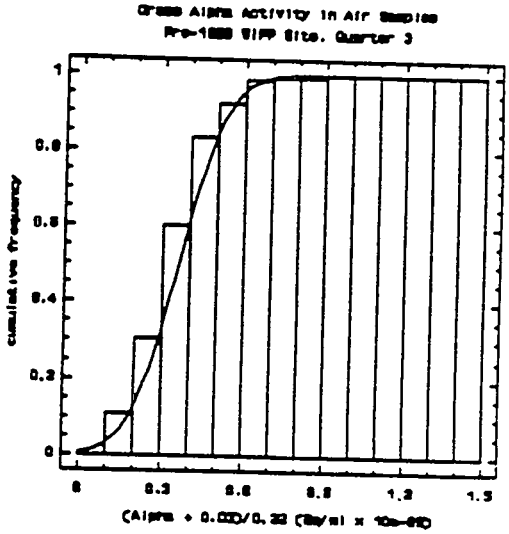

relative frequency

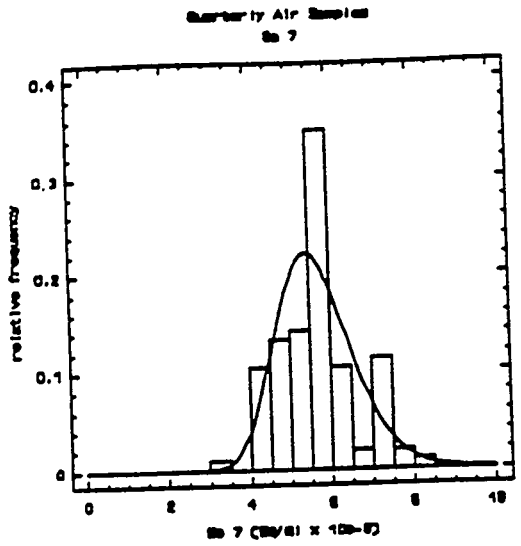

cumulative frequency

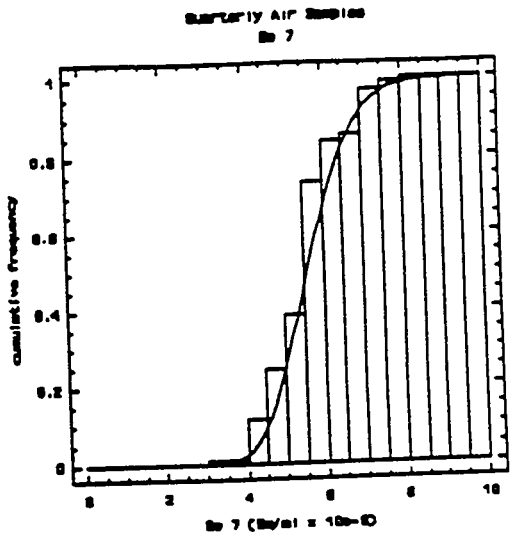

relative frequency

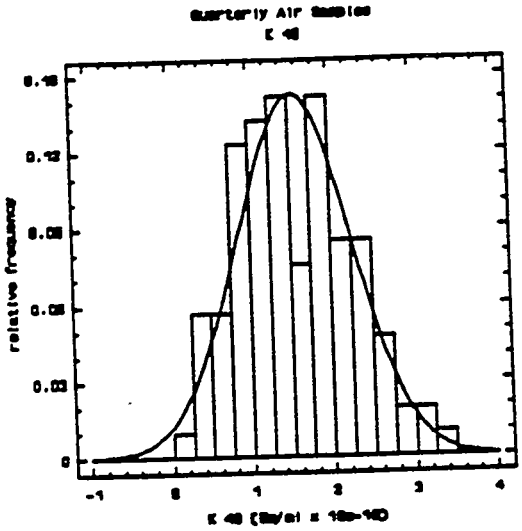

cumulative frequency

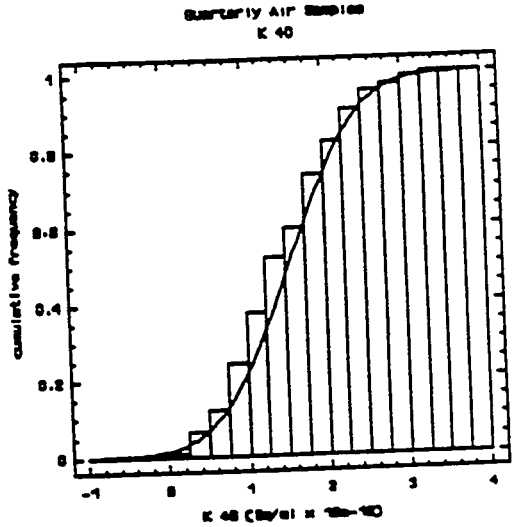

relative frequency

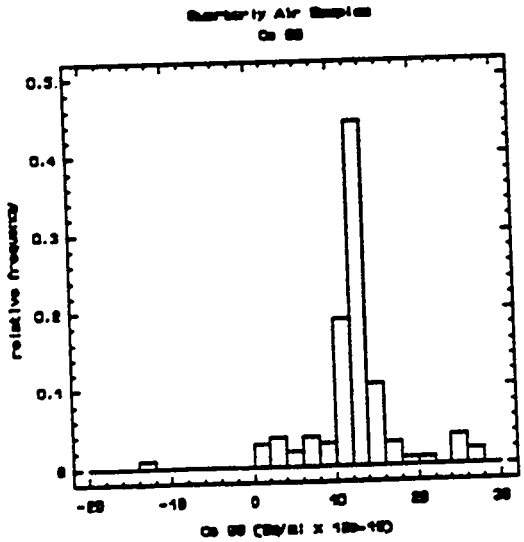

cumulative frequency

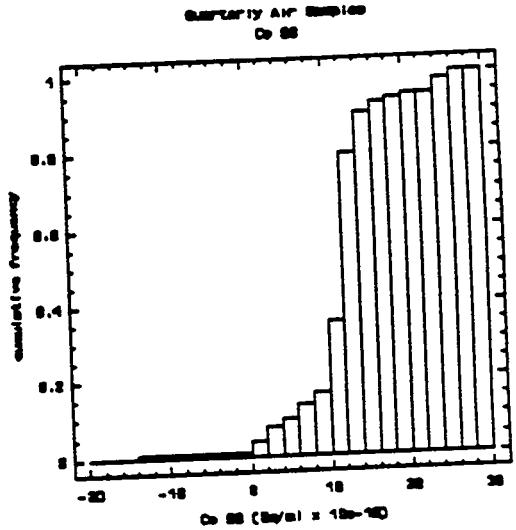

Quarterly Air Samples
Be 7
relative frequency
Be 7 (Bq/ml x 10e-9)

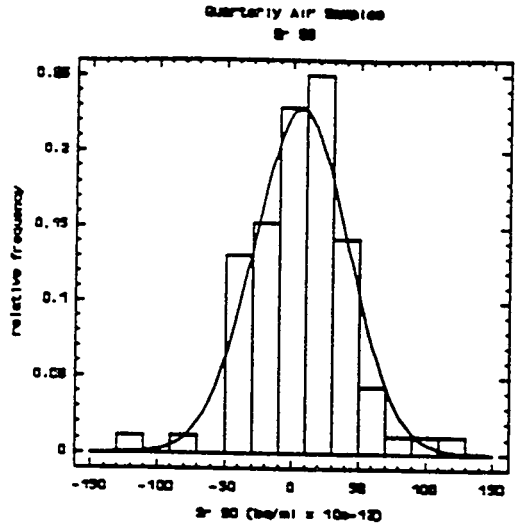

Quarterly Air Samples
Be 7
cumulative frequency
Be 7 (Bq/ml x 10e-9)

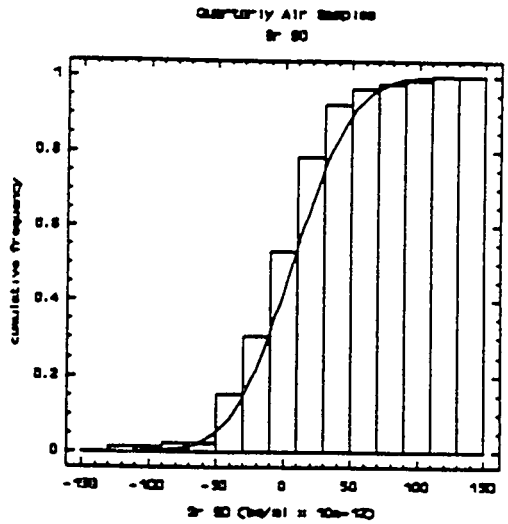

Quarterly Air Samples
K 40
relative frequency
K 40 (Bq/ml x 10e-10)

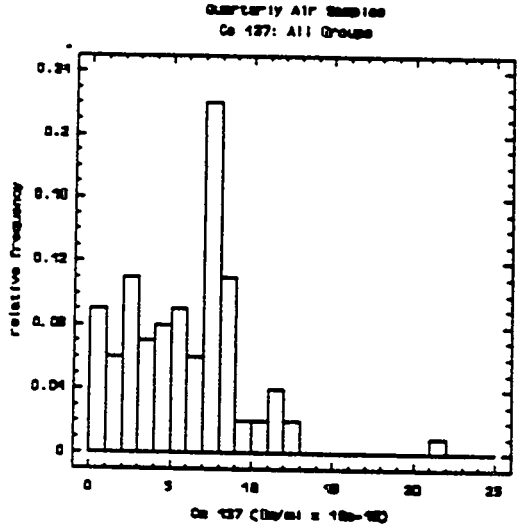

Quarterly Air Samples
K 40
cumulative frequency
K 40 (Bq/ml x 10e-10)

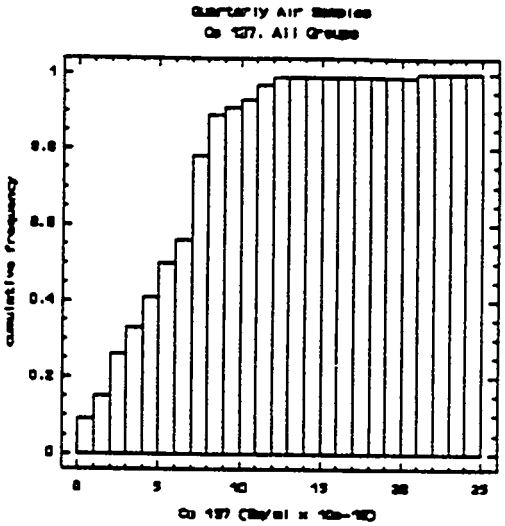

Quarterly Air Samples
Co 60
relative frequency
Co 60 (Bq/ml x 10e-10)

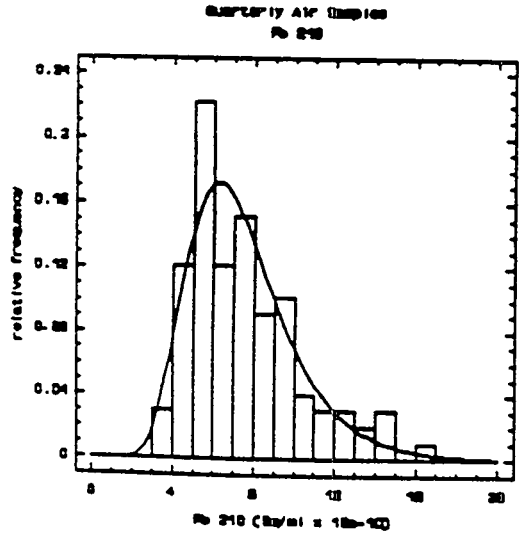

Quarterly Air Samples
Co 60
cumulative frequency
Co 60 (Bq/ml x 10e-10)

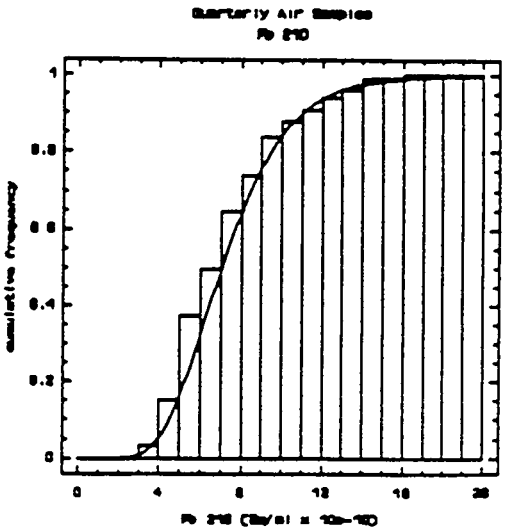

relative frequency

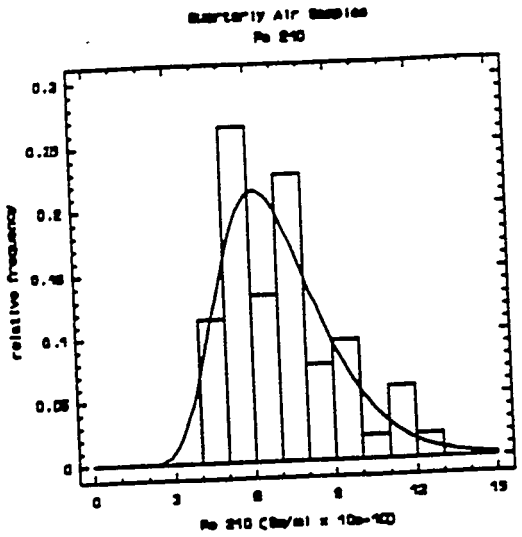

cumulative frequency

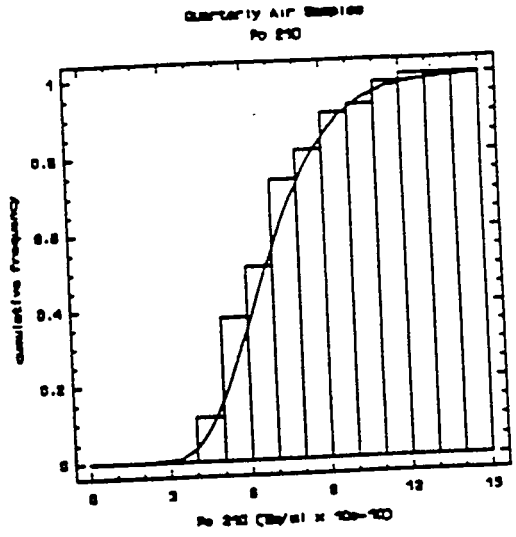

relative frequency

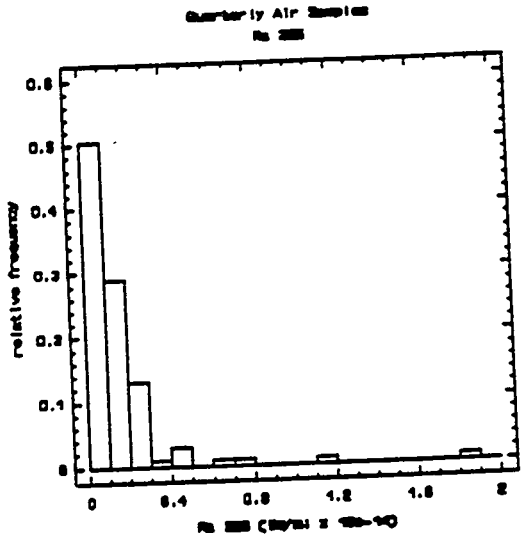

cumulative frequency

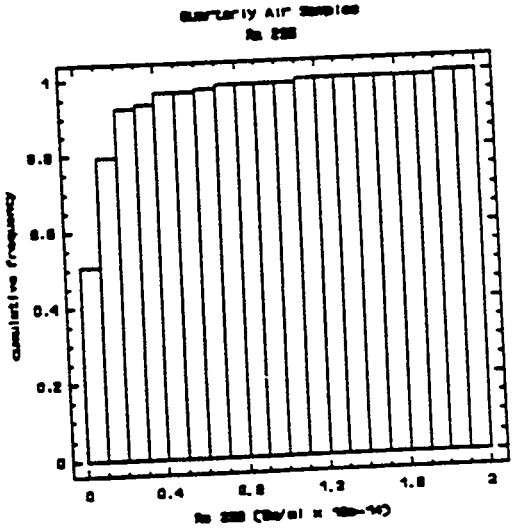

relative frequency

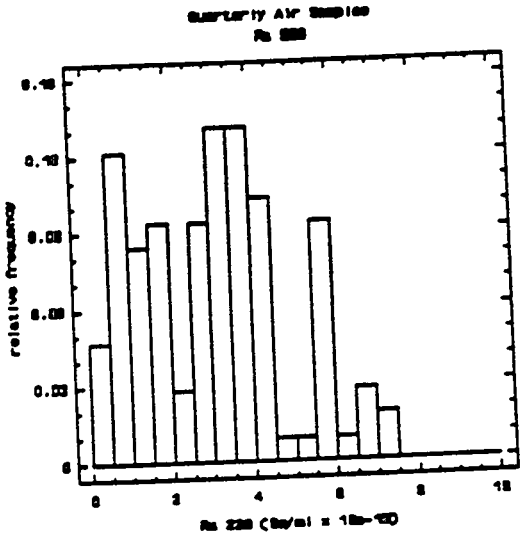

cumulative frequency

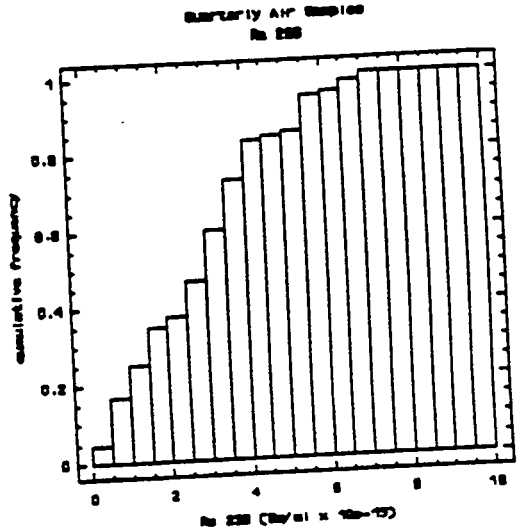

Quarterly Air Samples
Pb 210
relative frequency
Pb 210 (Bq/ml x 10e-10)

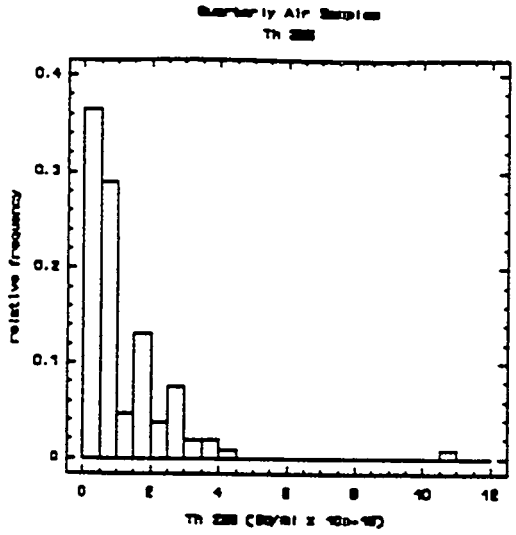

Quarterly Air Samples
Pb 210
cumulative frequency
Pb 210 (Bq/ml x 10e-10)

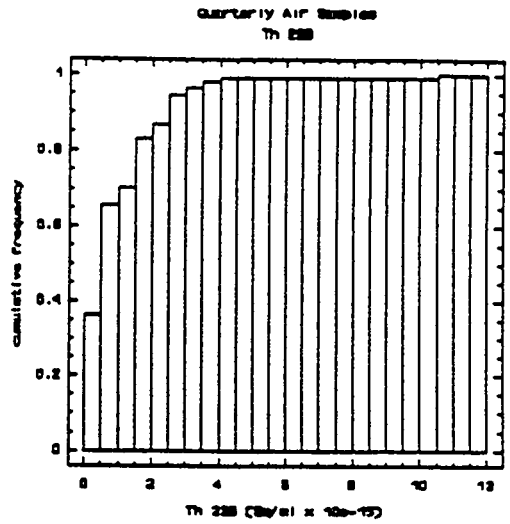

Quarterly Air Samples
relative frequency

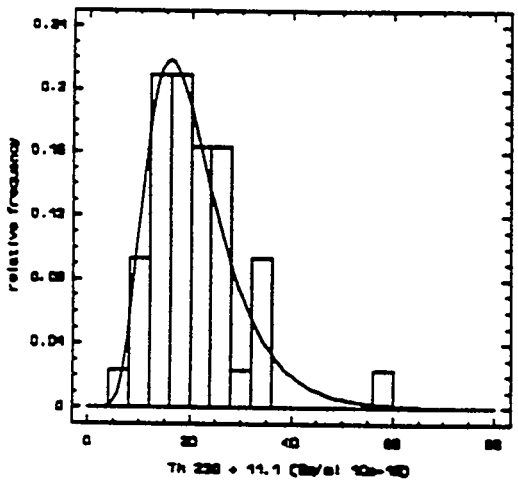

Quarterly Air Samples
cumulative frequency

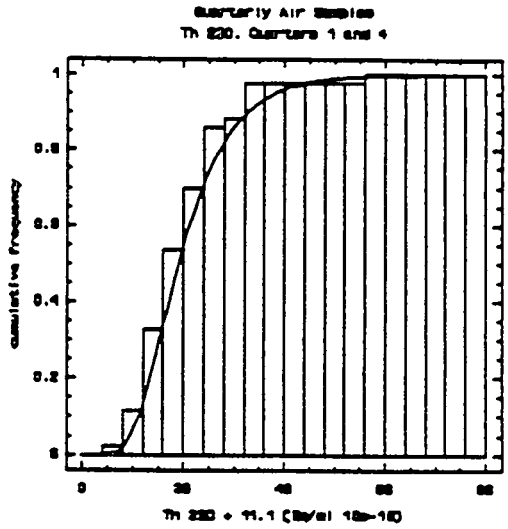

Quarterly Air Samples
relative frequency

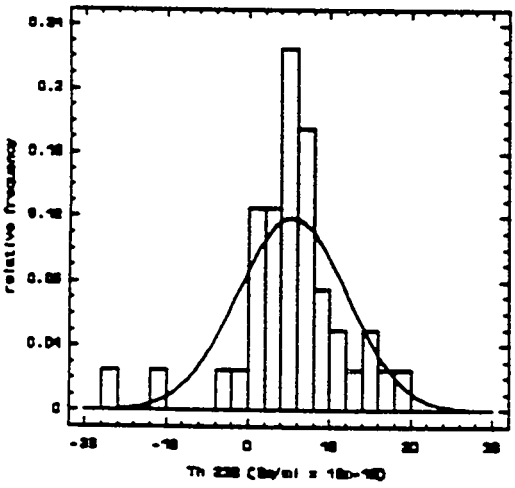

Quarterly Air Samples
cumulative frequency

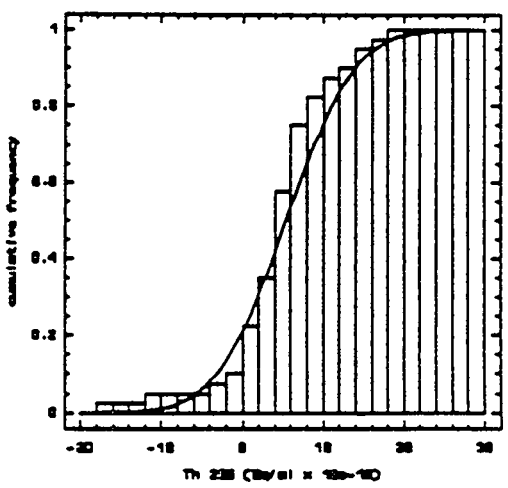

relative frequency

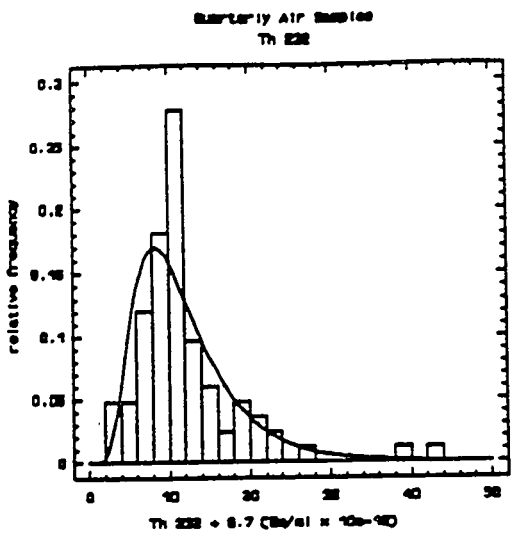

cumulative frequency

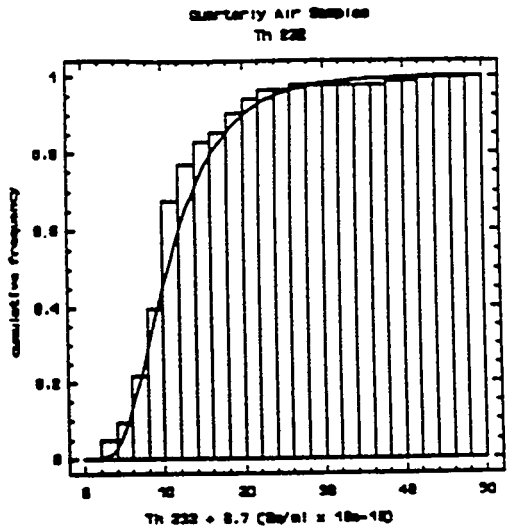

relative frequency

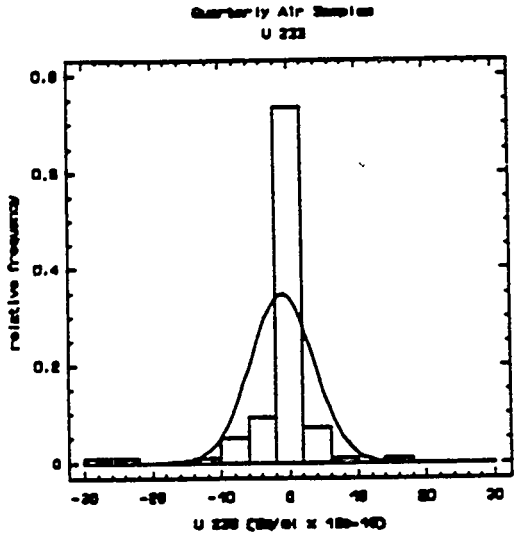

cumulative frequency

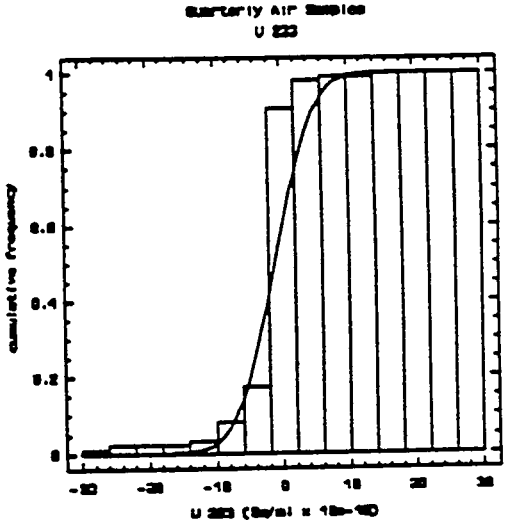

relative frequency

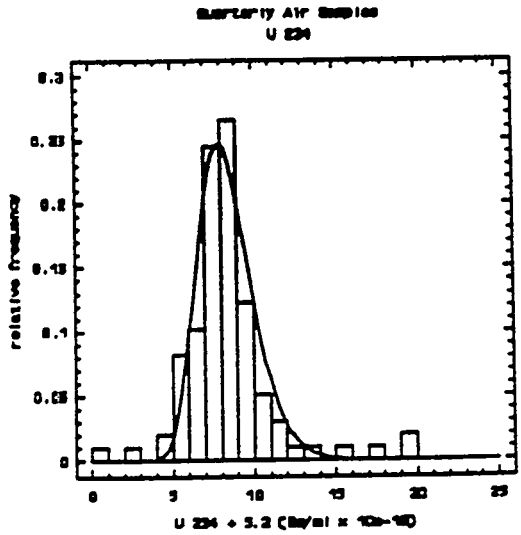

cumulative frequency

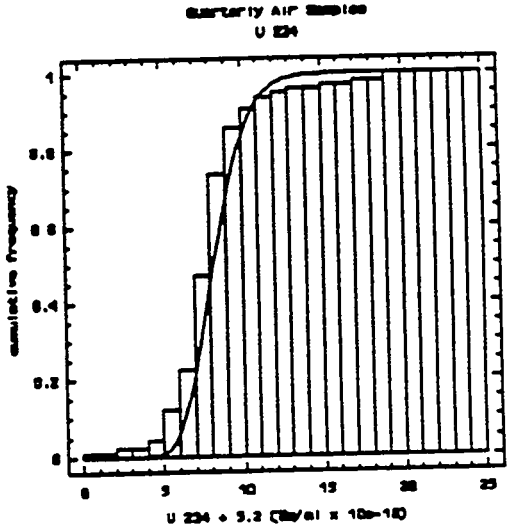

Quarterly Air Samples
Th 232
relative frequency
Th 232 + 8.7 (Bq/ml x 10e-10)

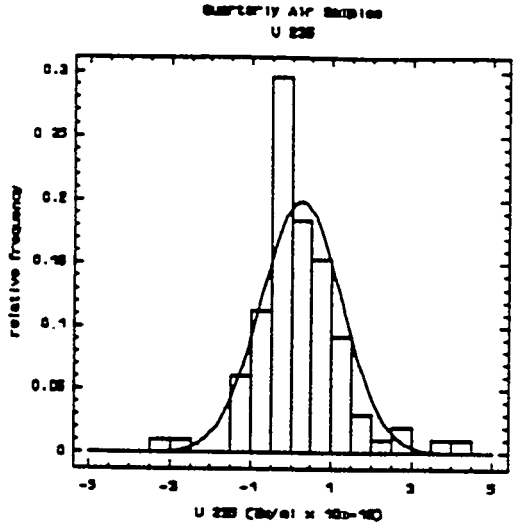

Quarterly Air Samples
Th 232
cumulative frequency
Th 232 + 8.7 (Bq/ml x 10e-10)

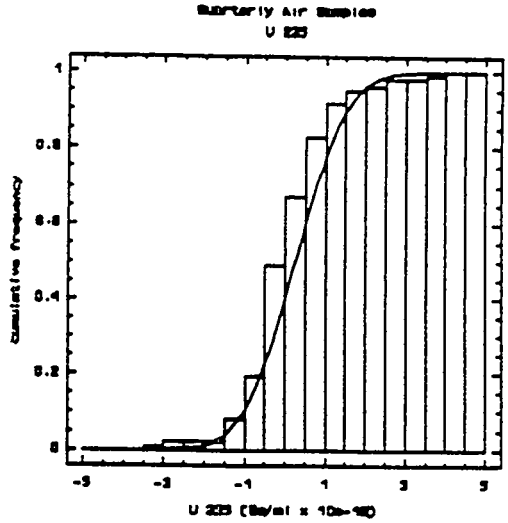

Quarterly Air Samples
U 233
relative frequency
U 233 (Bq/ml x 10e-10)

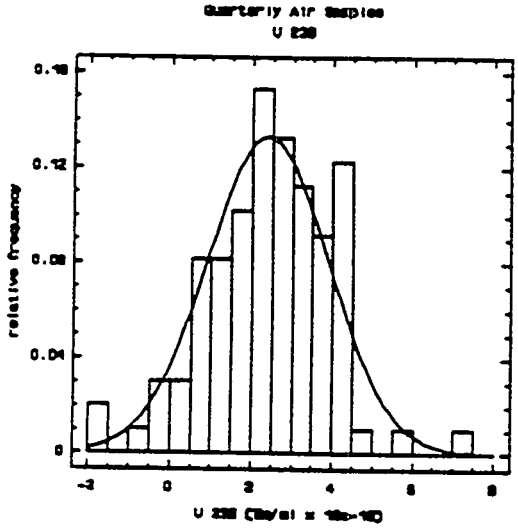

Quarterly Air Samples
U 233
cumulative frequency
U 233 (Bq/ml x 10e-10)

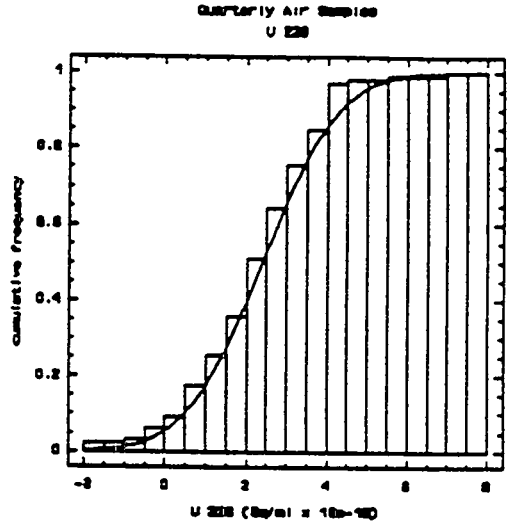

Quarterly Air Samples
U 234
relative frequency
U 234 + 5.2 (Bq/ml x 10e-10)

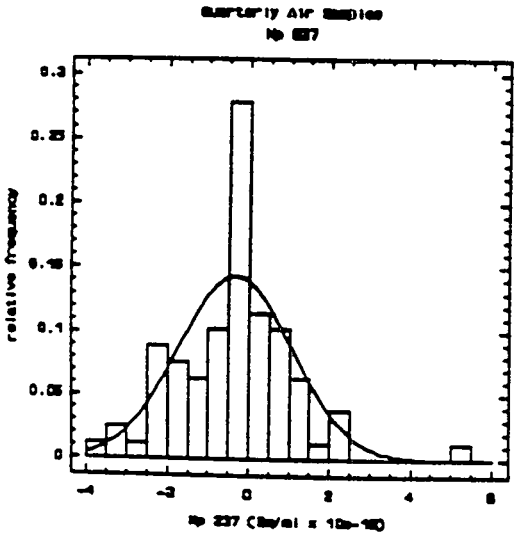

Quarterly Air Samples
U 234
cumulative frequency
U 234 + 5.2 (Bq/ml x 10e-10)

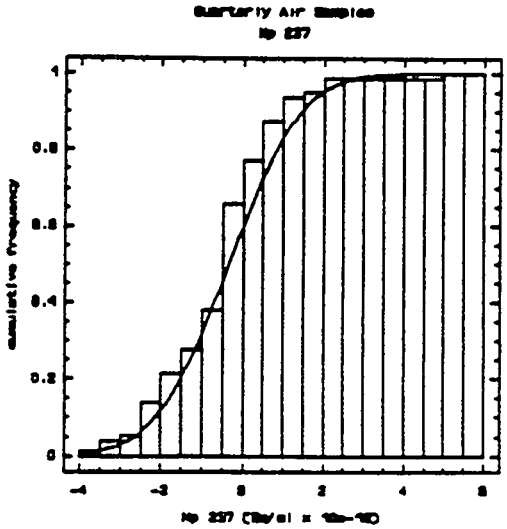

Quarterly Air Samples
U 238
relative frequency

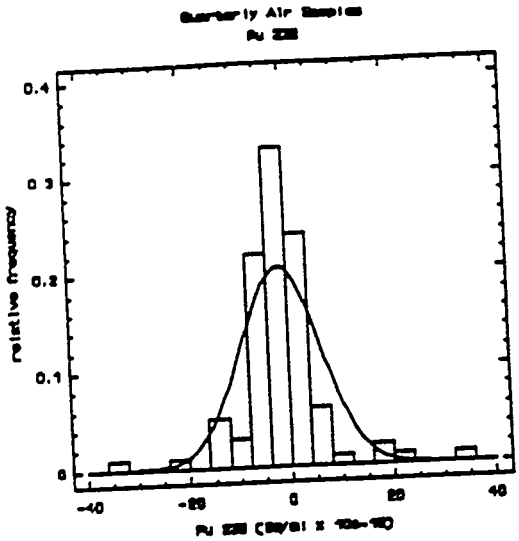

Quarterly Air Samples
U 235
cumulative frequency

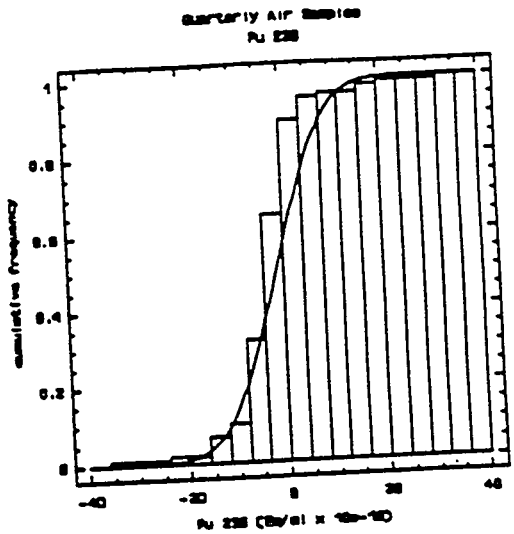

Quarterly Air Samples
U 238
relative frequency

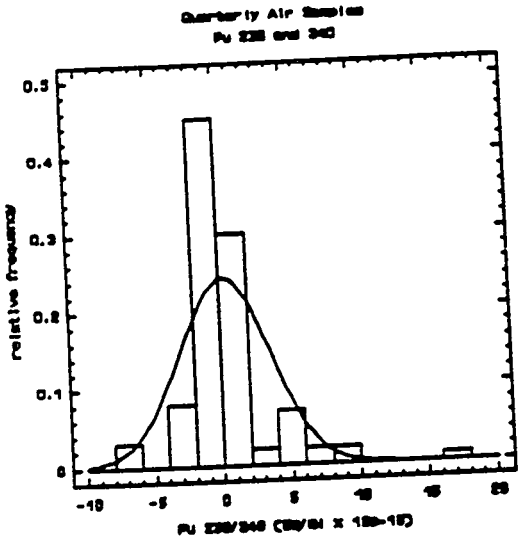

Quarterly Air Samples
U 238
cumulative frequency

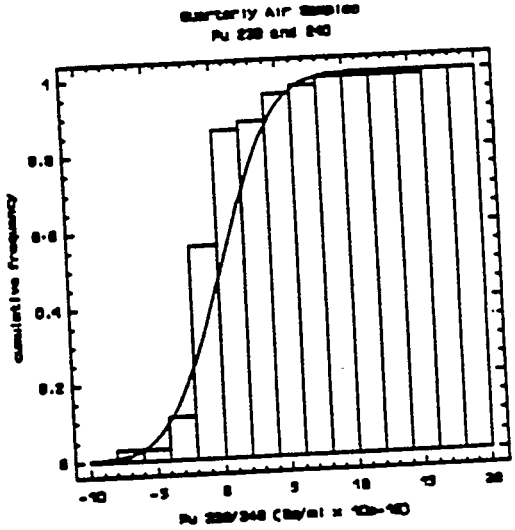

Quarterly Air Samples
Np 237
relative frequency

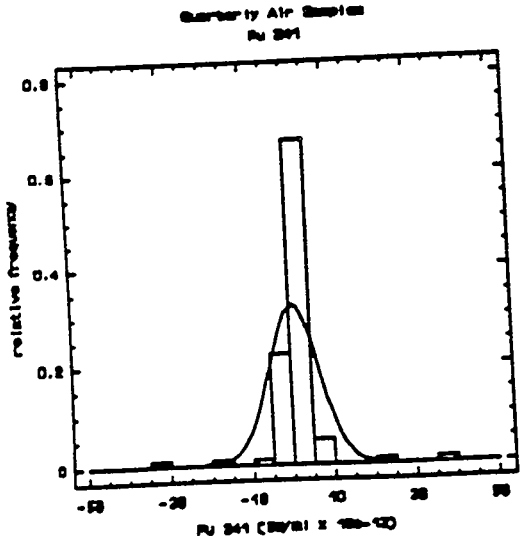

Quarterly Air Samples
Np 237
cumulative frequency

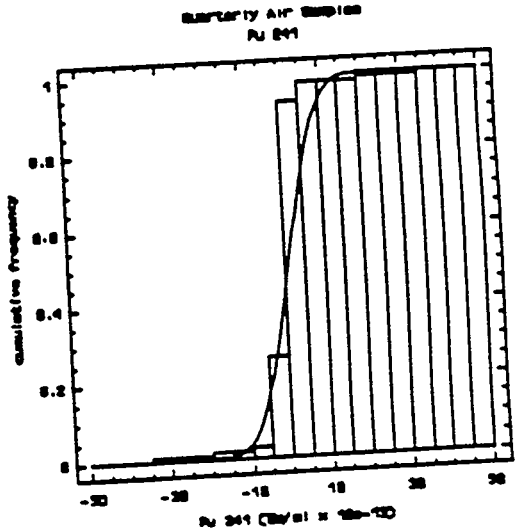

relative frequency

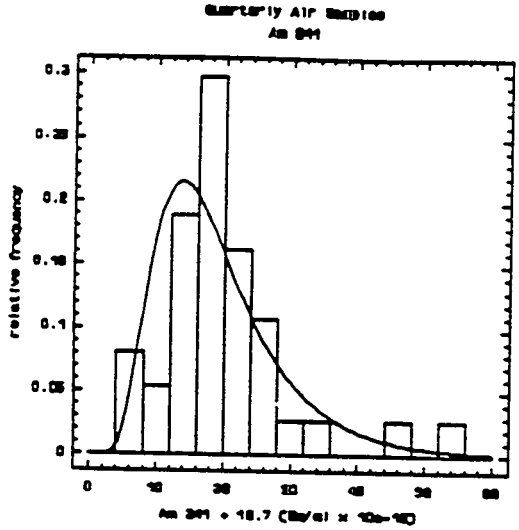

cumulative frequency

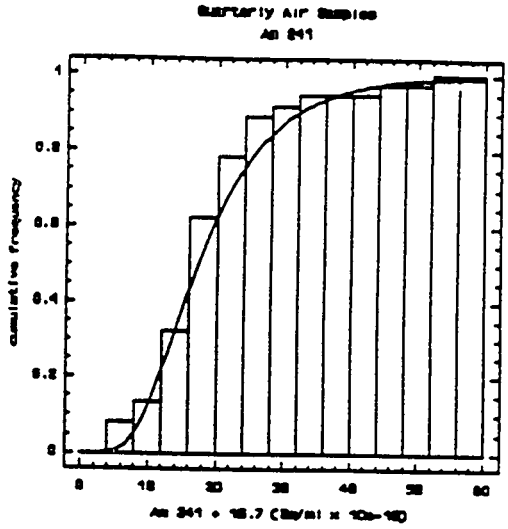

relative frequency

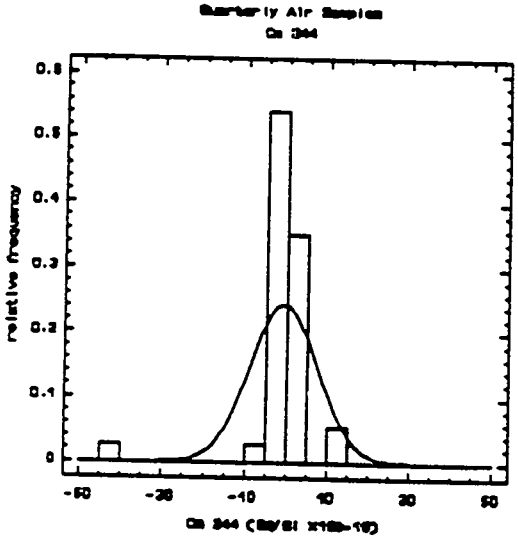

cumulative frequency

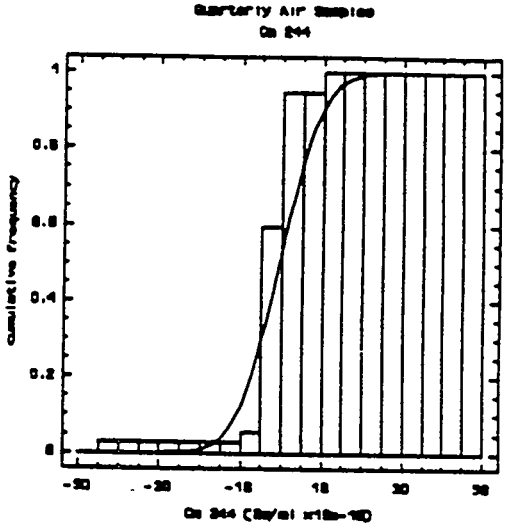

relative frequency

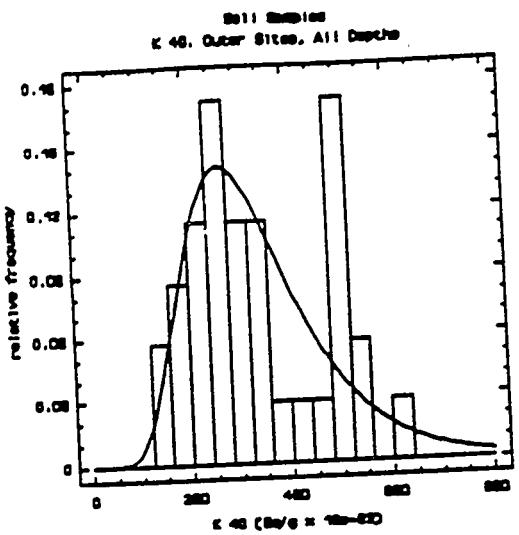

cumulative frequency

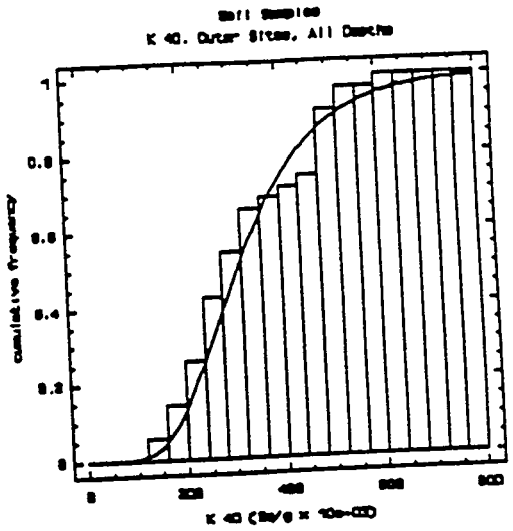

relative frequency

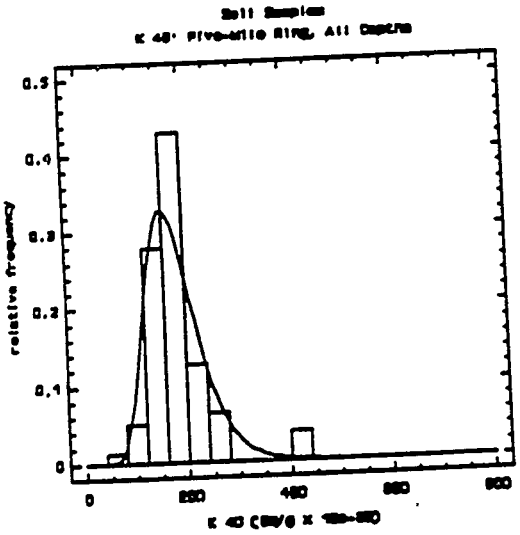

cumulative frequency

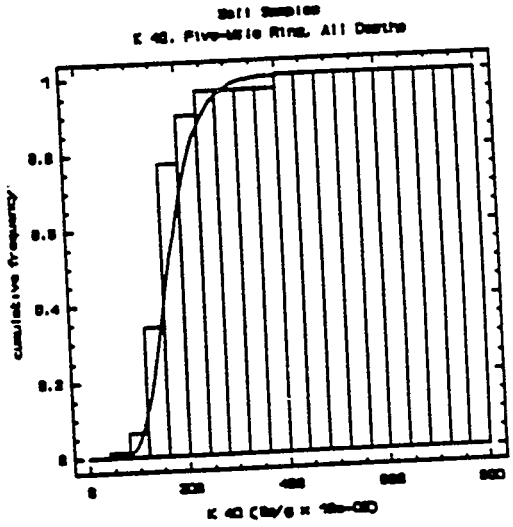

relative frequency

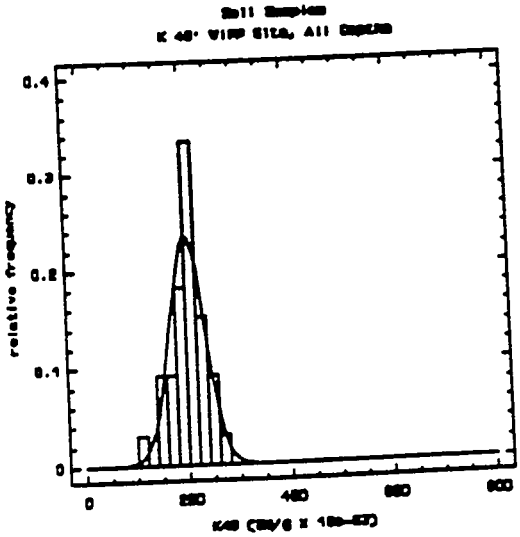

cumulative frequency

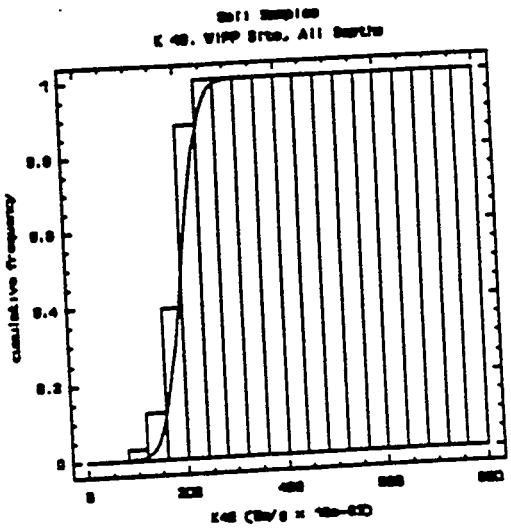

Soil Samples
K 40, Outer Sites, All Depths
relative frequency
K 40 (Bq/g x 10e-03)

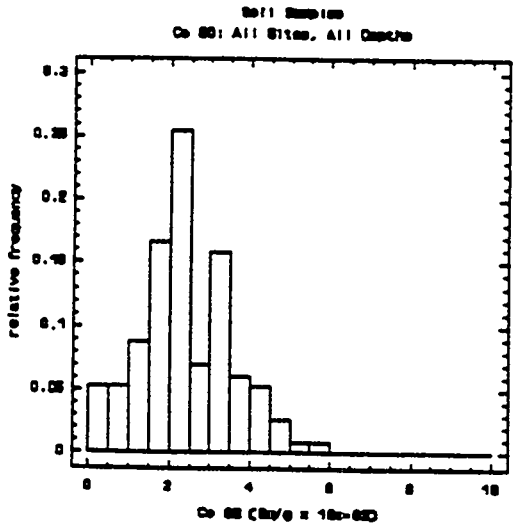

Soil Samples
K 40, Outer Sites, All Depths
cumulative frequency
K 40 (Bq/g x 10e-03)

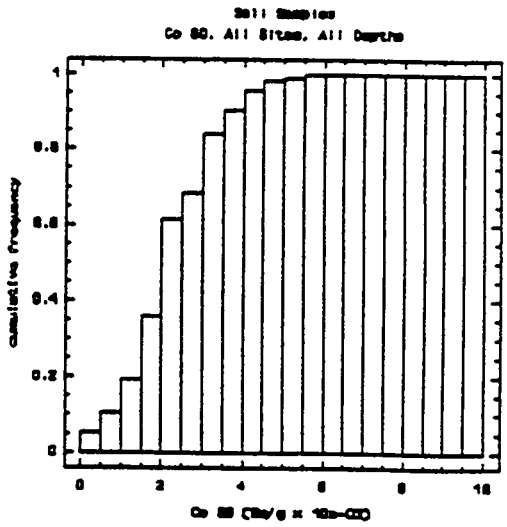

Soil Samples
K 40, Five-Mile Ring, All Depths
relative frequency
K 40 (Bq/g x 10e-03)

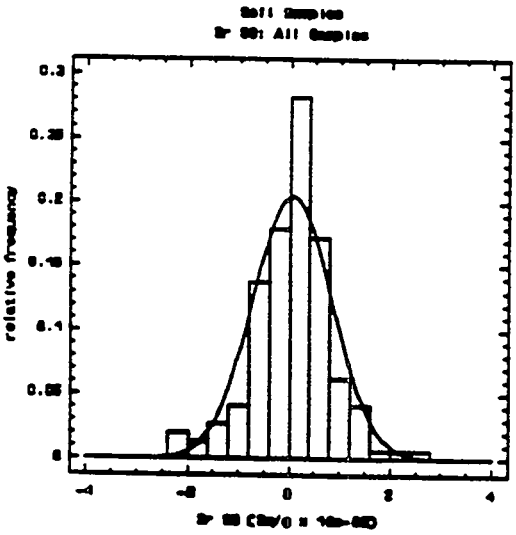

Soil Samples
K 40, Five-Mile Ring, All Depths
cumulative frequency
K 40 (Bq/g x 10e-03)

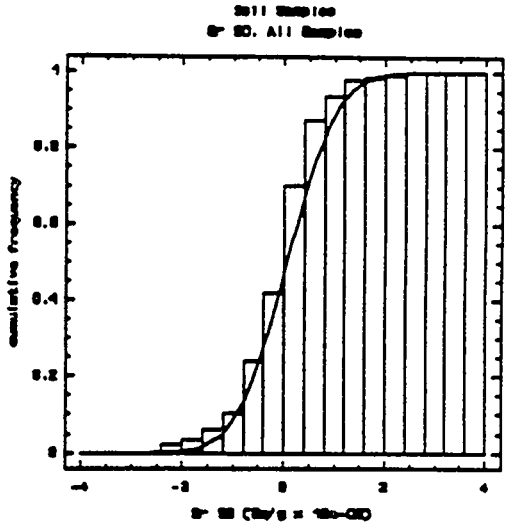

Soil Samples
K 40, WIPP Site, All Depths
relative frequency
K40 (Bq/g x 10e-03)

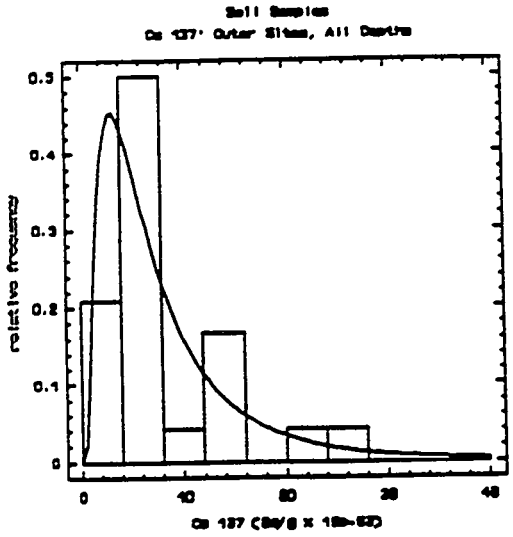

Soil Samples
K 40, WIPP Site, All Depths
cumulative frequency
K40 (Bq/g x 10e-03)

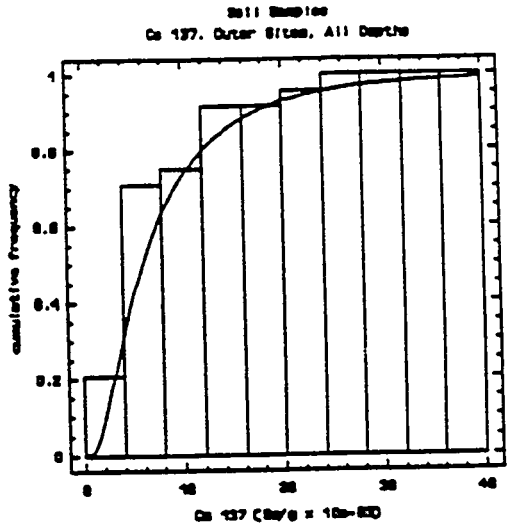

relative frequency

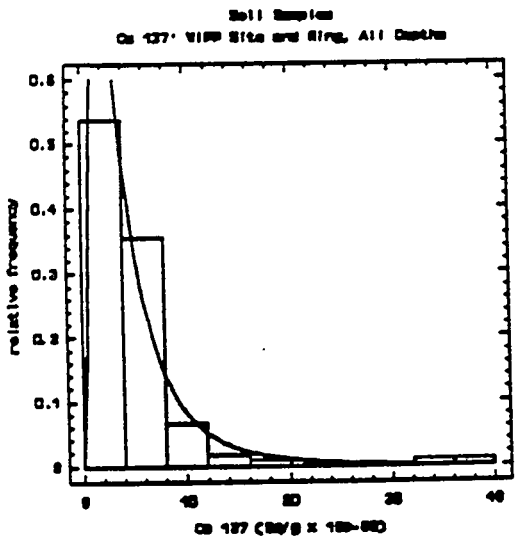

cumulative frequency

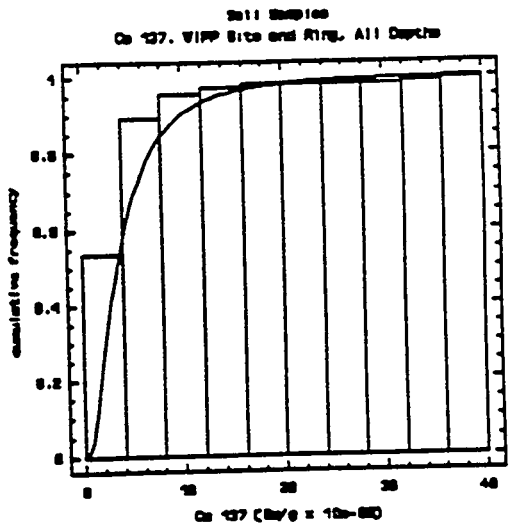

relative frequency

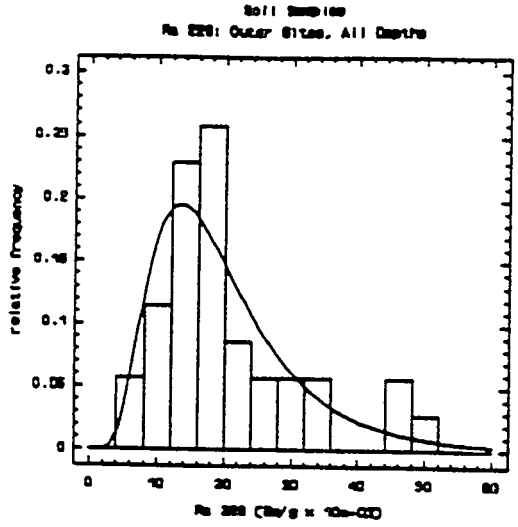

cumulative frequency

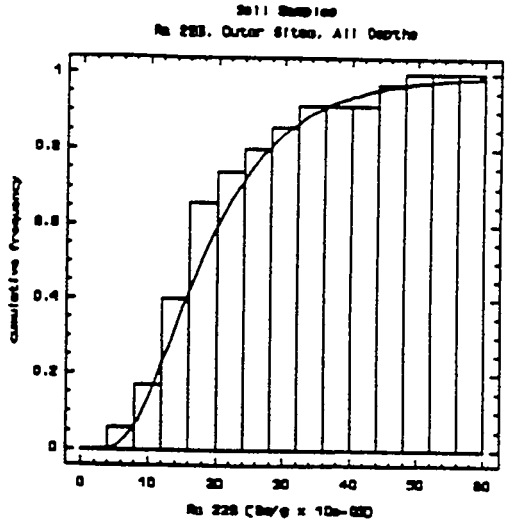

Soil Samples
Cs 137, Outer Sites, All Depths
relative frequency
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40

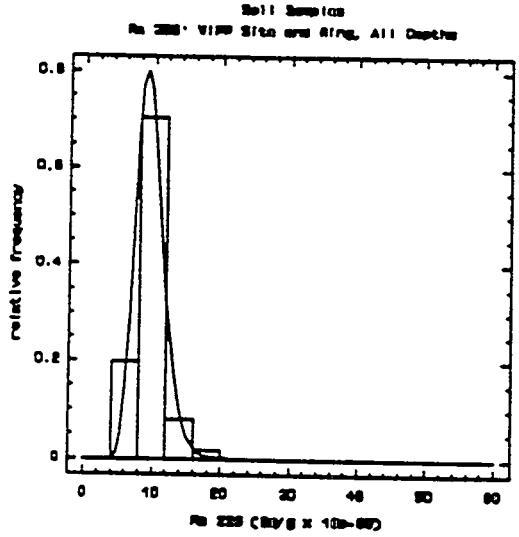

Soil Samples
Cs 137, Outer Sites, All Depths
cumulative frequency
1
0.8
0.6
0.4
0.2
0
0
10
20
30
40

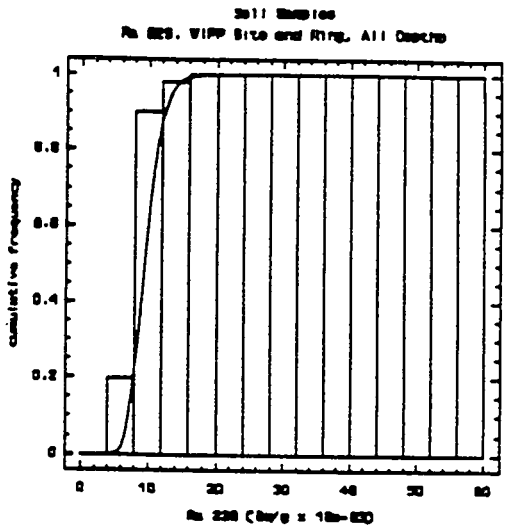

Soil Samples
Cs 137, VIRP Site and Ring, All Depths
relative frequency
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40

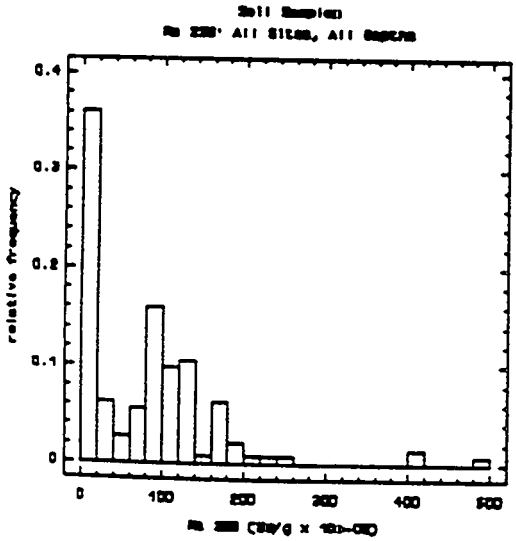

Soil Samples
Cs 137, VIRP Site and Ring, All Depths
cumulative frequency
1
0.8
0.6
0.4
0.2
0
0
10
20
30
40

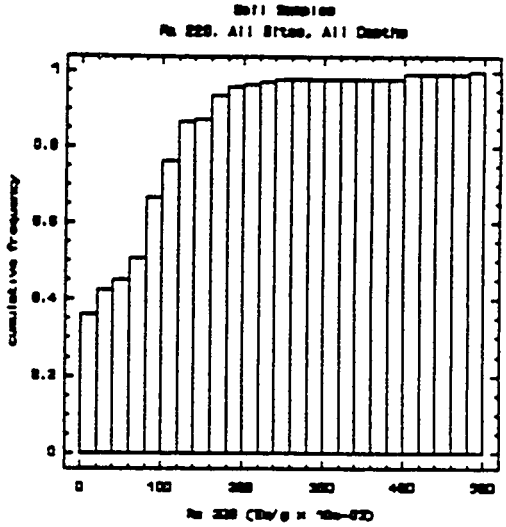

Soil Samples
Ra 226: Outer Sites, All Depths
relative frequency

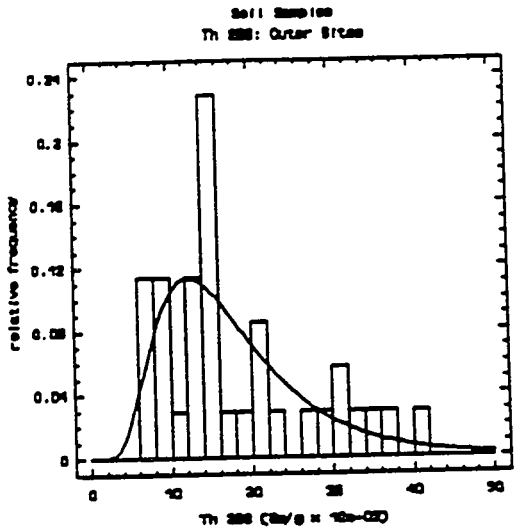

Soil Samples
Ra 226. Outer Sites, All Depths
cumulative frequency

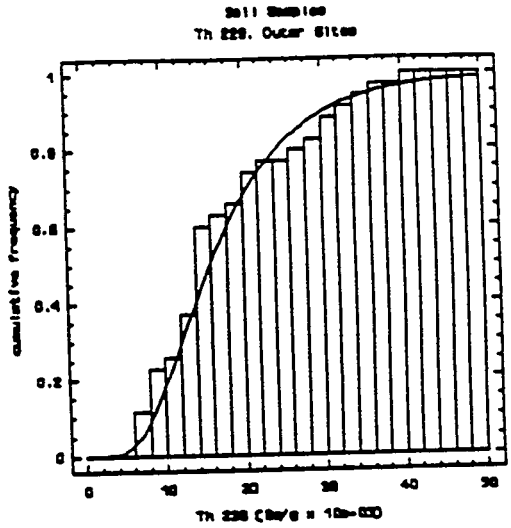

Soil Samples
relative frequency

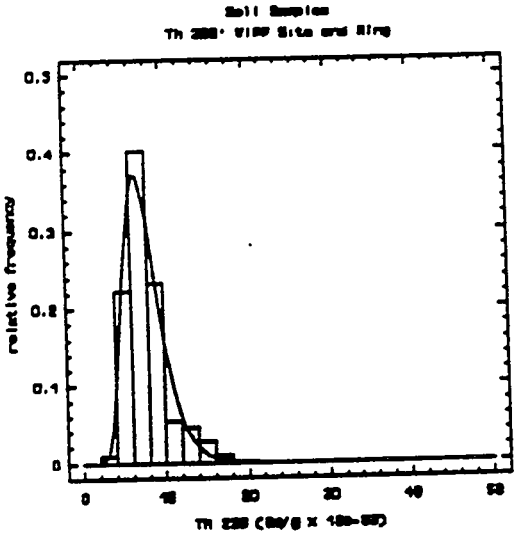

Soil Samples
cumulative frequency

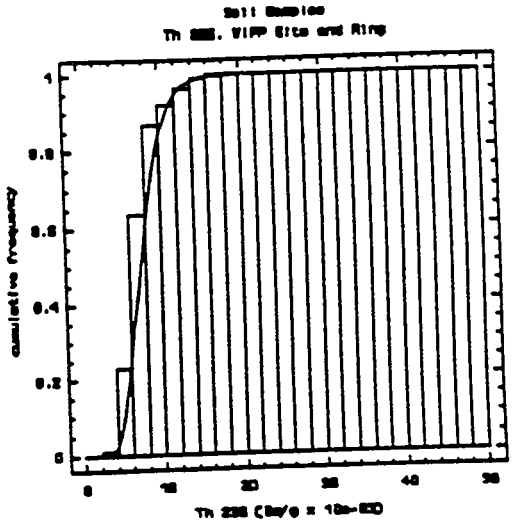

Soil Samples
relative frequency

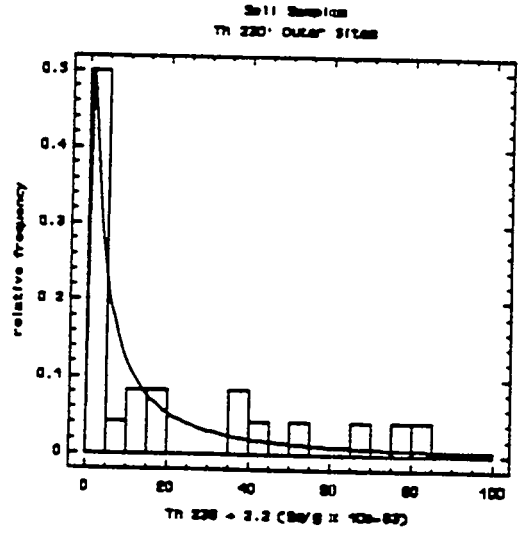

Soil Samples
Ra 226. All Sites, All Depths
cumulative frequency

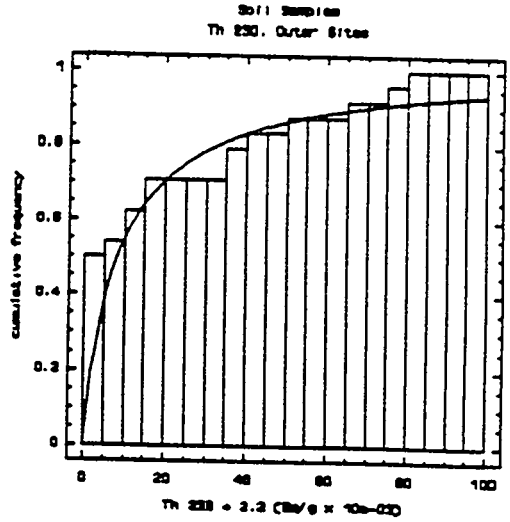

relative frequency

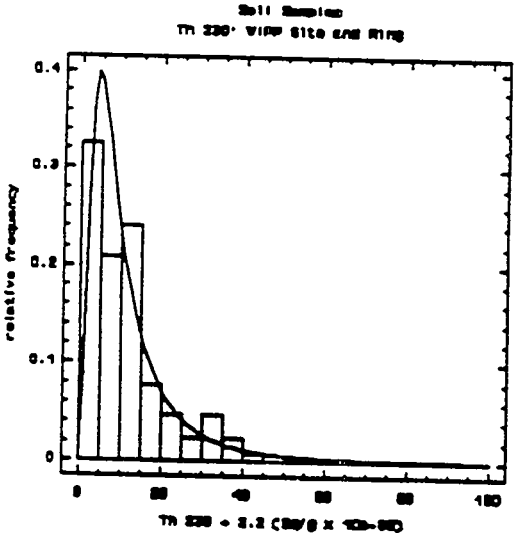

cumulative frequency

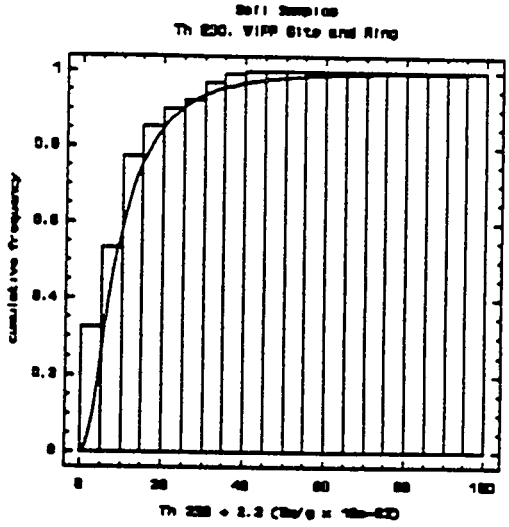

relative frequency

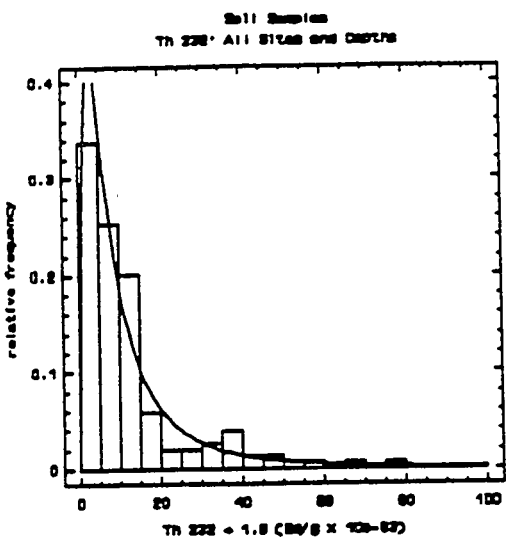

cumulative frequency

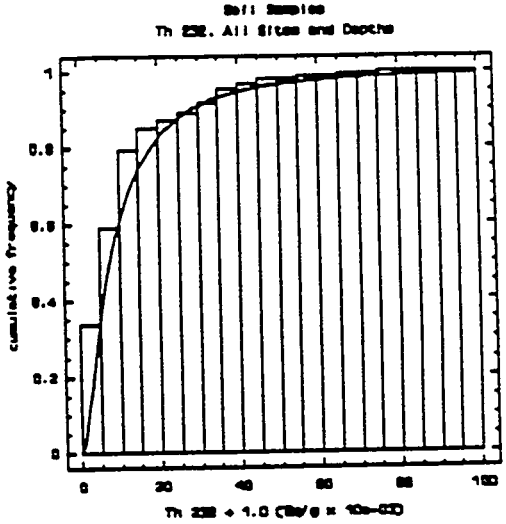

relative frequency
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100

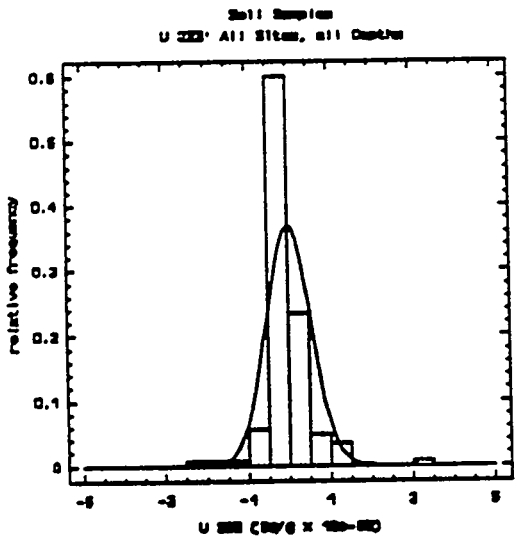

cumulative frequency
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100

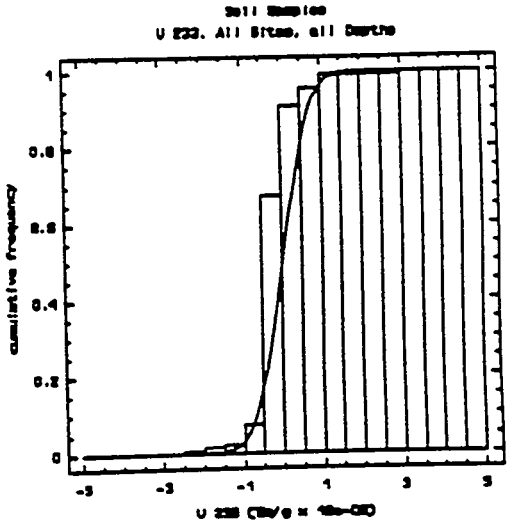

relative frequency
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100

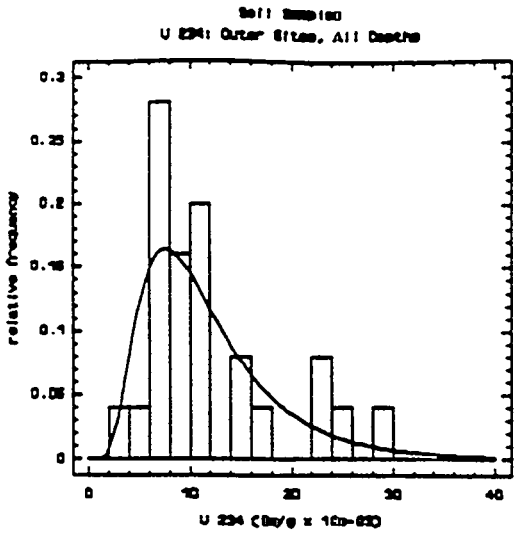

cumulative frequency
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100

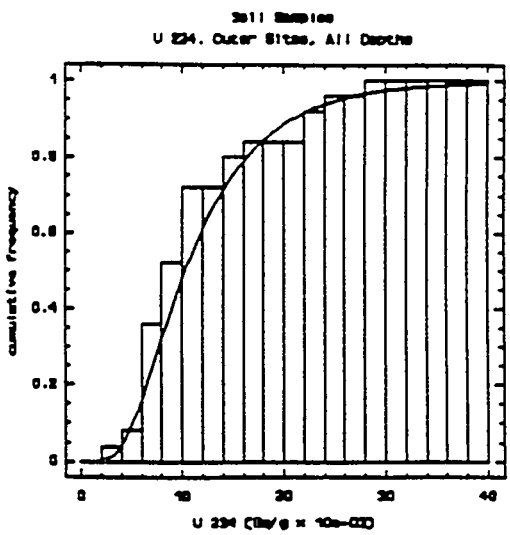

relative frequency
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100

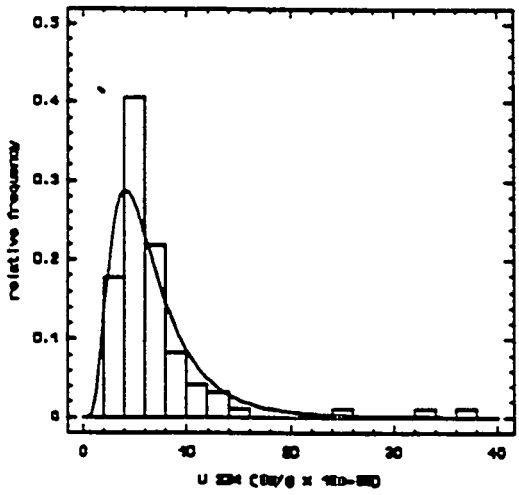

cumulative frequency
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100

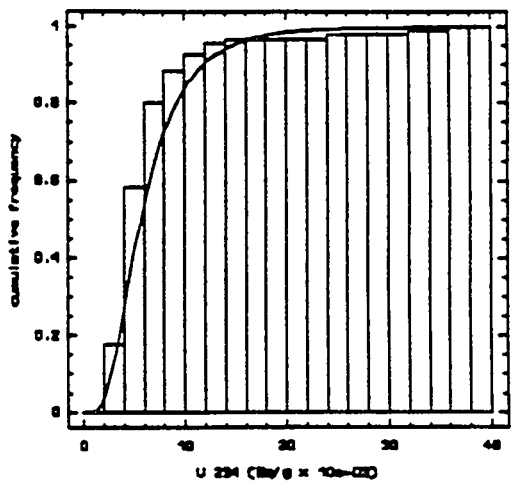

relative frequency
0.6
0.5
0.4
0.3
0.2
0.1
0
-5
-3
-1
1
3
5

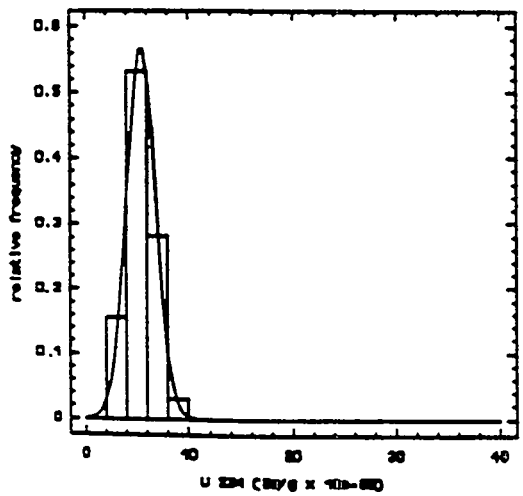

cumulative frequency
1
0.8
0.6
0.4
0.2
0
-5
-3
-1
1
3
5

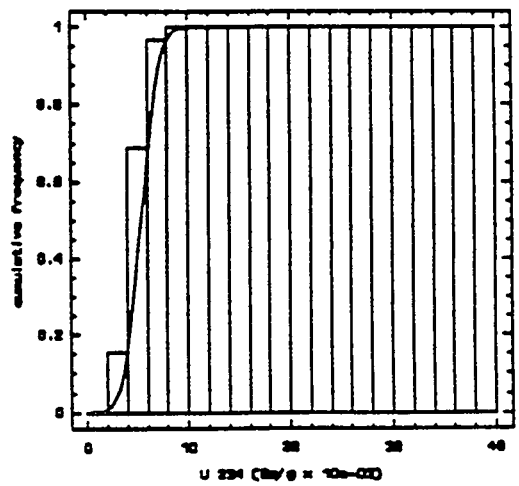

relative frequency
0.3
0.25
0.2
0.15
0.1
0.05
0
0
10
20
30
40

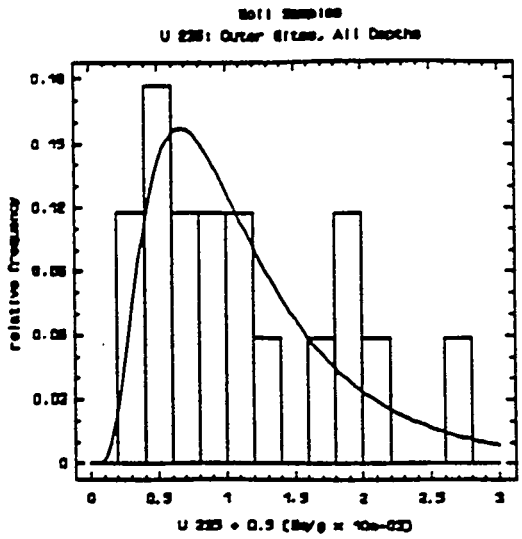

cumulative frequency
1
0.8
0.6
0.4
0.2
0
0
10
20
30
40

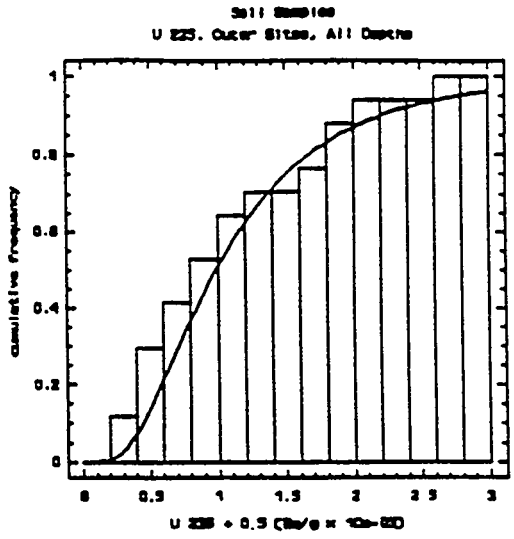

relative frequency
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40

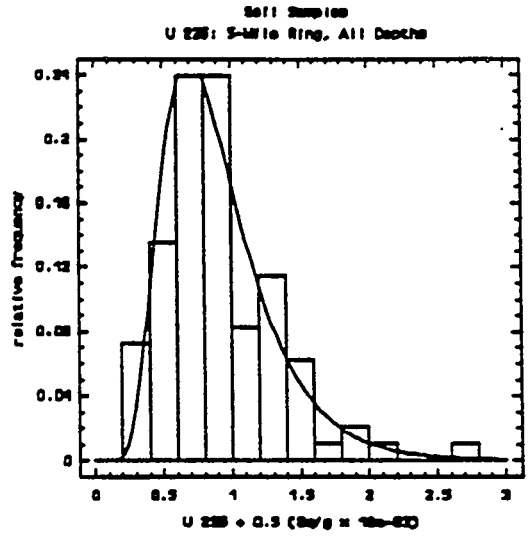

cumulative frequency
1
0.8
0.6
0.4
0.2
0
0
10
20
30
40

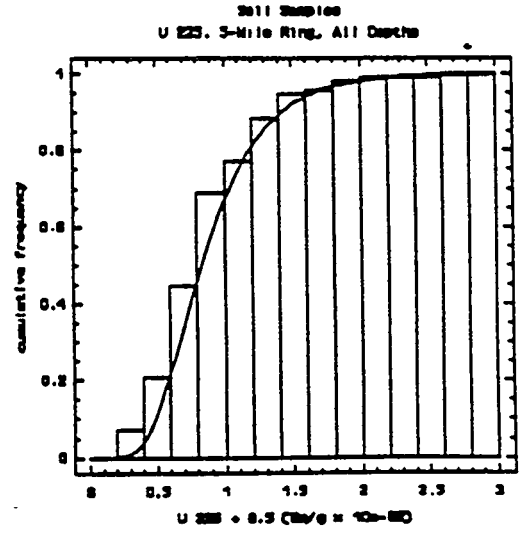

relative frequency
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40

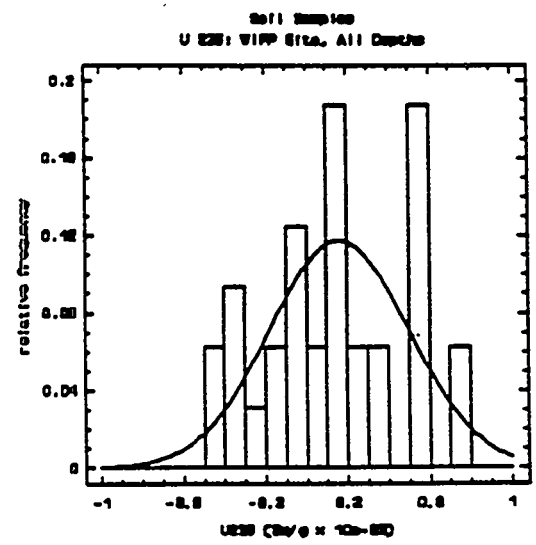

cumulative frequency
1
0.8
0.6
0.4
0.2
0
0
10
20
30
40

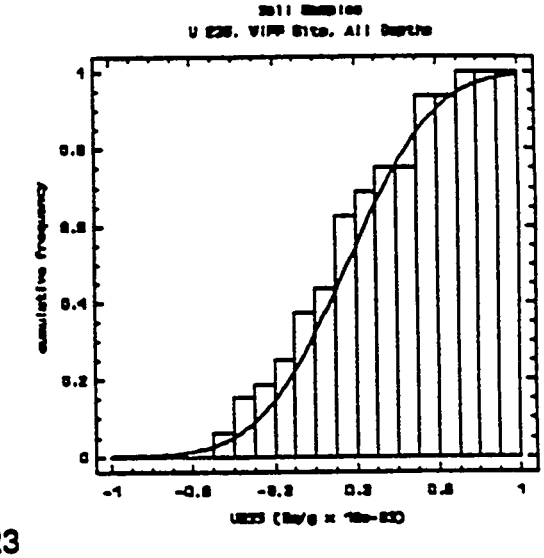

Soil Samples
U 238: Outer Sites, All Depths
relative frequency
0.16
0.12
0.08
0.04
0
0
0.5
1
1.5
2
2.5
3

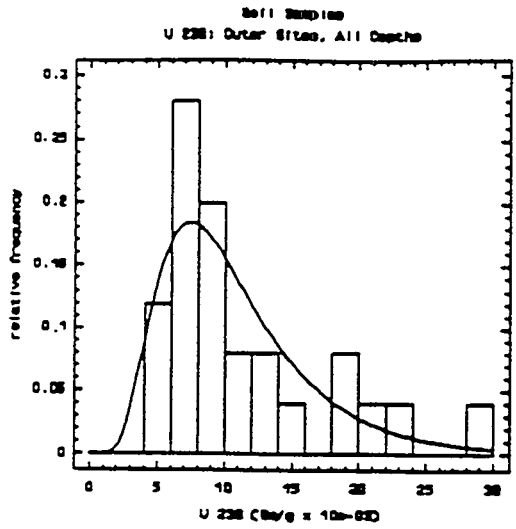

Soil Samples
U 238: Outer Sites, All Depths
cumulative frequency
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
3

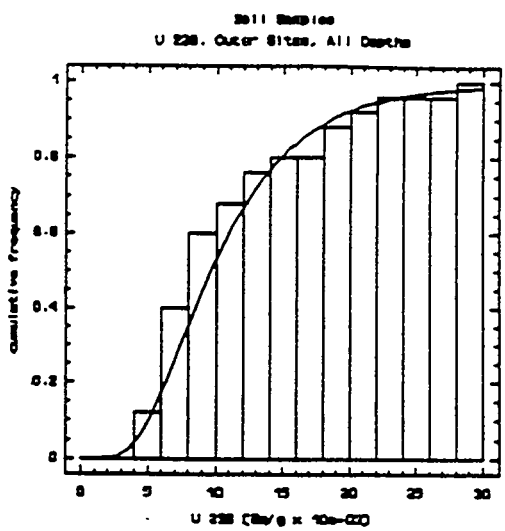

Soil Samples
U 238: 5-Mile Ring, All Depths
relative frequency
0.24
0.2
0.16
0.12
0.08
0.04
0
0
0.5
1
1.5
2
2.5
3

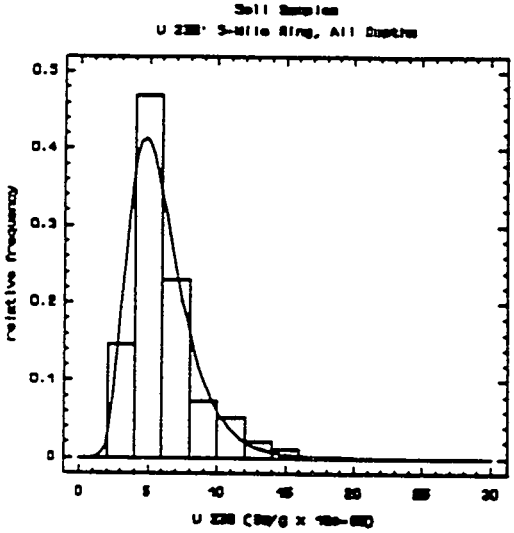

Soil Samples
U 238: 5-Mile Ring, All Depths
cumulative frequency
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
3

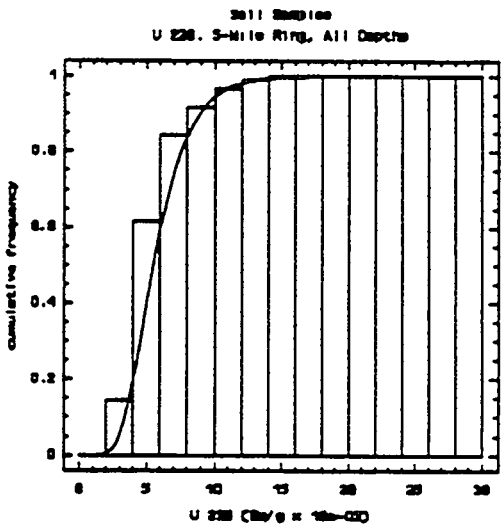

Soil Samples
U 238: WIPP Site, All Depths
relative frequency
0.2
0.16
0.12
0.08
0.04
0
-1
-0.8
-0.6
-0.2
0.2
0.6
1

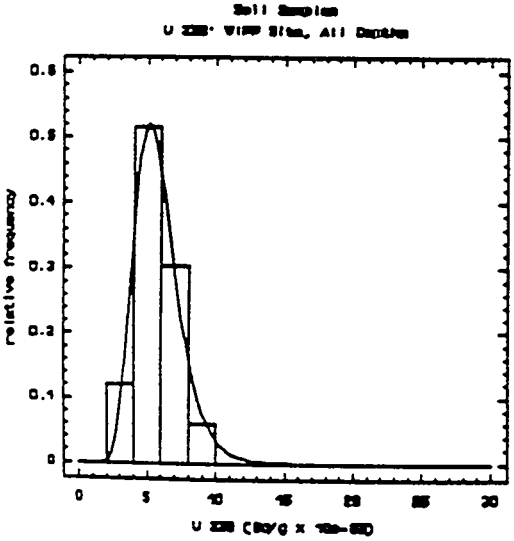

Soil Samples
U 238: WIPP Site, All Depths
cumulative frequency
1
0.8
0.6
0.4
0.2
0
-1
-0.8
-0.6
-0.2
0.2
0.6
1

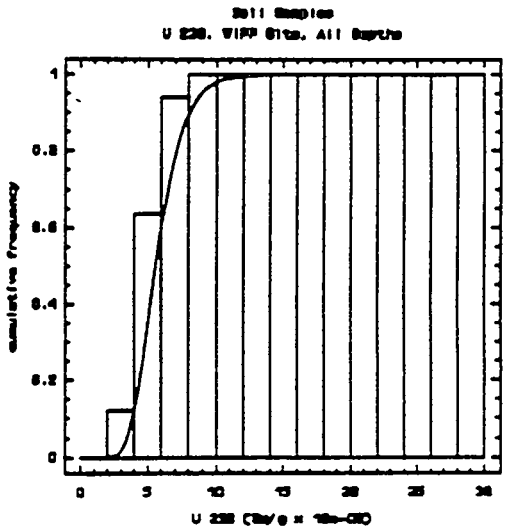

relative frequency

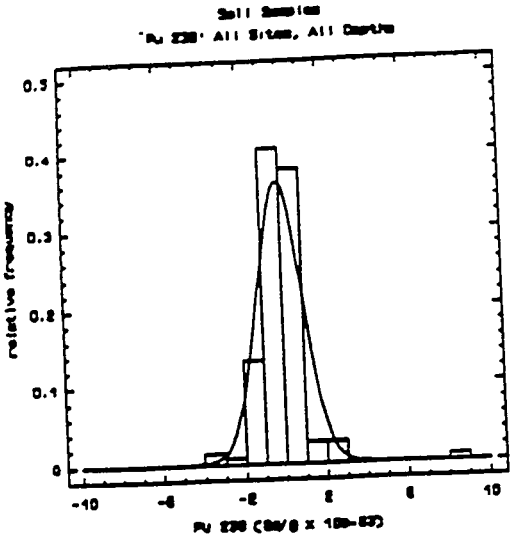

cumulative frequency

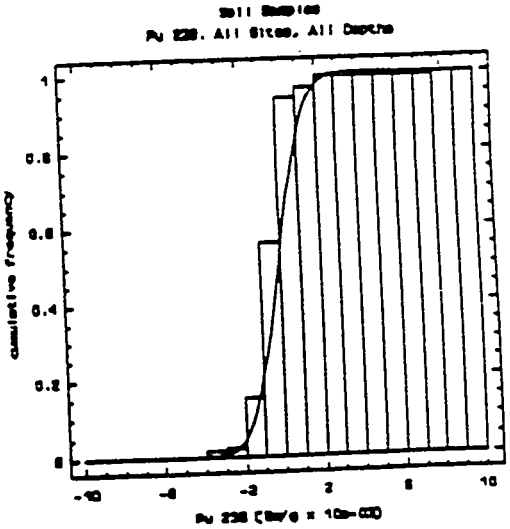

relative frequency

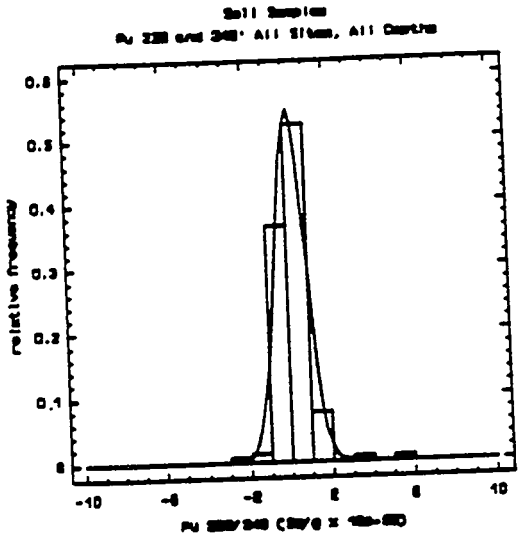

cumulative frequency

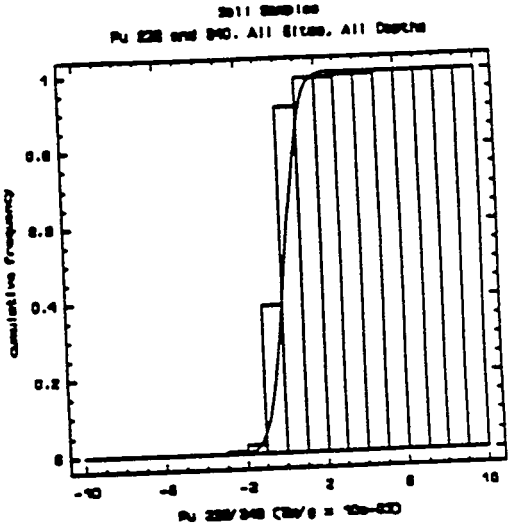

relative frequency

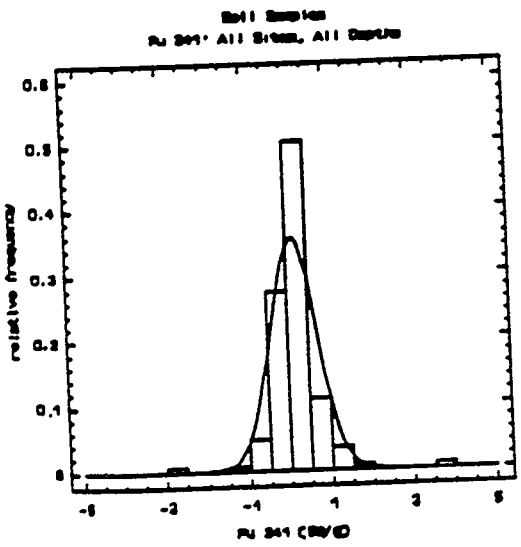

cumulative frequency

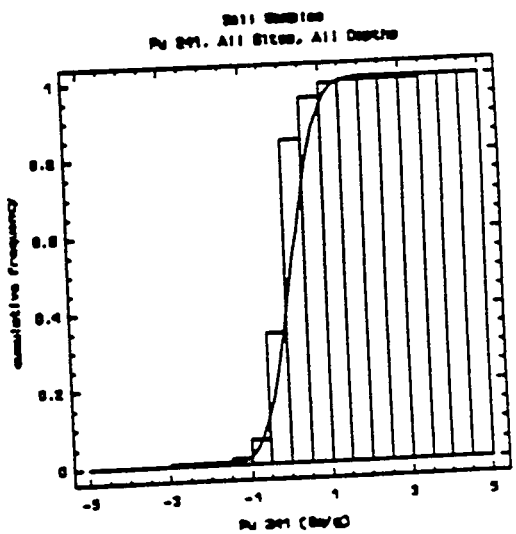


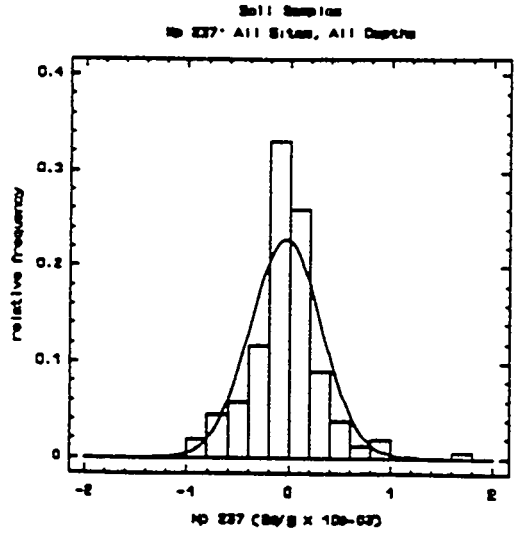


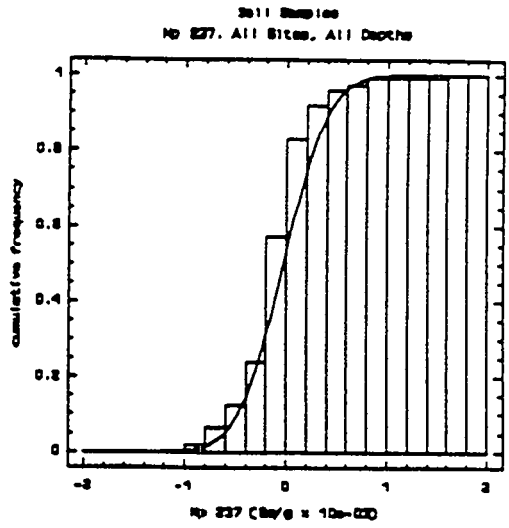


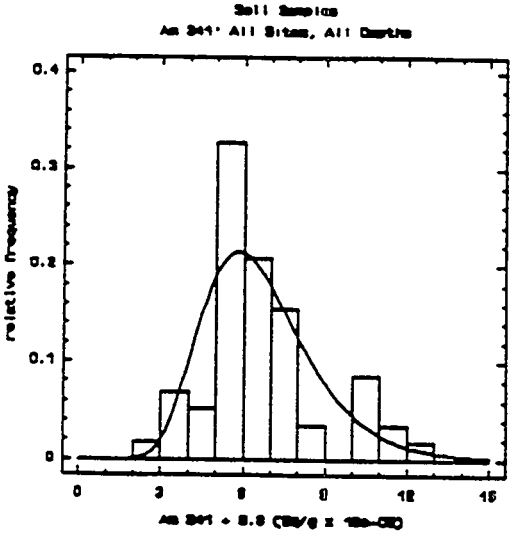


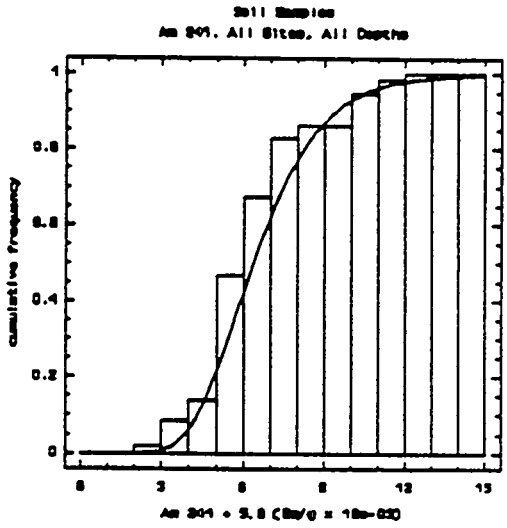


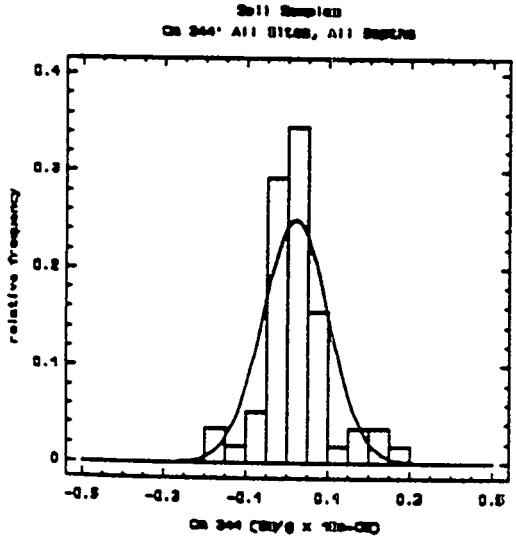


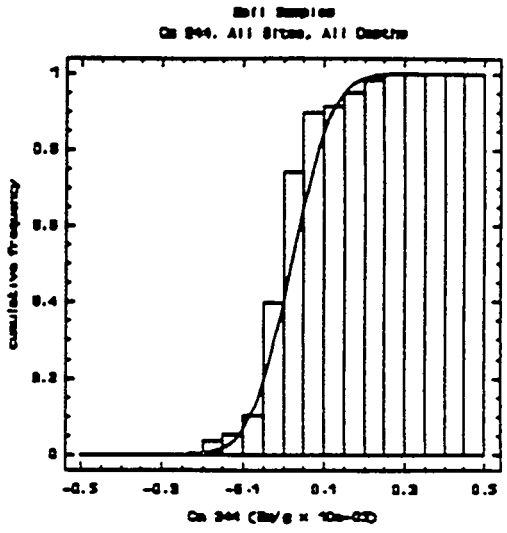

Soil Samples
Np 237, All Sites, All Depths
relative frequency
Np 237 (Bq/g x 10e-03)

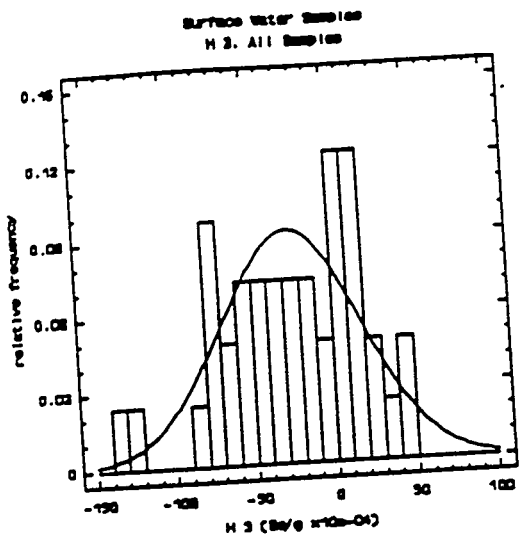

Soil Samples
Np 237, All Sites, All Depths
cumulative frequency
Np 237 (Bq/g x 10e-03)

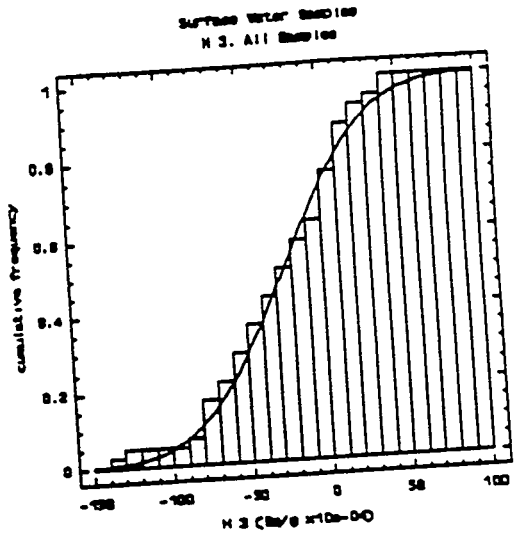

Soil Samples
Am 241, All Sites, All Depths
relative frequency

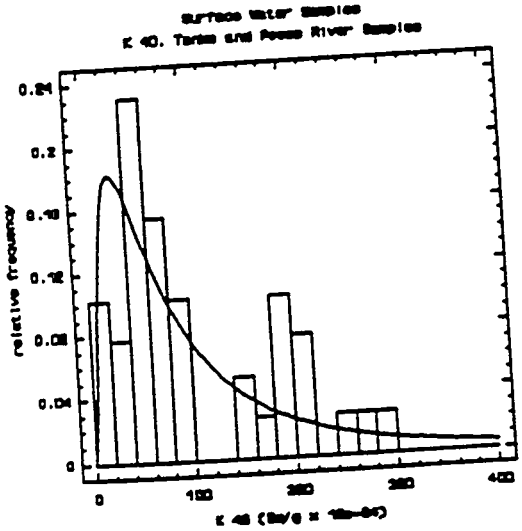

Soil Samples
Am 241, All Sites, All Depths
cumulative frequency

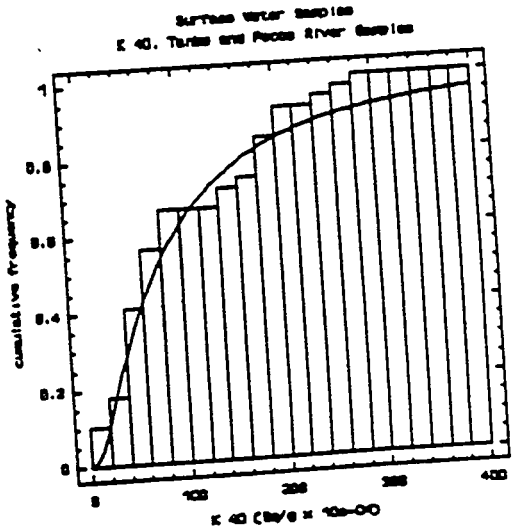

Soil Samples
Cs 244, All Sites, All Depths
relative frequency

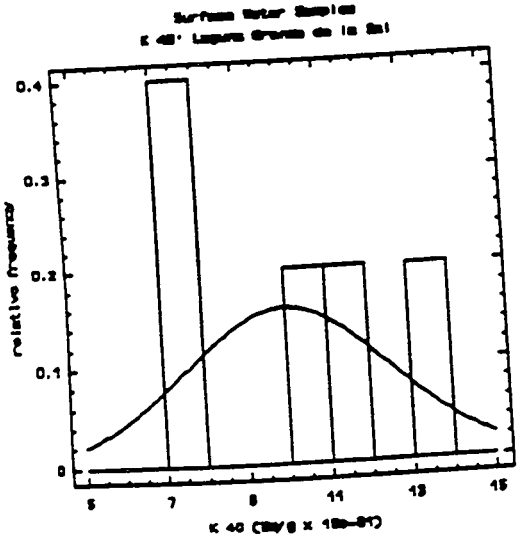

Soil Samples
Cs 244, All Sites, All Depths
cumulative frequency

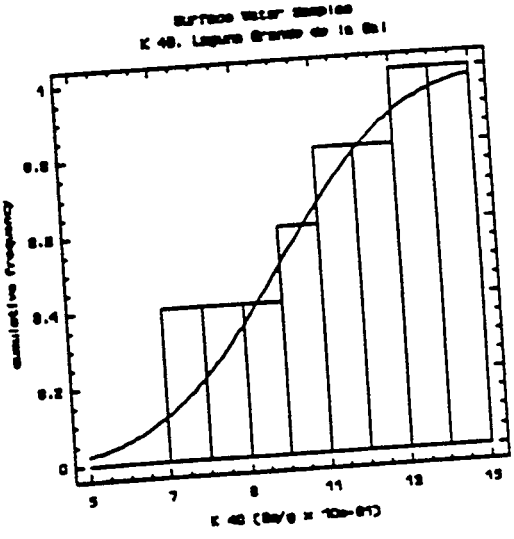

Surface Water Samples
H 3. All Samples
relative frequency
H 3 (Bq/g x10e-04)

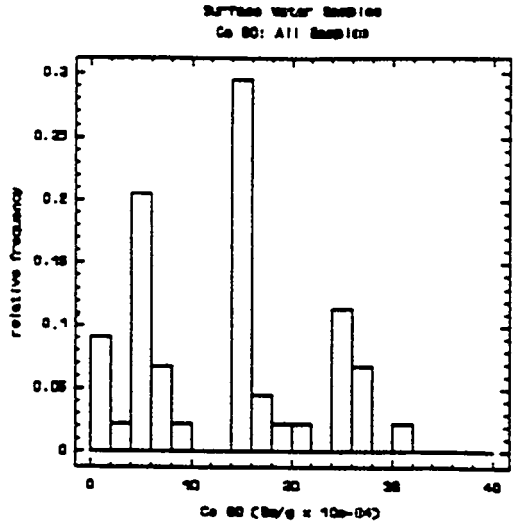

Surface Water Samples
H 3. All Samples
cumulative frequency
H 3 (Bq/g x10e-04)

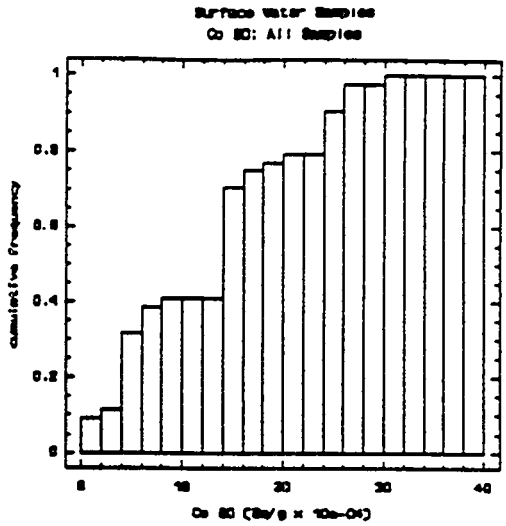

Surface Water Samples
K 40. Tarde and Pecos River Samples
relative frequency
K 40 (Bq/g x 10e-04)

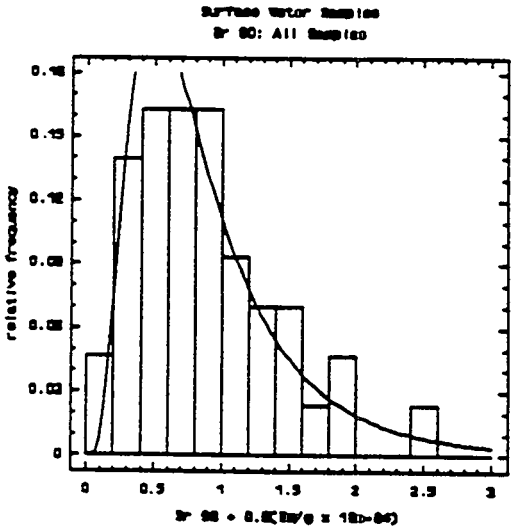

Surface Water Samples
K 40. Tarde and Pecos River Samples
cumulative frequency
K 40 (Bq/g x 10e-04)

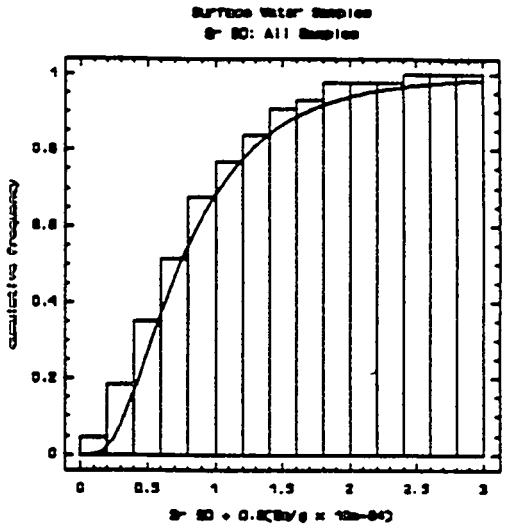

Surface Water Samples
K 40. Laguna Grande de la Sal
relative frequency
K 40 (Bq/g x 10e-01)

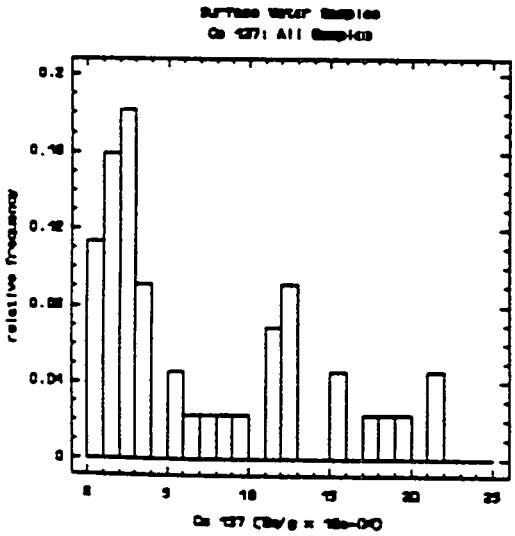

Surface Water Samples
K 40. Laguna Grande de la Sal
cumulative frequency
K 40 (Bq/g x 10e-01)

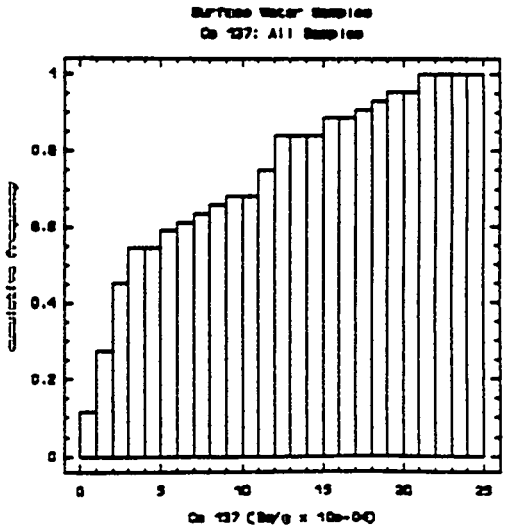

relative frequency

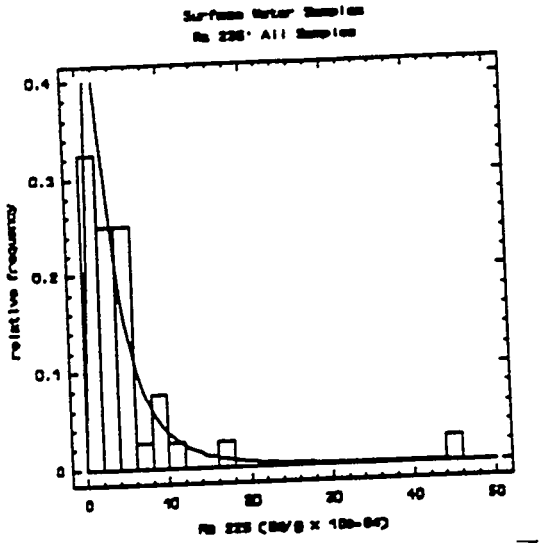

cumulative frequency

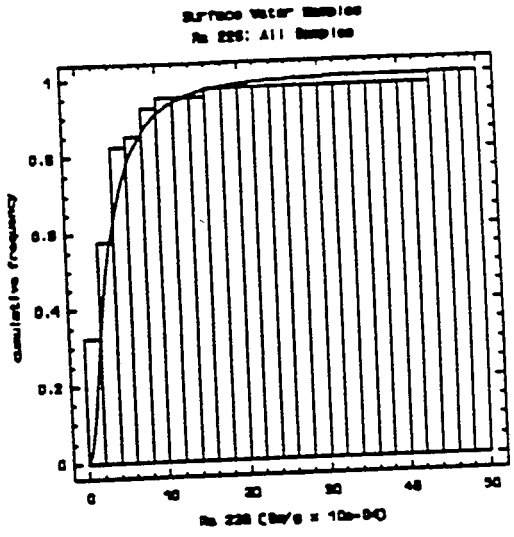

relative frequency

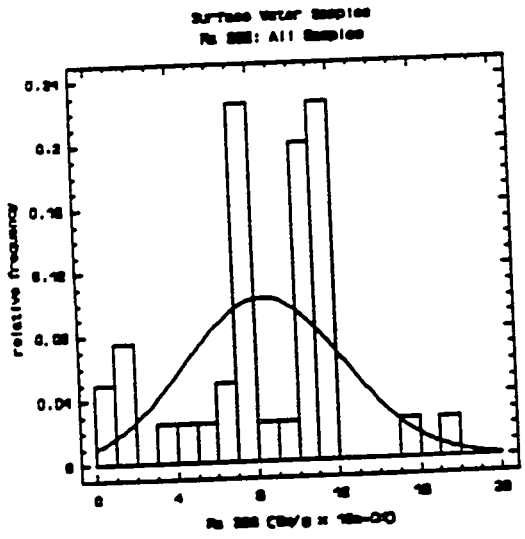

cumulative frequency

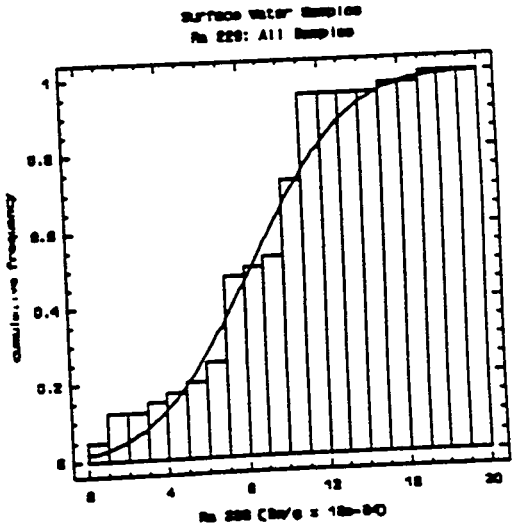

relative frequency

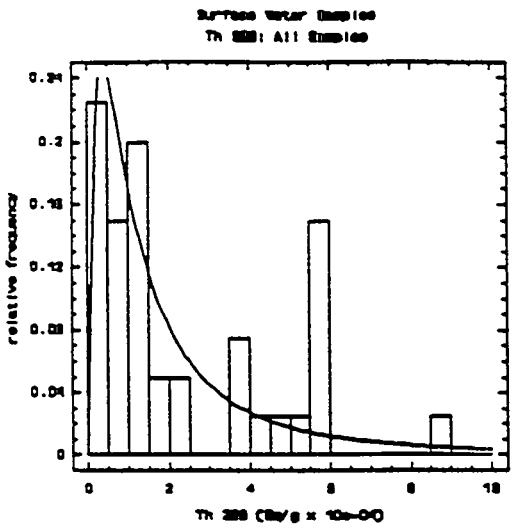

cumulative frequency

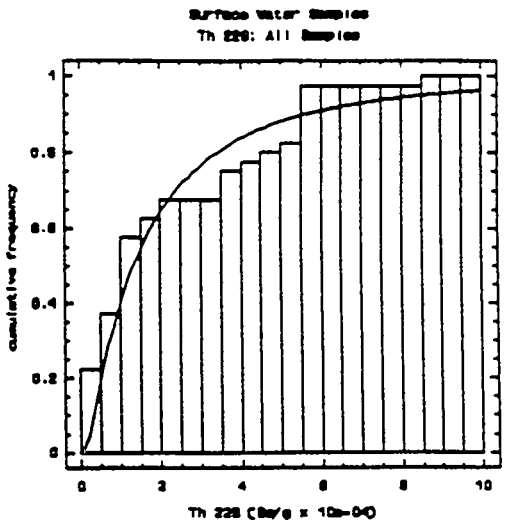

relative frequency
0.4
0.3
0.2
0.1
0
0
10
20
40
50

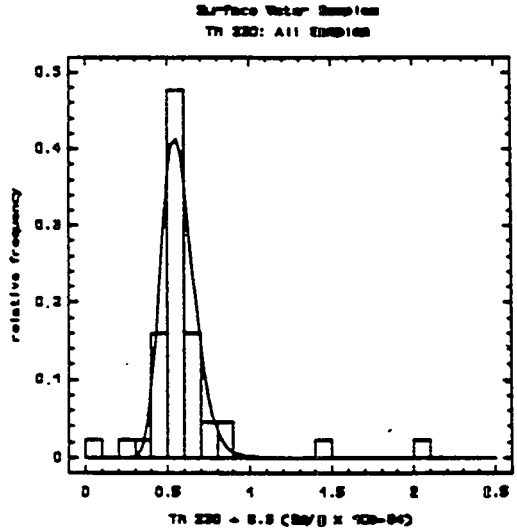

cumulative frequency
1
0.8
0.6
0.4
0.2
0
0
10
20
30
40
50

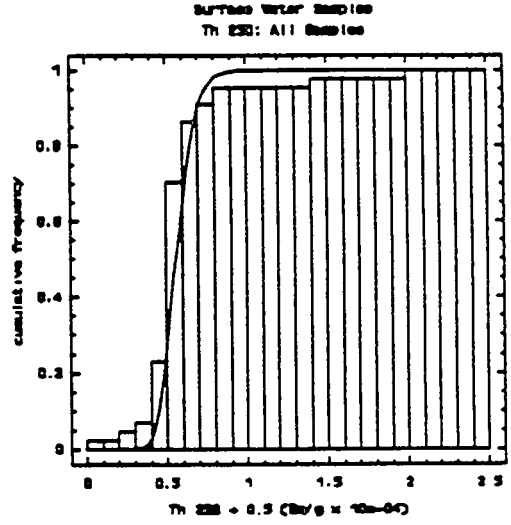

relative frequency
0.2
0.16
0.12
0.08
0.04
0
0
4
8
12
16
20

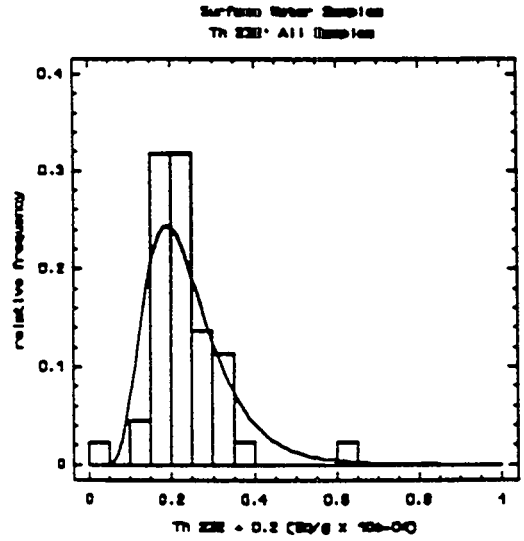

cumulative frequency
1
0.8
0.6
0.4
0.2
0
0
4
8
12
16
20

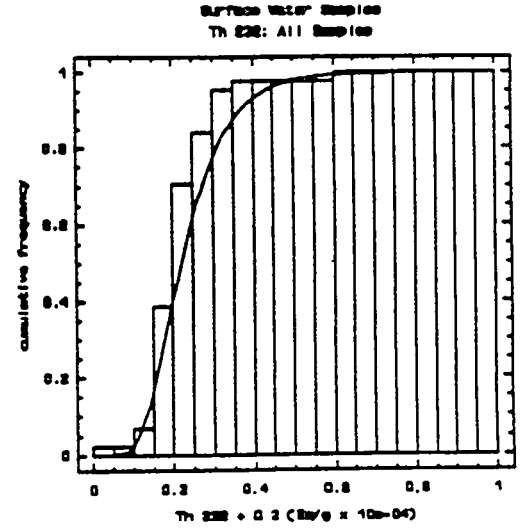


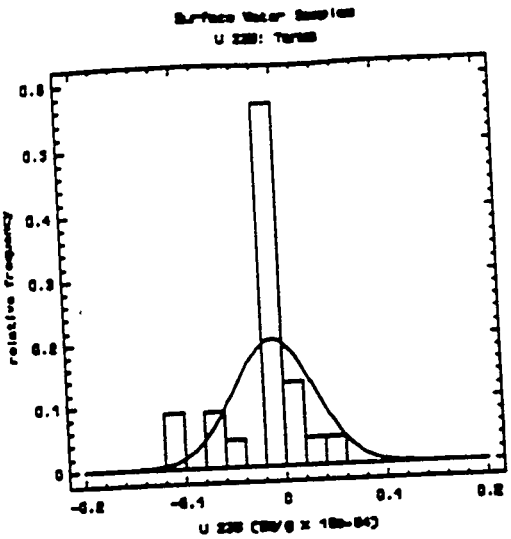


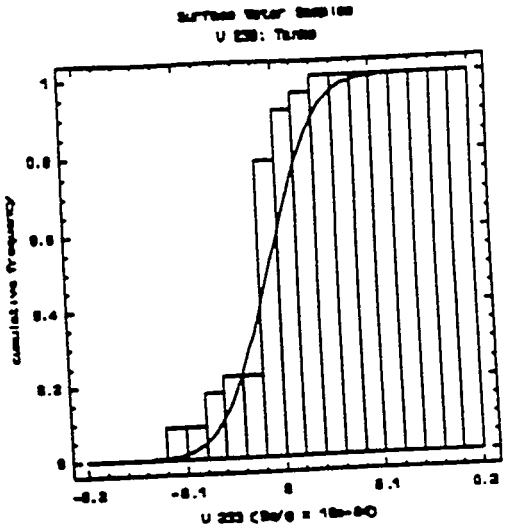


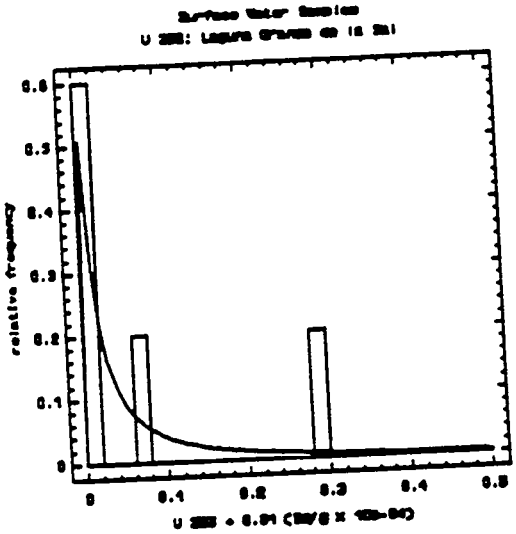


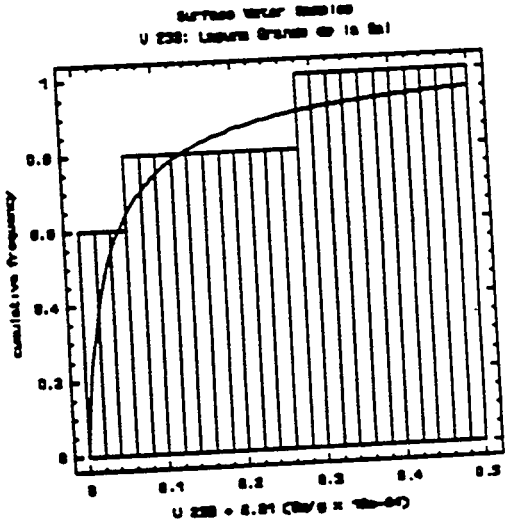


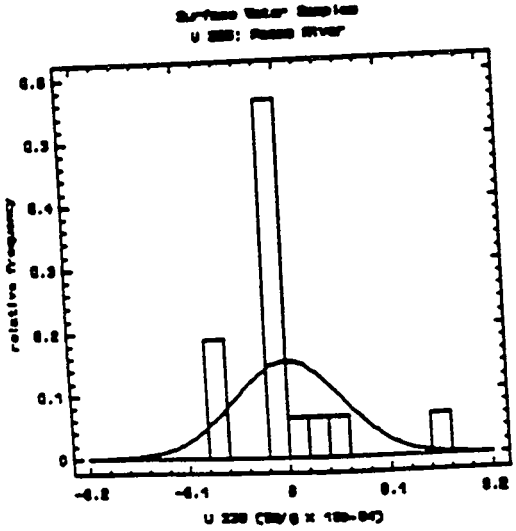


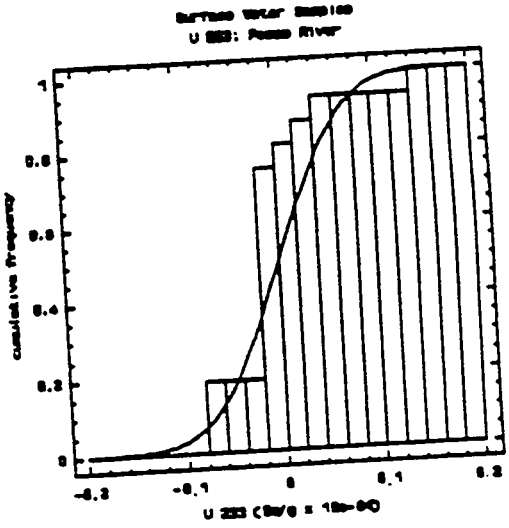


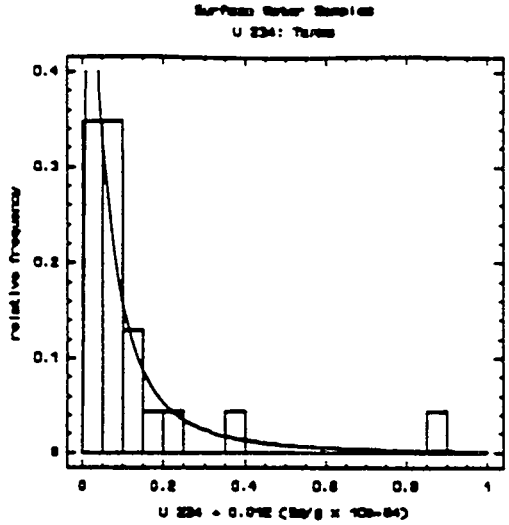


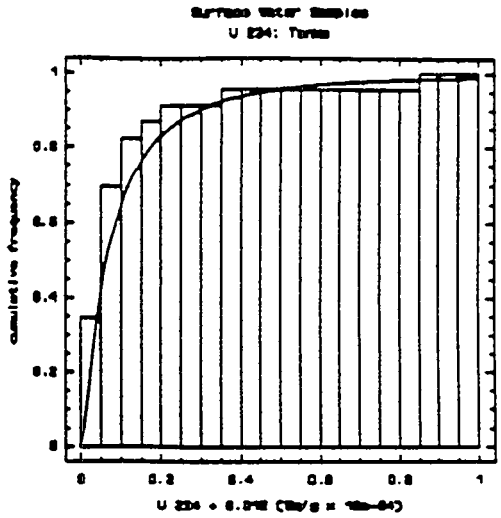


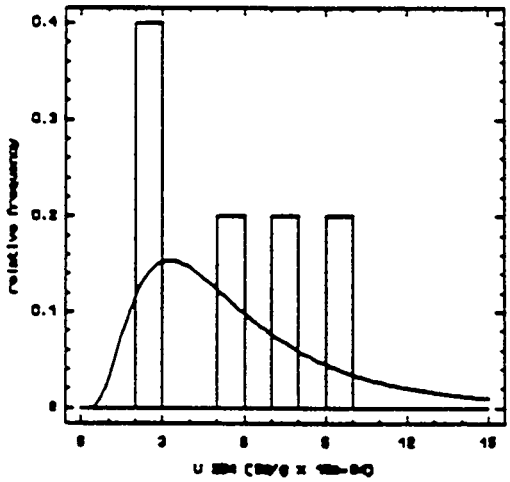


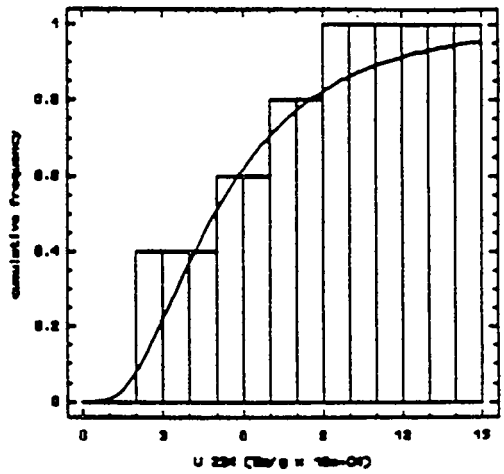


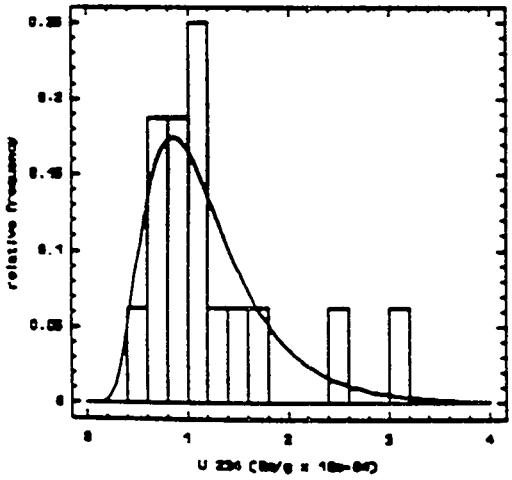


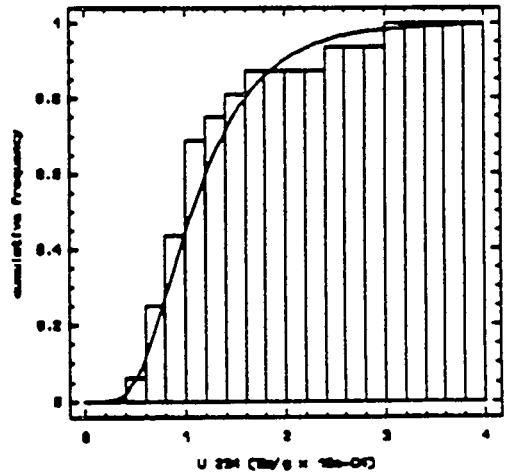

relative frequency

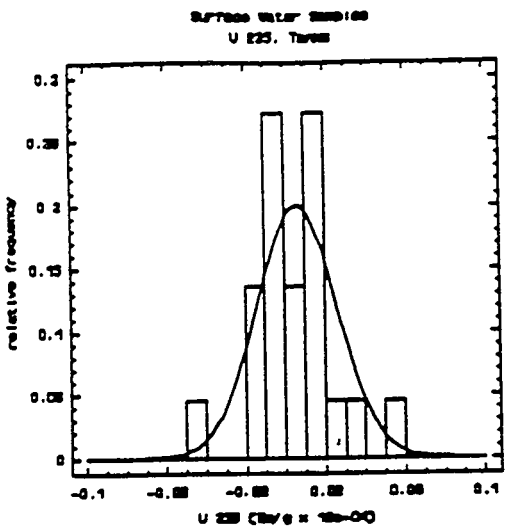

cumulative frequency

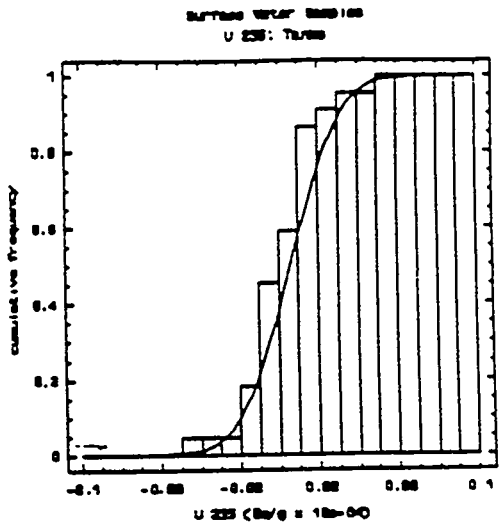

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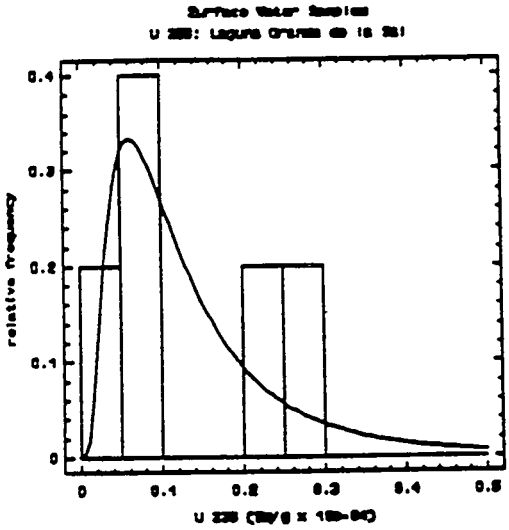

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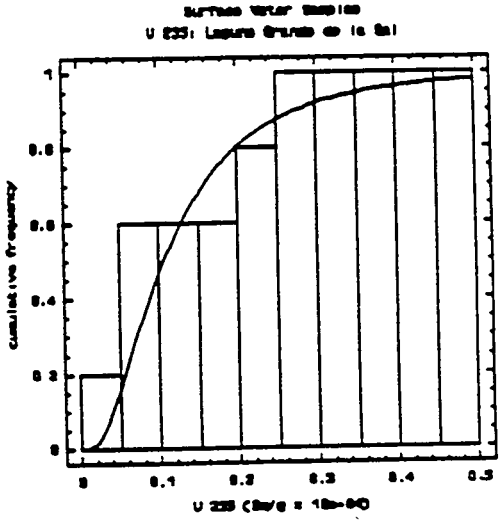

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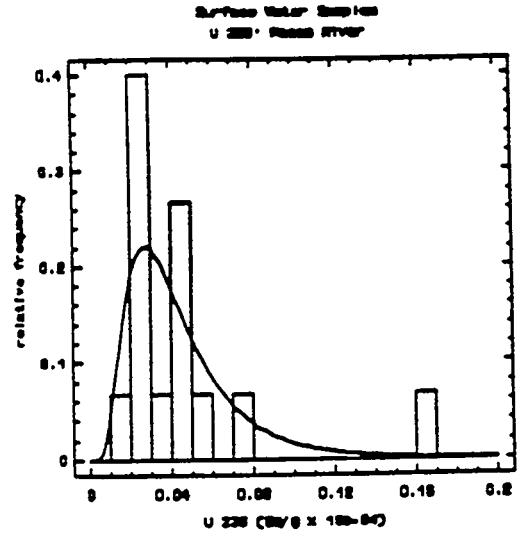

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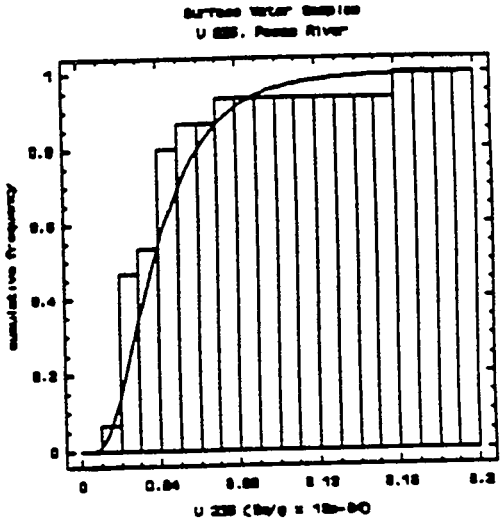


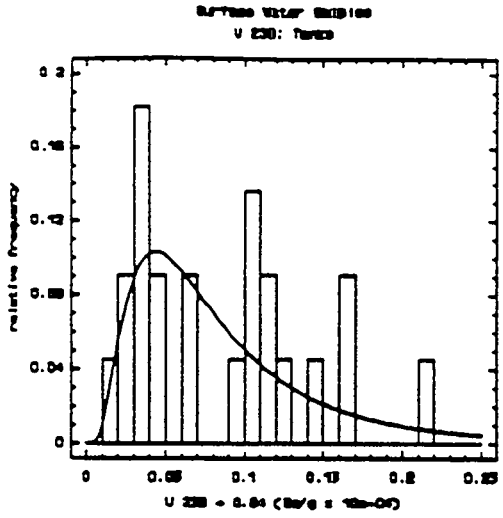


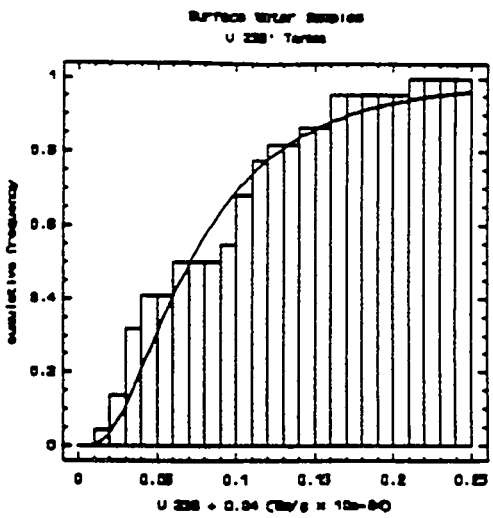


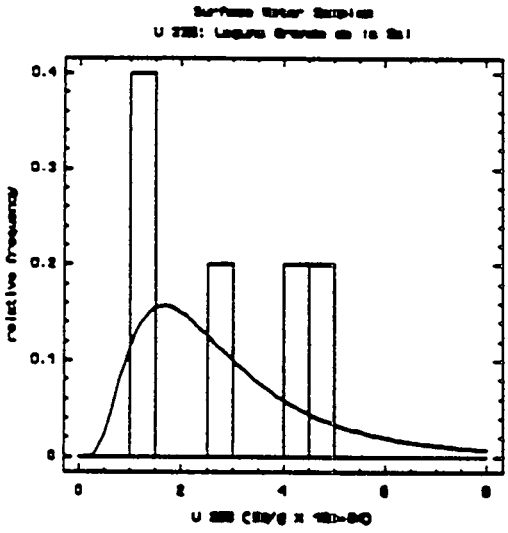


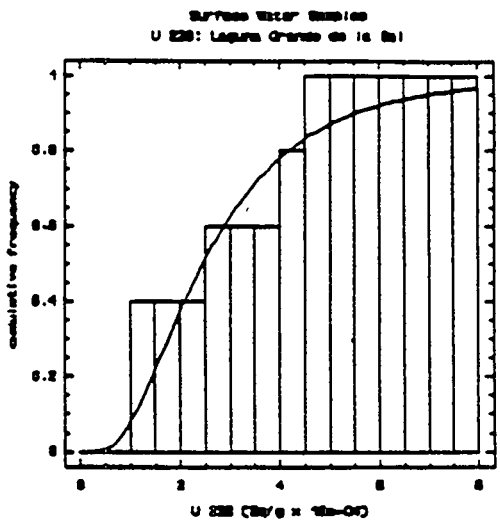


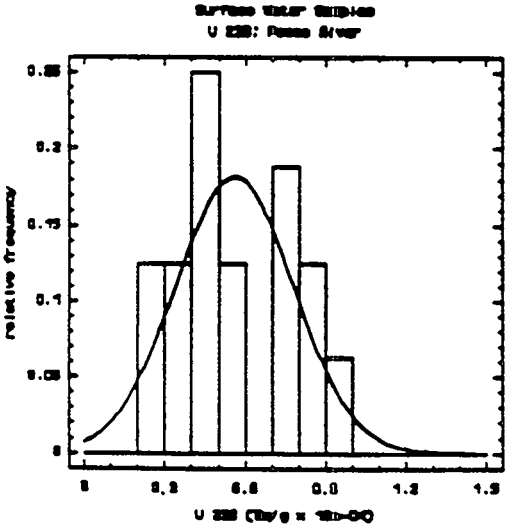


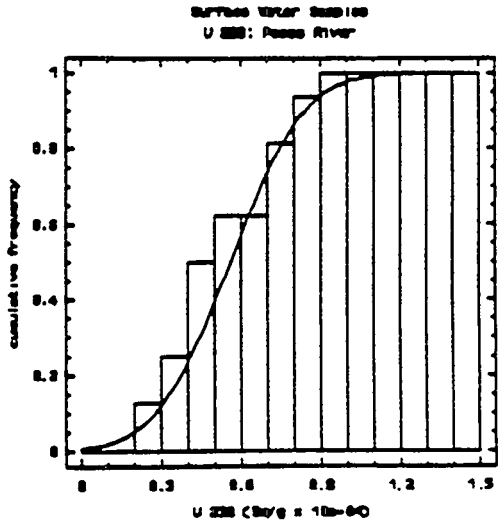


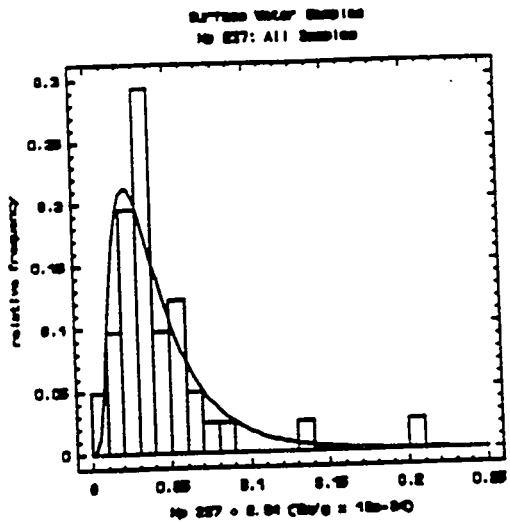


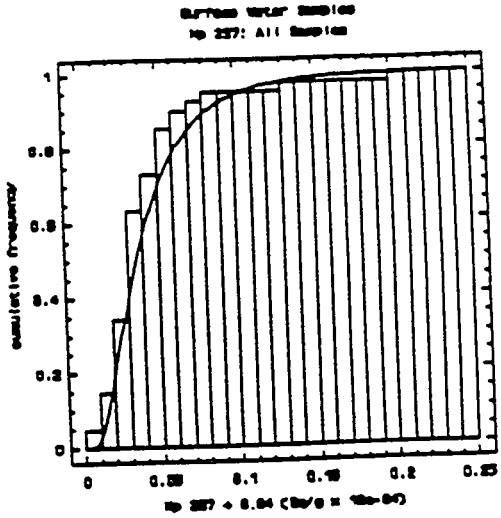


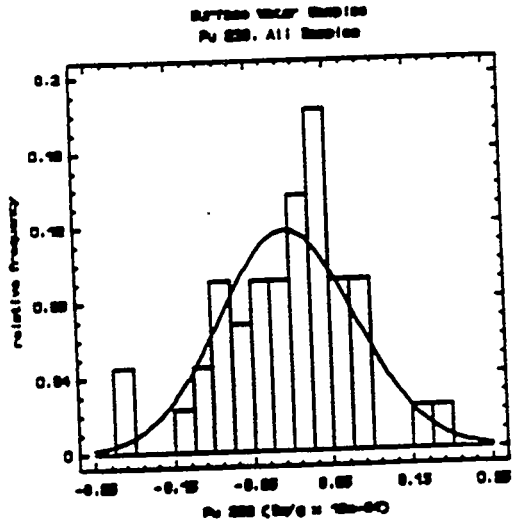


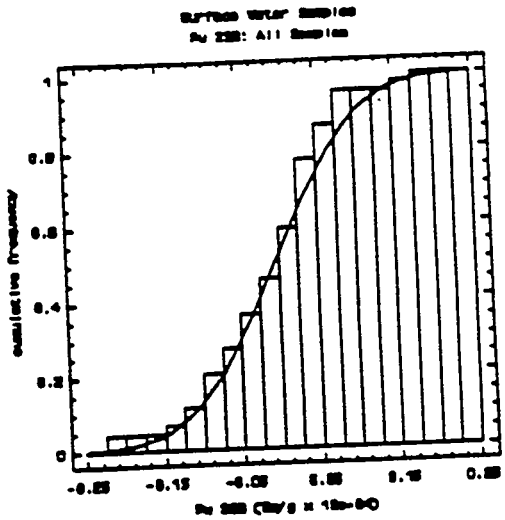


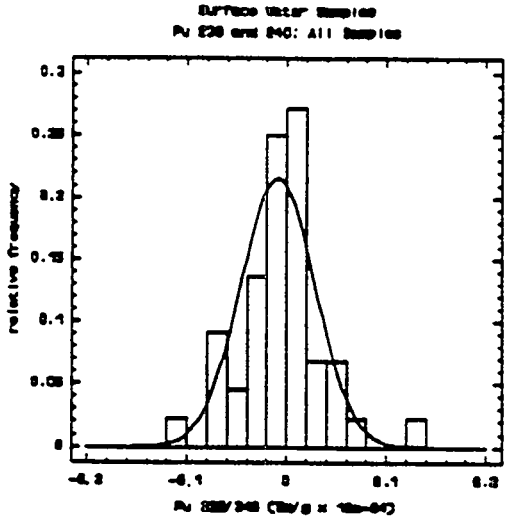


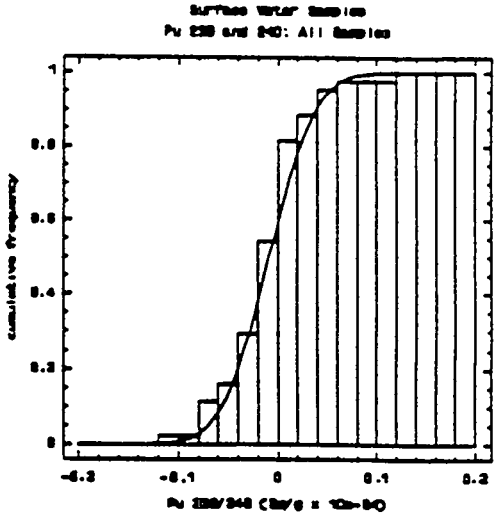


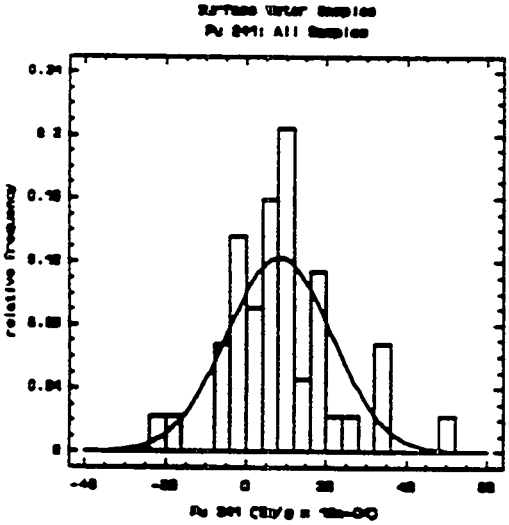


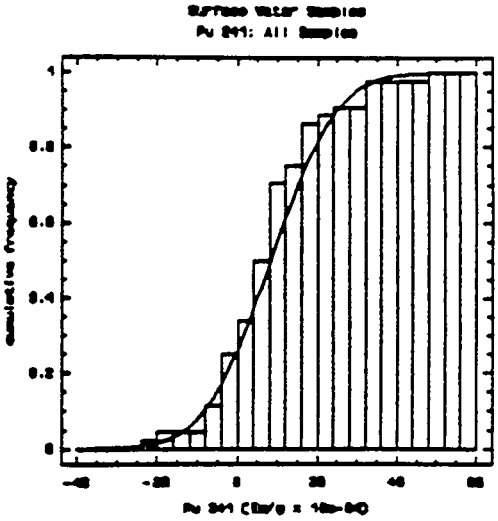


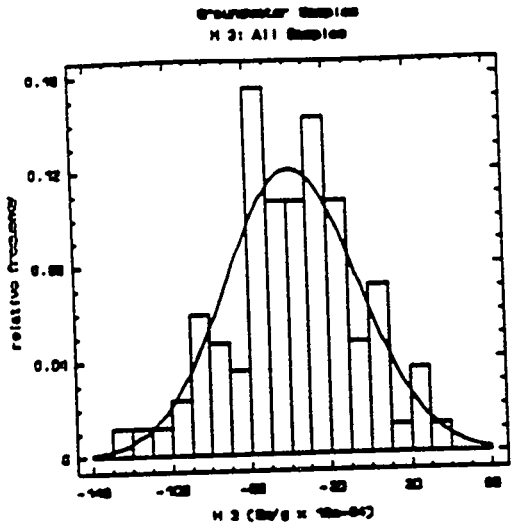


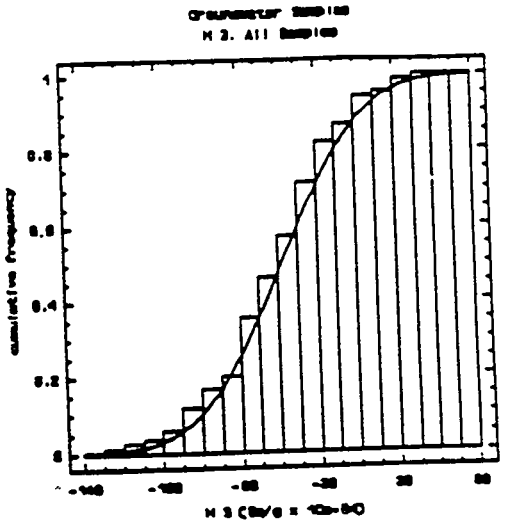


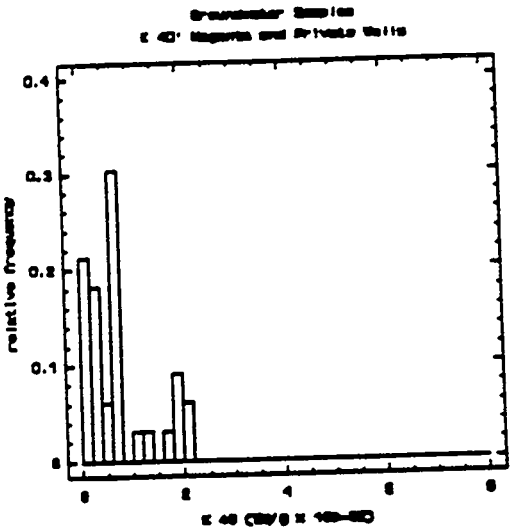


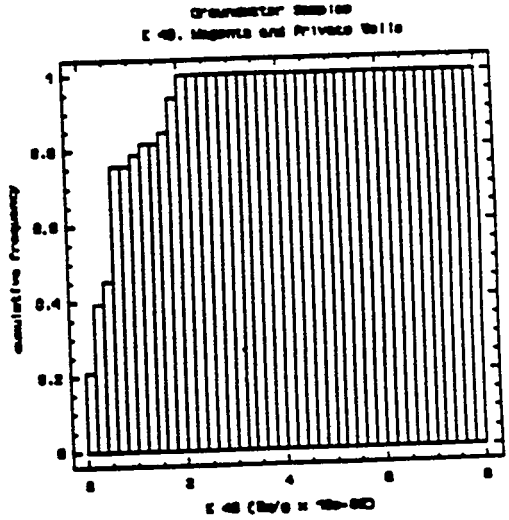


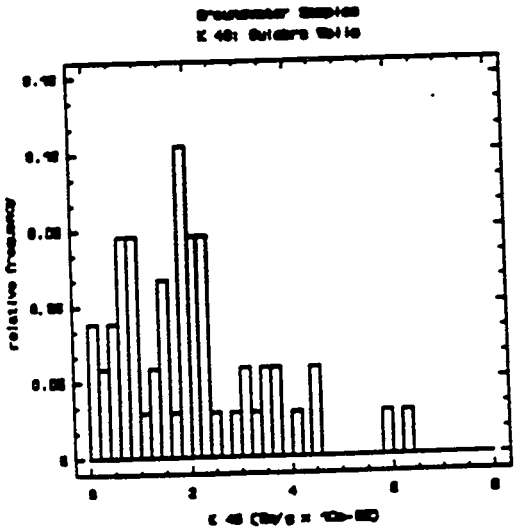


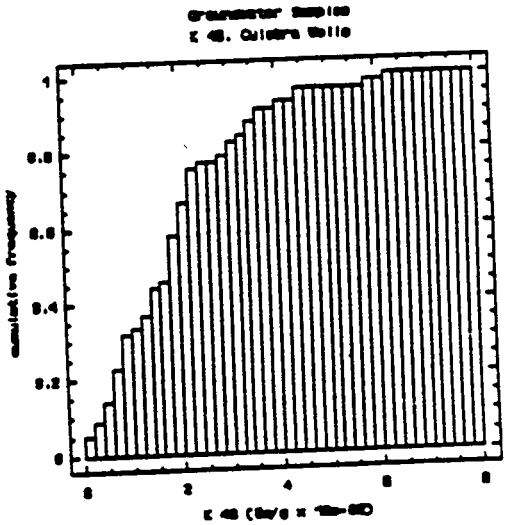


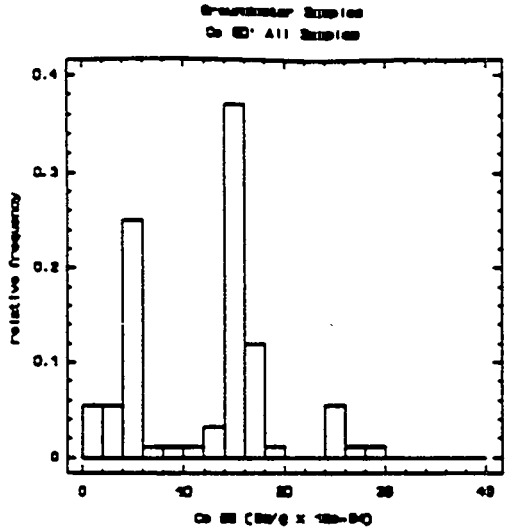


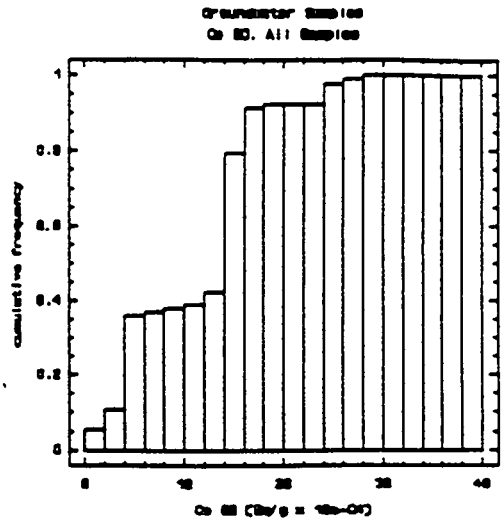


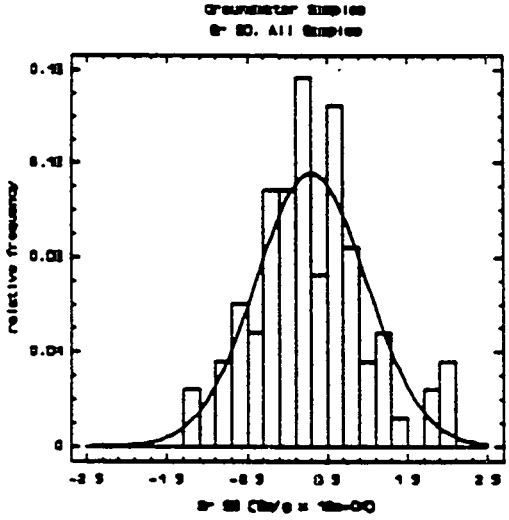


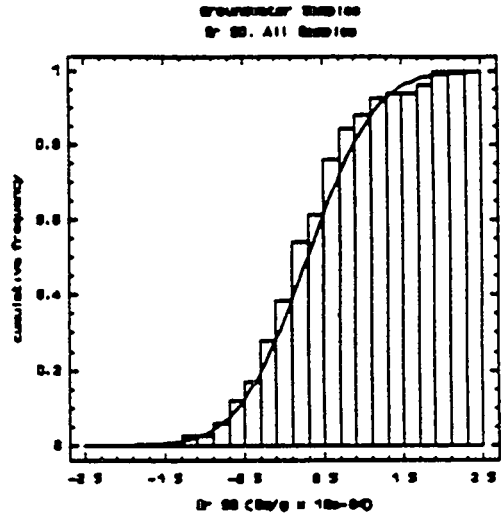


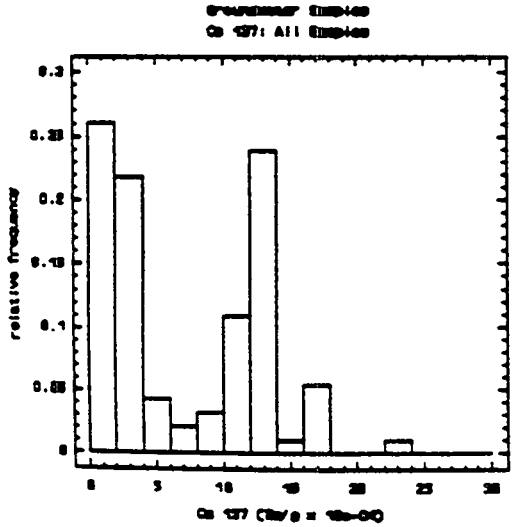


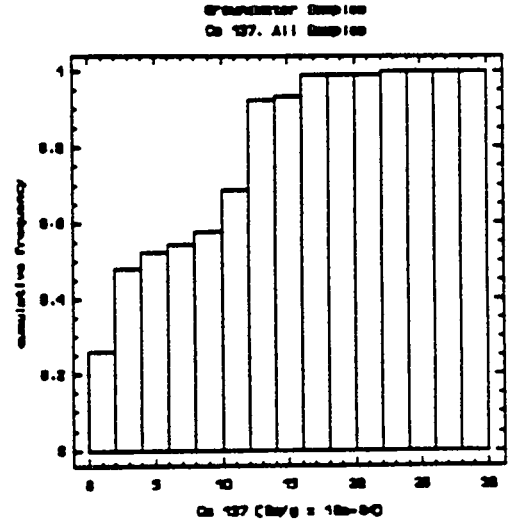

relative frequency

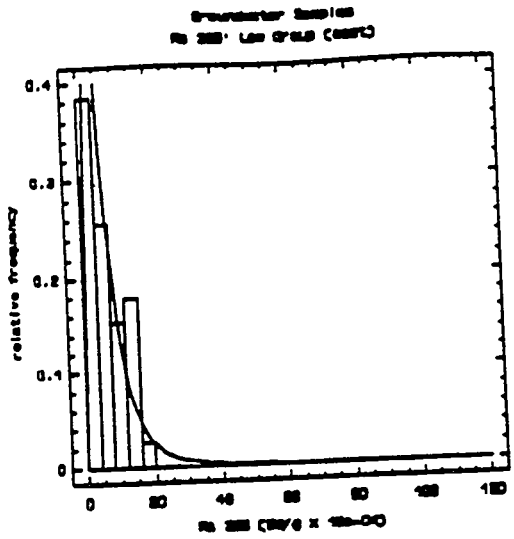

cumulative frequency

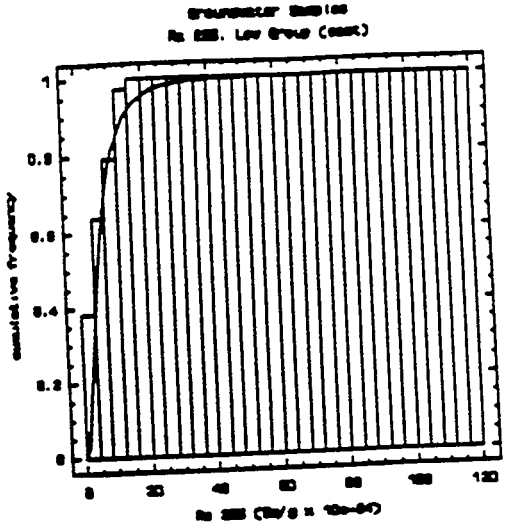

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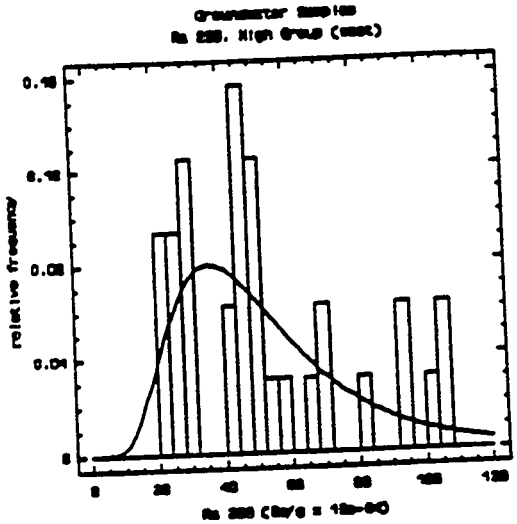

cumulative frequency

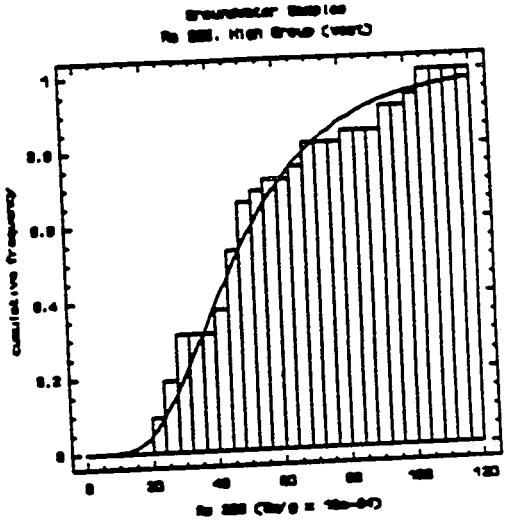

relative frequency

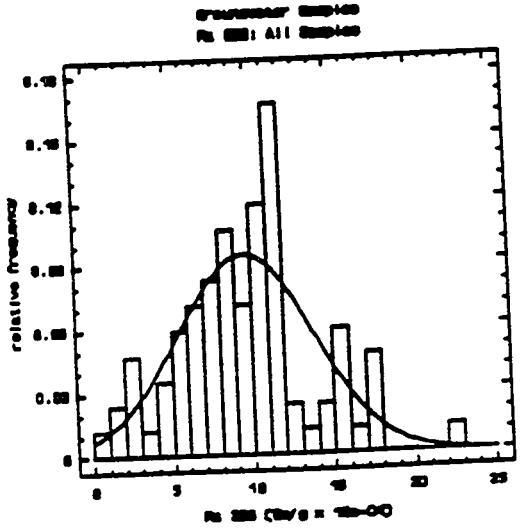

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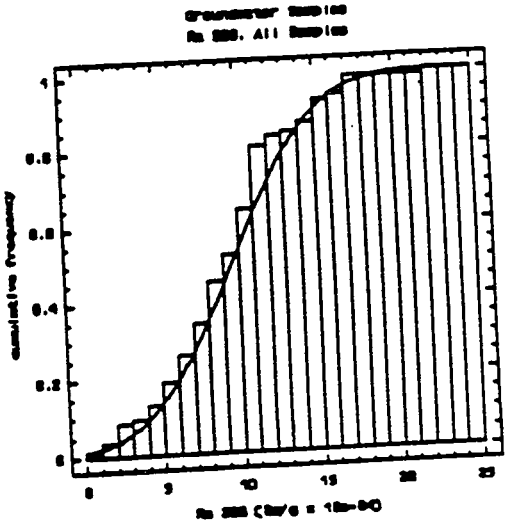


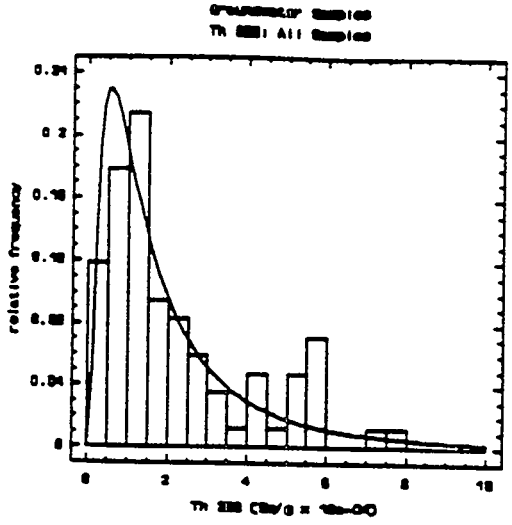


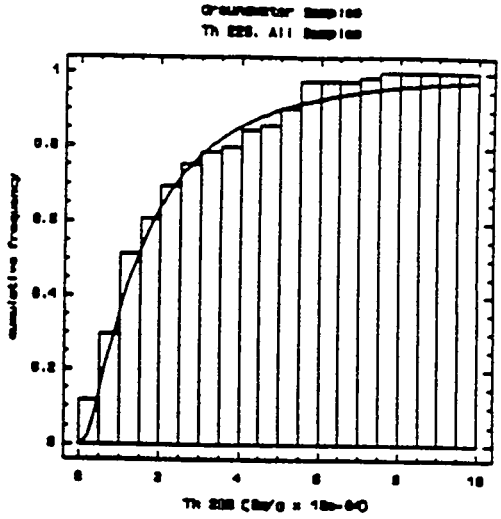


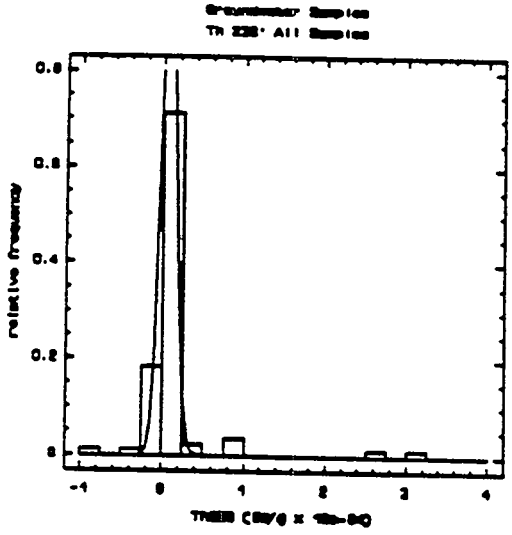


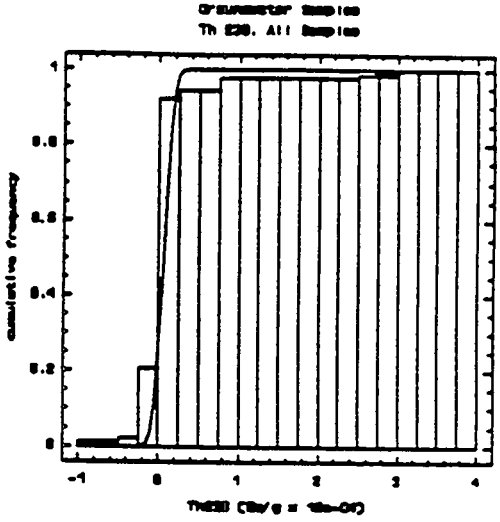


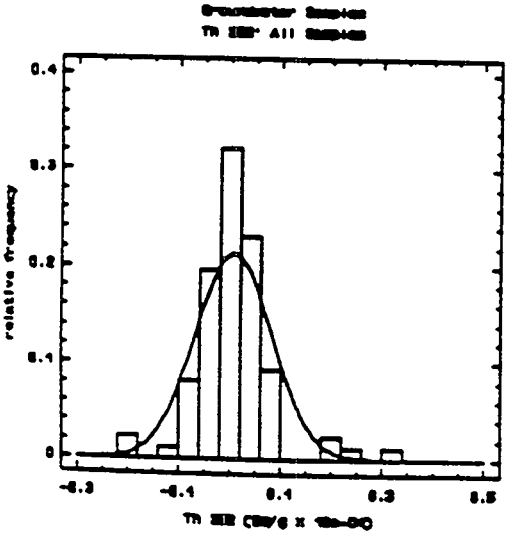


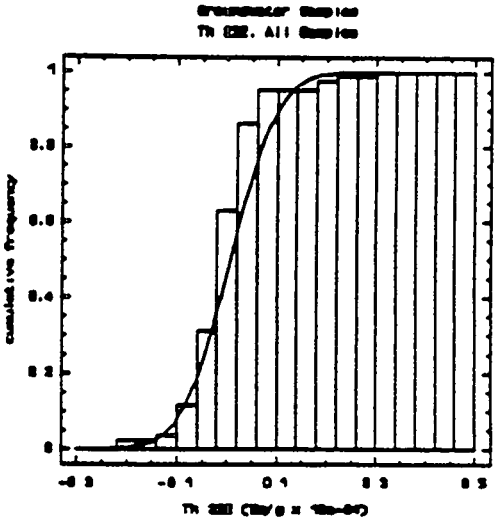


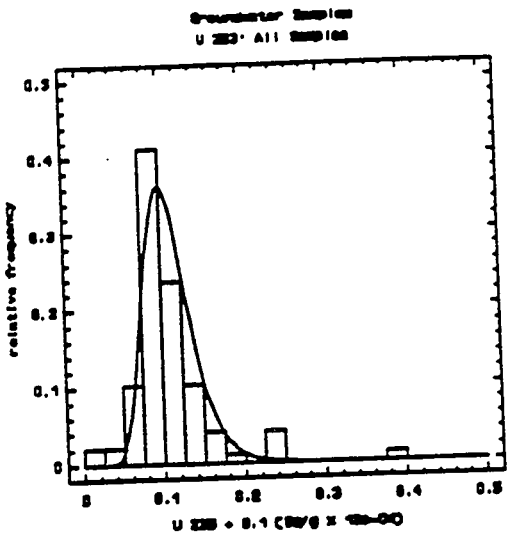


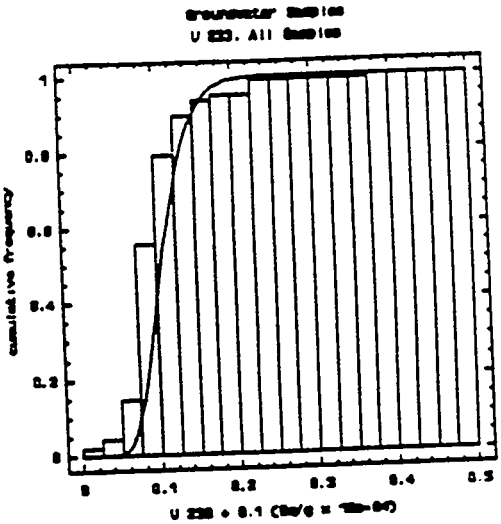


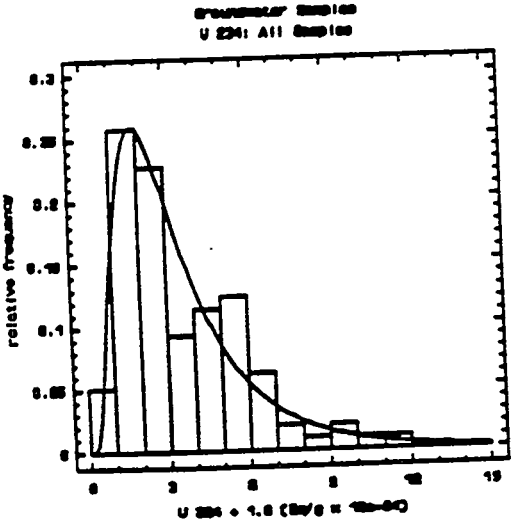


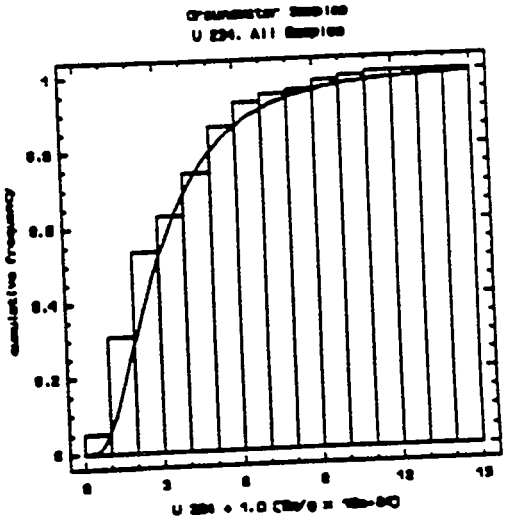


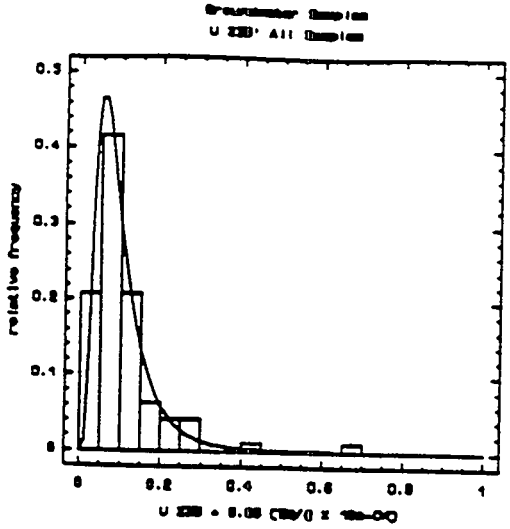


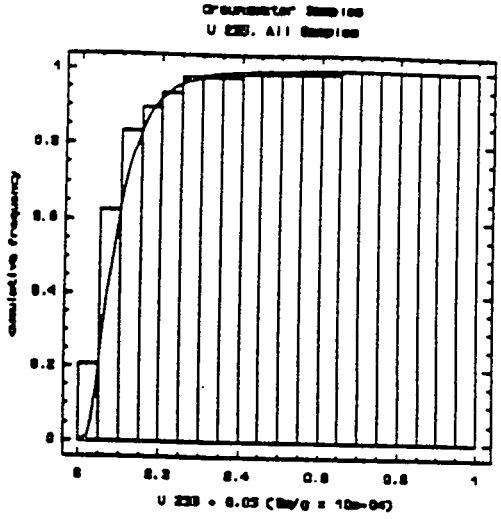

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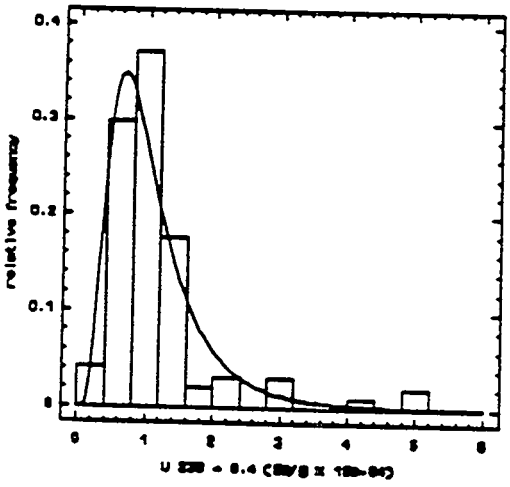

cumulative frequency

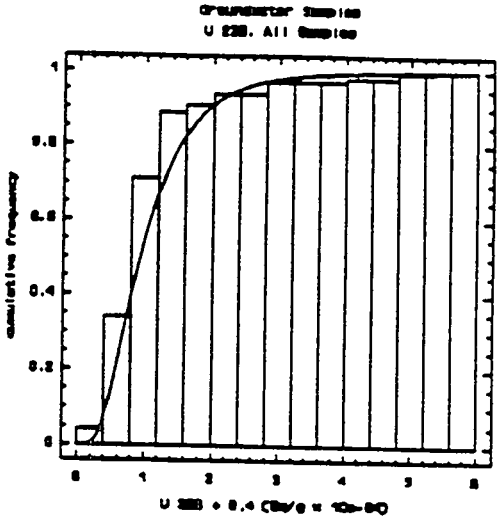

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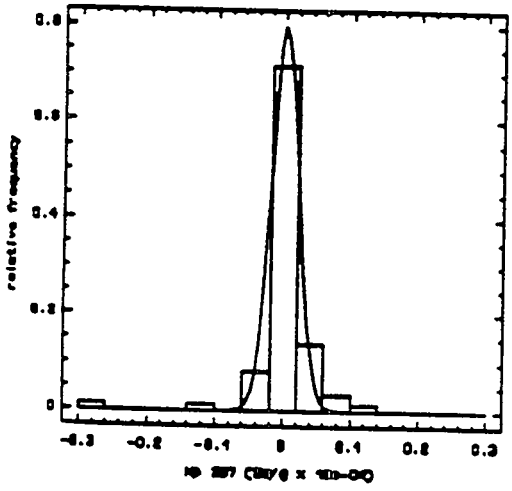

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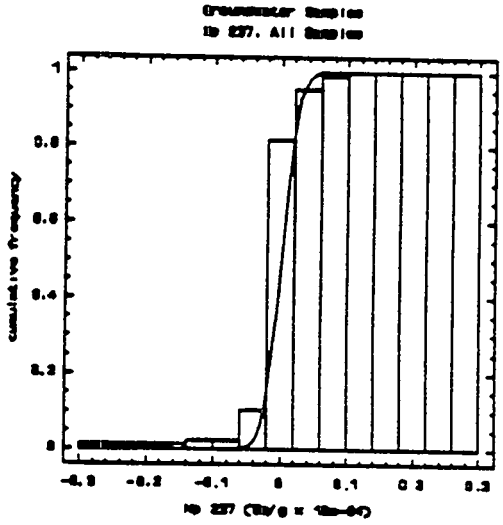

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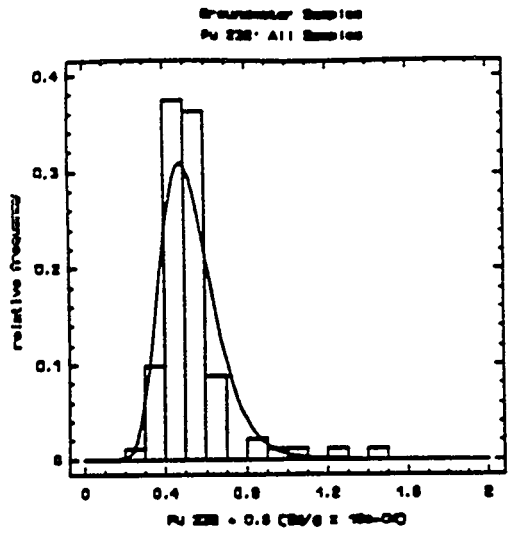

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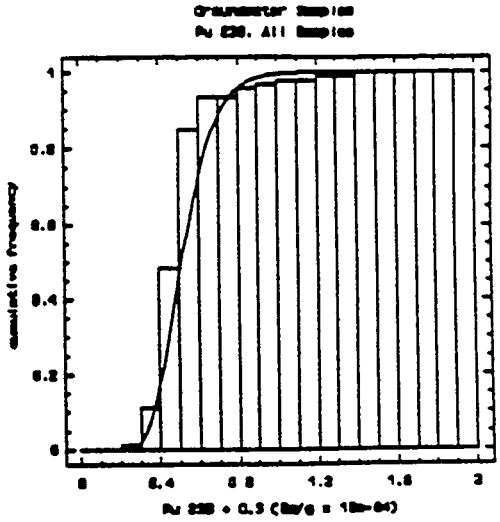

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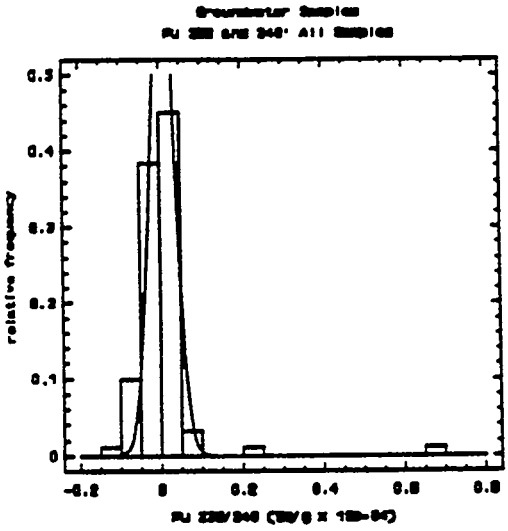

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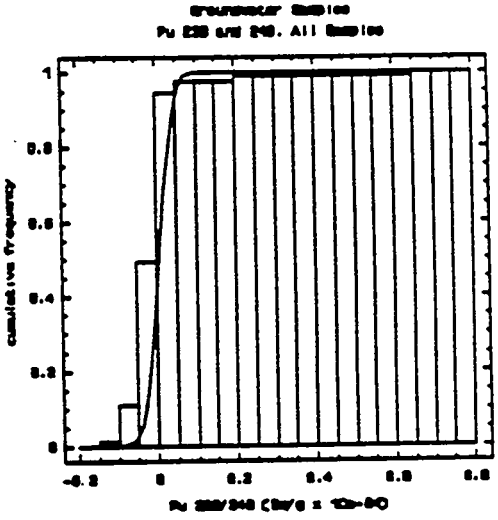

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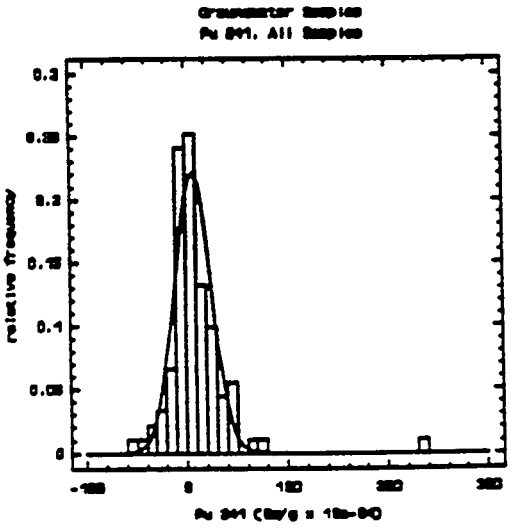

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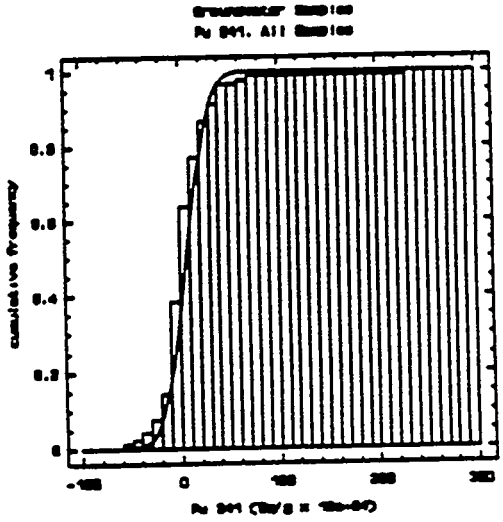

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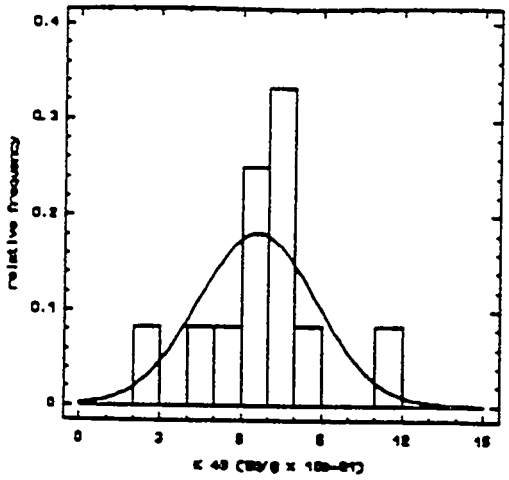

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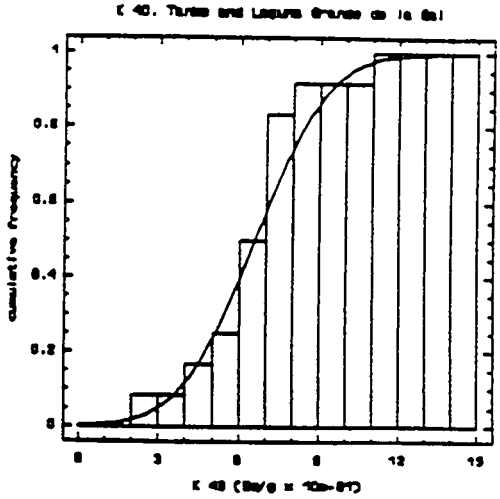

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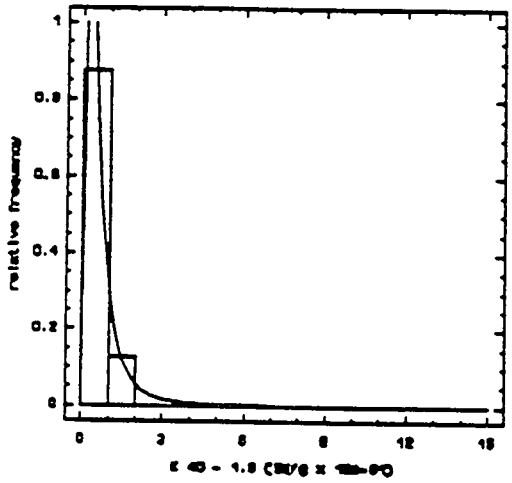

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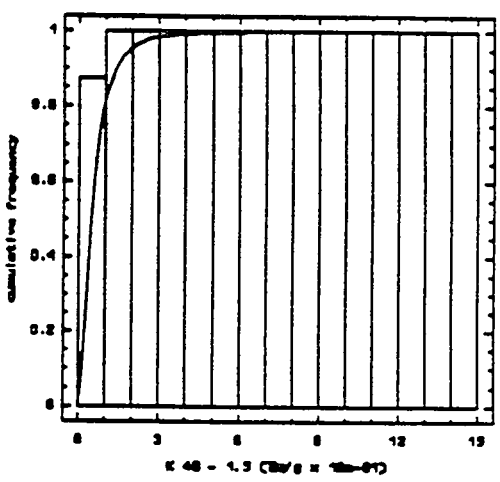

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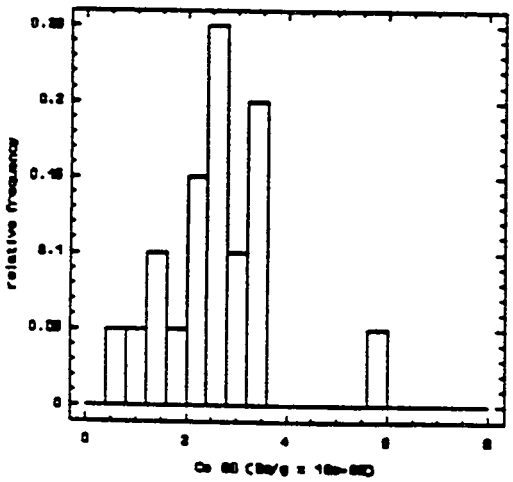

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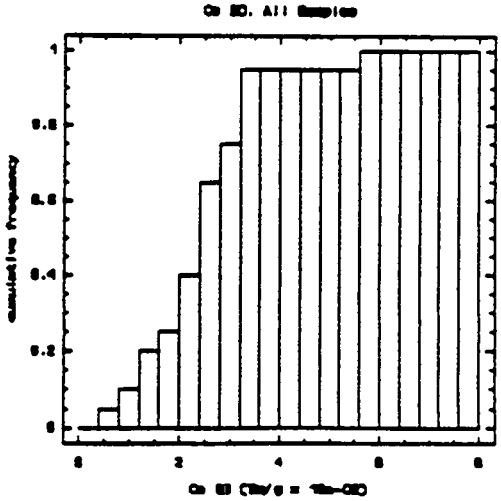

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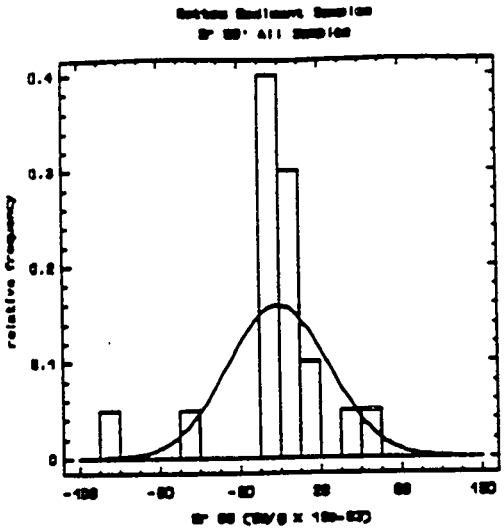

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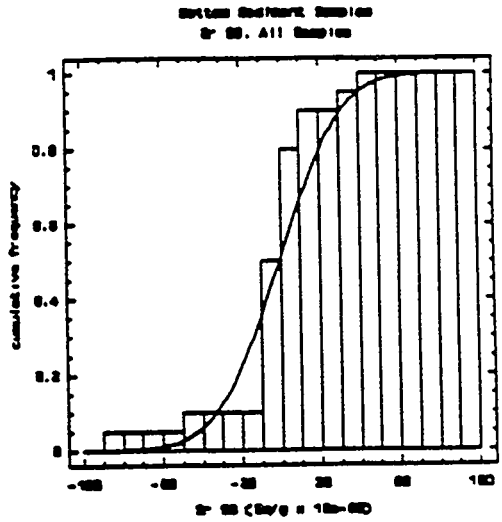

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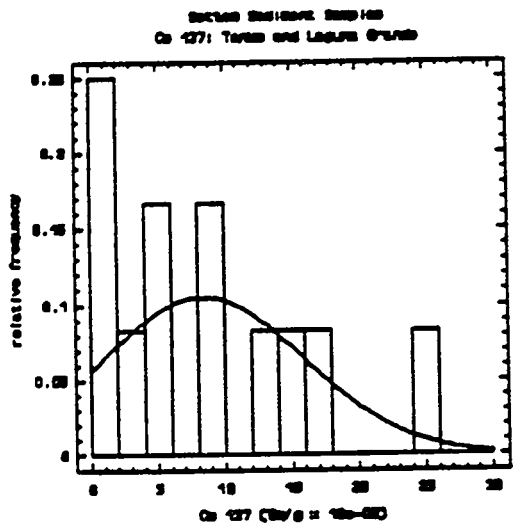

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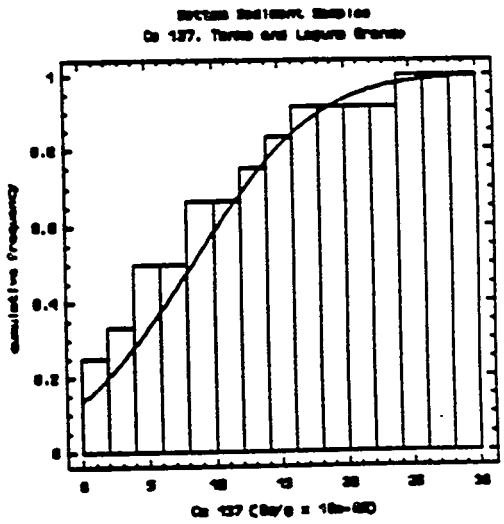

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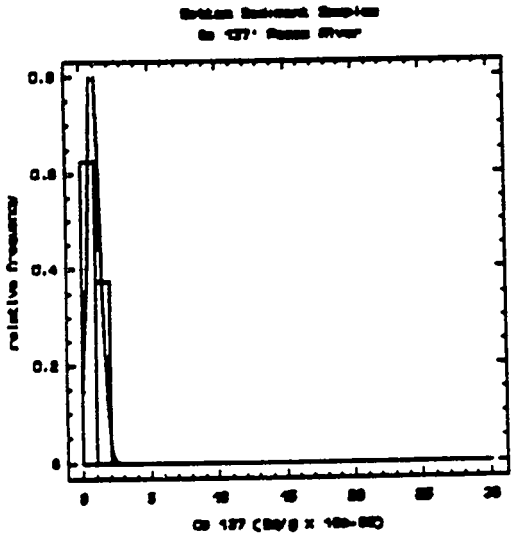

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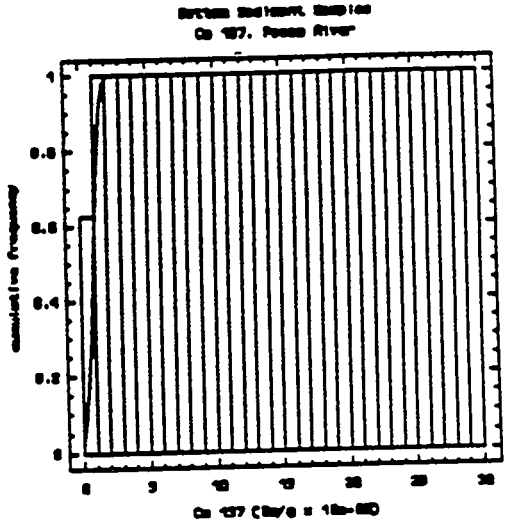


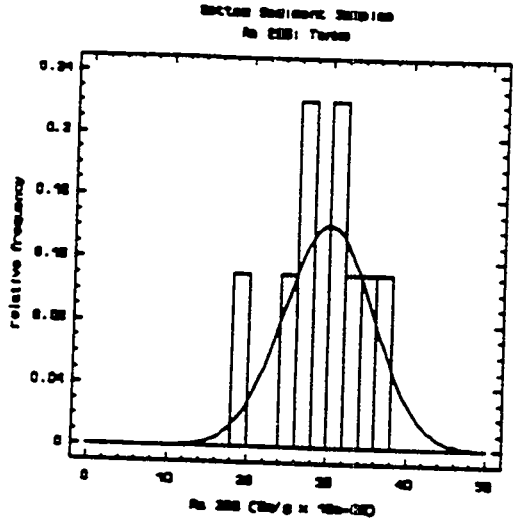


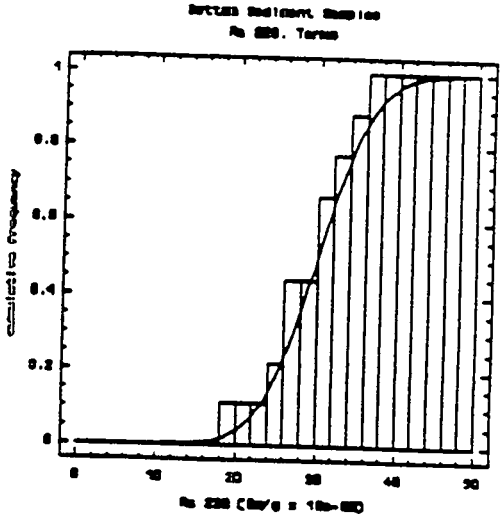


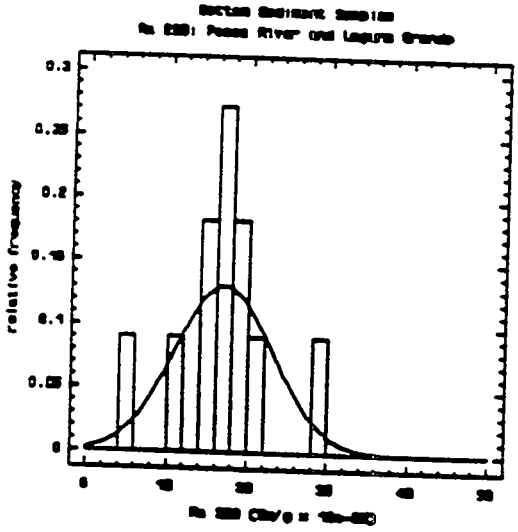


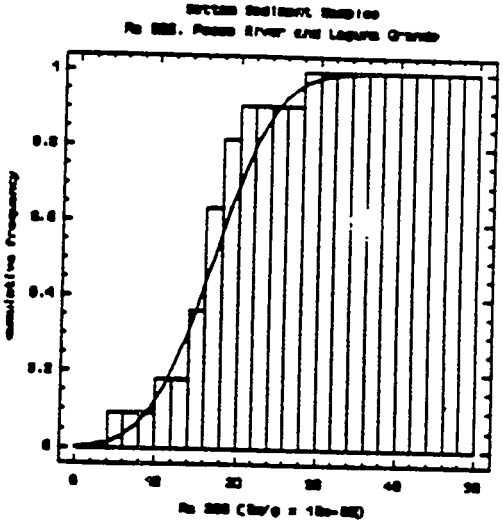


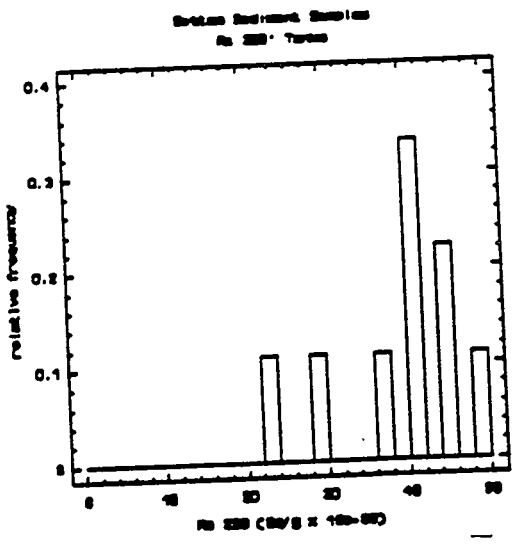


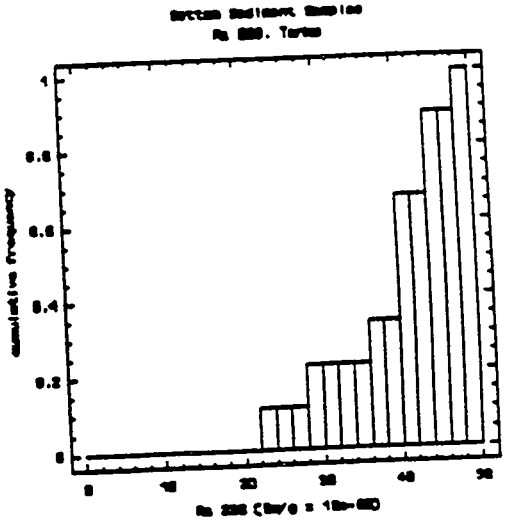


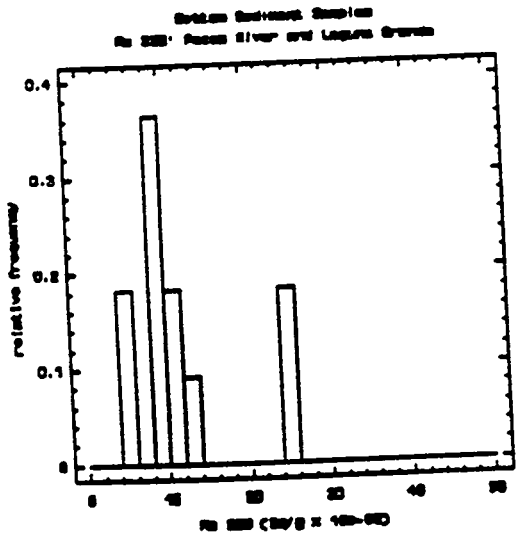


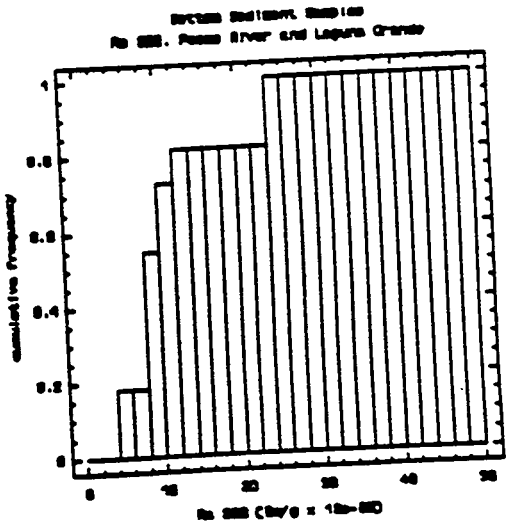


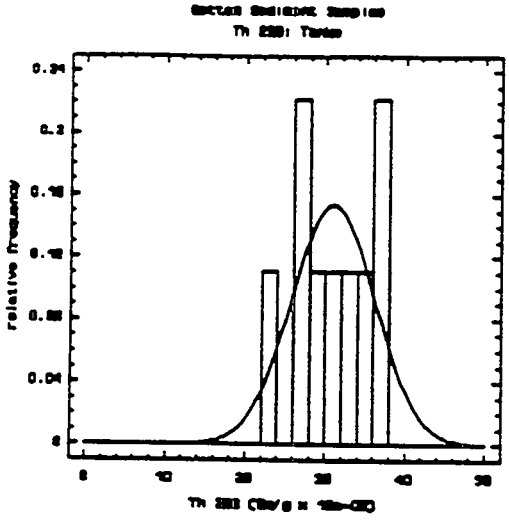


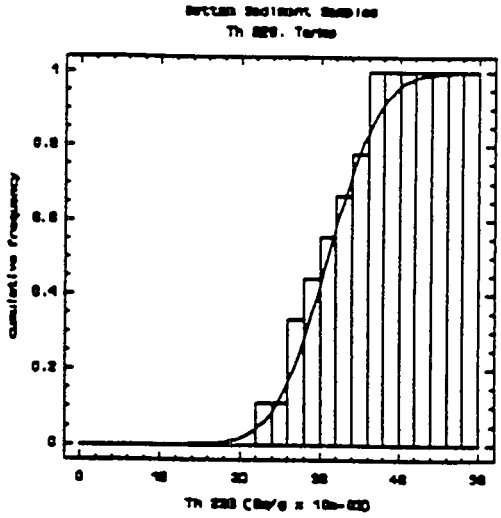

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0.2
0.1
0
0
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20
30
40
50

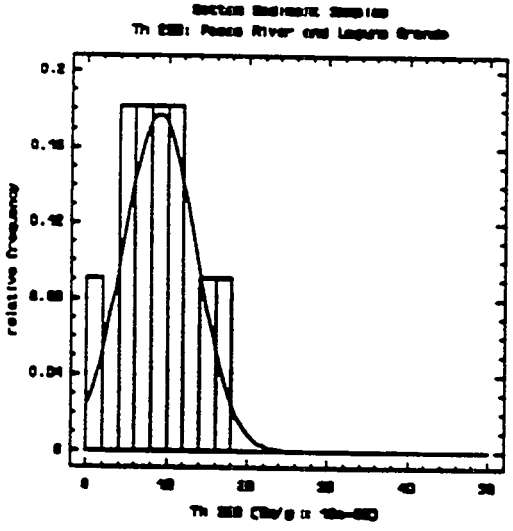

cumulative frequency
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0.4
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20
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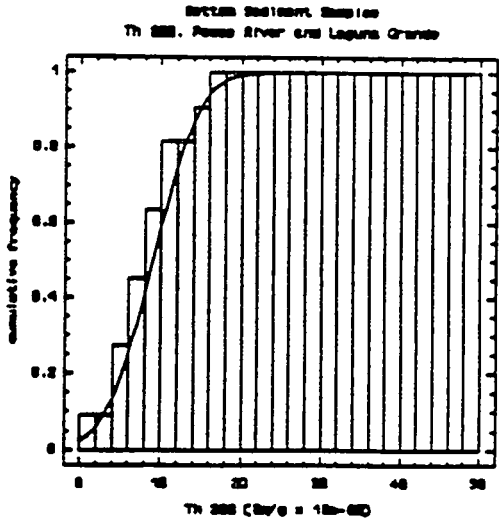

relative frequency
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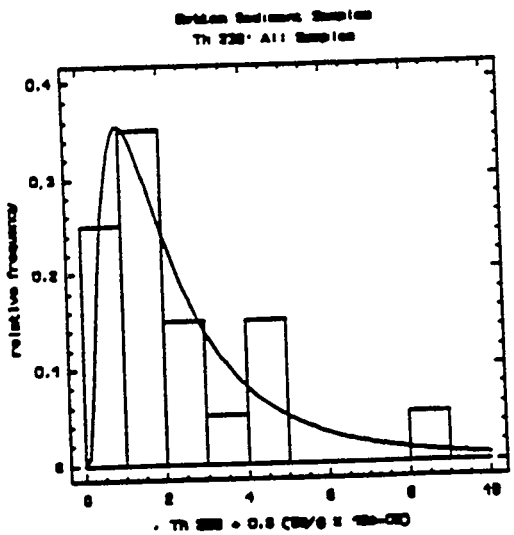

cumulative frequency
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0.4
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20
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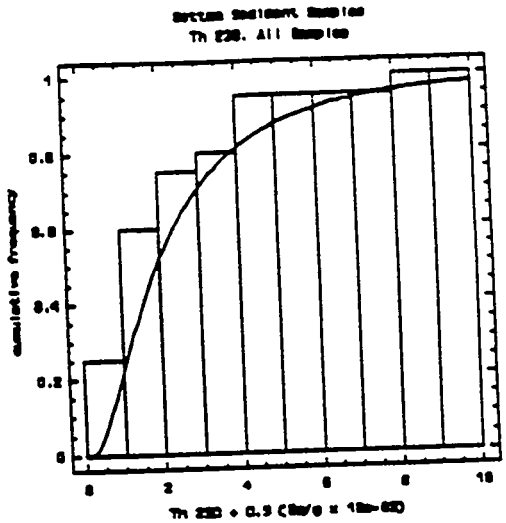


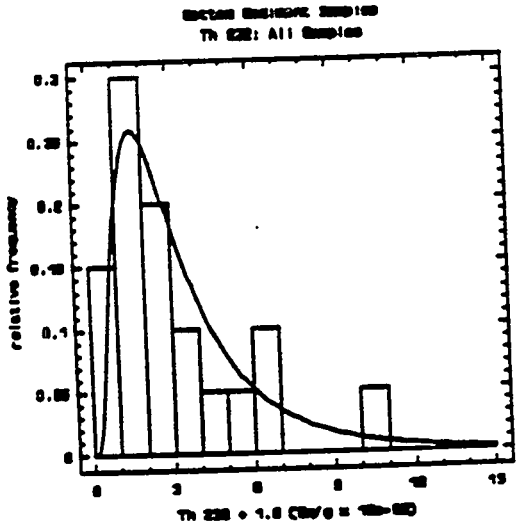


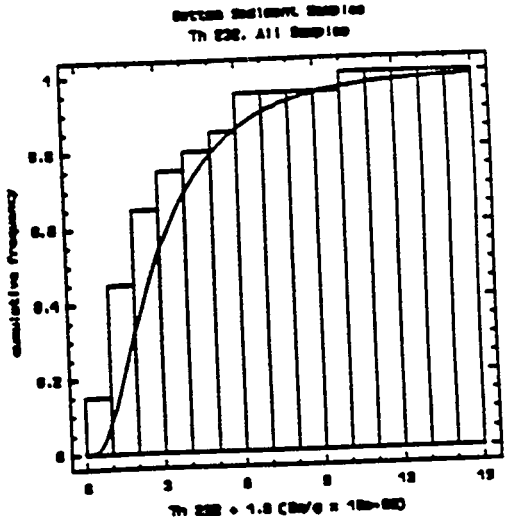


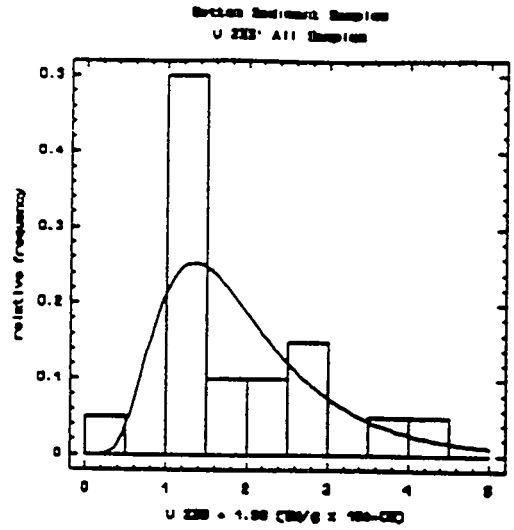


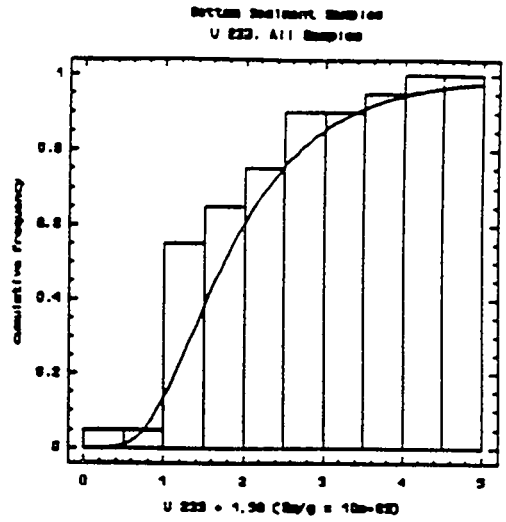

relative frequency
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0.2
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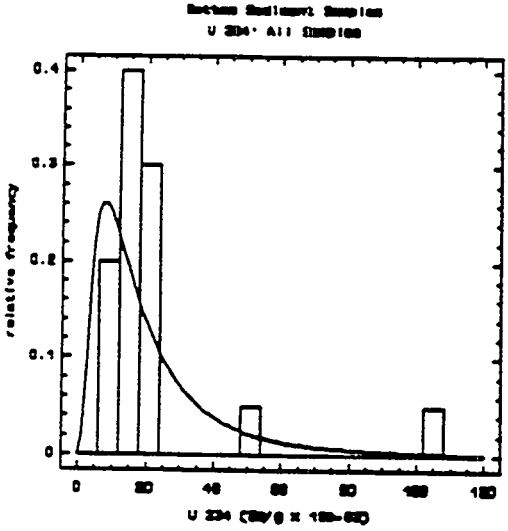

cumulative frequency
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0.6
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8
10

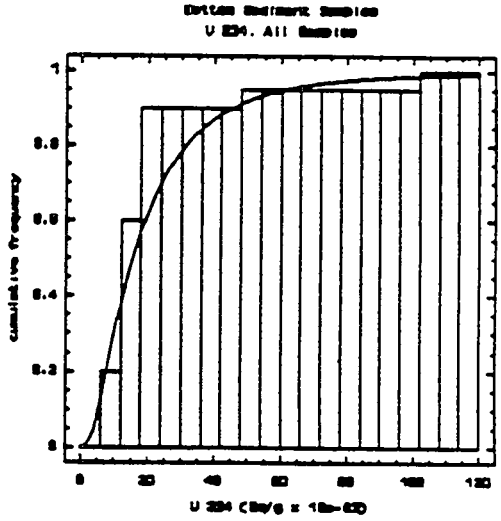

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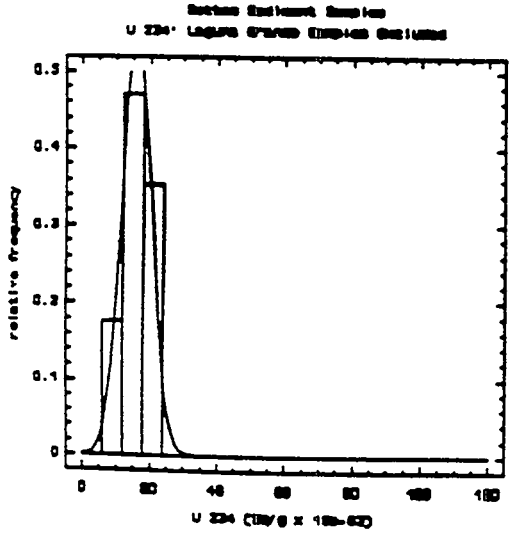

cumulative frequency
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0.4
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9
12
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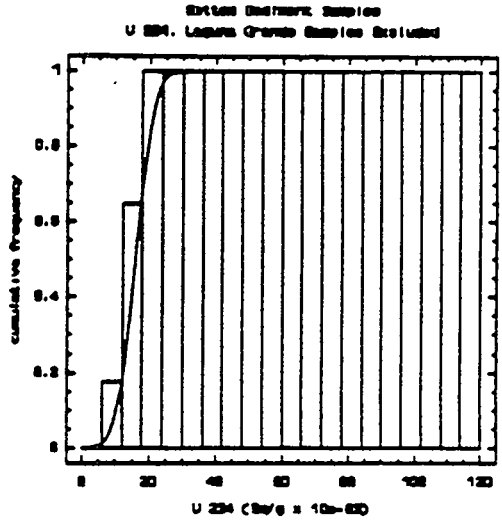

relative frequency


cumulative frequency


relative frequency


cumulative frequency


relative frequency


cumulative frequency

