3151

SAND78-2194C

Conf. 790204-4

MASTER

# GEOTECHNICAL EVALUATION OF THE PROPOSED WIPP SITE IN SOUTHEAST NEW MEXICO*



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*Work supported by the U.S. Department of Energy

October, 1978

## ABSTRACT

The Department of Energy is proposing to demonstrate the acceptability of geologic disposal of radioactive waste by locating a Waste Isolation Pilot Plant (WIPP) in the salt beds 26 miles east of Carlsbad, New Mexico. The WIPP will serve as a permanent repository for defense generated transuranic contaminated waste and will also be used as a facility in which experiments and demonstrations with all radioactive waste types can be conducted. The present area being proposed for the WIPP is the second such location in the Delaware Basin for which new site data have been developed; the first site proved geologically unacceptable. Ecologic and socioeconomic aspects have been investigated and extensive geophysical, geologic and hydrologic studies have been conducted to allow an evaluation of site acceptability. This paper will deal principally with the geotechnical aspects of site characterization. These studies are now sufficiently complete that the site can be recommended for further development of the WIPP.

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## INTRODUCTION

For twenty years the Department of Energy (DOE) and its predecessor organizations, the Atomic Energy Commission and the Energy Research and Development Administration, have pursued a research effort investigating the phenomena accompanying the emplacement of radioactive waste in rock salt. This program, which has not revealed any effects which would preclude the use of salt beds for geologic disposal of radioactive waste, has led to the implementation of the Waste Isolation Pilot Plant (WIPP) project.

The WIPP, as presently conceived (Fig. 1) will utilize the deep salt beds in southeast New Mexico to provide geologic isolation for transuranic (TRU) contaminated waste generated by United States defense programs. In addition, the WIPP will provide an underground "laboratory" where realistic and large-scale tests can be conducted using high-level waste (HLW). While variations and additions to this WIPP mission have been proposed from time to time (the charter for this facility is presently under discussion within the DOE) these two central features have remained a fundamental part of the WIPP. From the outset, however, site selection has been conducted utilizing siting factors appropriate for a high-level waste repository in order to provide as much flexibility for future options as possible.

## SITE SELECTION FOR THE "WIPP"

The AEC had proposed in 1972 that salt beds near Lyons, Kansas, be used to develop the first geologic repository for nuclear wastes. When this specific location proved to be unacceptable, the United States Geological Survey (USGS) and Oak Ridge National Laboratories (ORNL) evaluated existing information on salt bodies within the United States (Fig. 2) to determine which of them could best meet the site screening criteria. The Delaware Basin, a structural sub-element of the Permian Basin, was identified as possessing the greatest potential for conforming to more of the site selection factors than other salt basins. More detailed examination of available data for four potential regions in the southeastern New Mexico portion of the Delaware Basin led to the selection of an area 30 miles east of Carlsbad, New Mexico where the first two exploratory holes were drilled by ORNL in the spring of 1974.[1,2,3,4,5,6] Further work at this site area was suspended until Sandia Laboratories was assigned technical responsibility for WIPP and resumed exploratory work by drilling the third exploratory hole in the summer of 1975. This test hole encountered an anticlinal structure within the deep salt beds which was of sufficient magnitude to rule out use of the area for a repository. In addition to the unacceptable dip of the beds, a substantial reservoir of geopressured brine existed within the porosity created by fracturing anhydrite beds of the Castile Formation. Rejection of this specific location led to a renewed investigation for an acceptable site within the New Mexico portion of the Delaware Basin.

## SELECTION OF THE PRESENT WIPP SITE

The renewed site selection activities proceeded through several stages. Stage 1 involved a re-evaluation of site selection factors as they pertain to the Delaware Basin. Stage 2 applied these site selection criteria and factors to the salt beds of the Delaware Basin in Southeast New Mexico. Stage 3 was the detailed characterization of the area selected by this screening process.

Stage 1 consisted of a re-evaluation of the general and specific site selection factors to allow incorporation of information gained since the area was originally chosen. The New Mexico portion of the Delaware Basin still appeared attractive for repository siting but an additional factor was established to assure that severe salt flow structures, now known to occur near the Capitan Reef, were avoided. This restriction eliminated consideration of a band five miles wide paralleling the front of the underground Capitan Reef. Another factor, the avoidance of deep drill holes which penetrate through the evaporite rocks, was relaxed from a stand-off distance of two miles to one mile from the boundary of the underground repository. This change was based on consideration of several studies.[7,8,9] The implications of these studies, viewed in the perspective of the site specific geologic and hydrologic setting in the Delaware Basin, was that even one-mile stand-off was very conservative for deep boreholes.

The major siting criteria and factors considered are listed in the following paragraphs. In most cases the nature of the factor desired can be indicated but not quantitatively specified a priori since the acceptable combinations of factors under the multiple barrier concept is so large. Many of the desired factors are just that - desired. They are sufficient but may not be necessary for long-term repository safety. The following site selection factors are specific to WIPP and southeast New Mexico. They should not be arbitrarily applied to other repositories and locations.

Geology Criterion: 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.

Factors: Topography - Must permit access for transportation. Effect on inducing salt flow during excavation must be considered. Surface water flow and potential for future inundation must be evaluated.

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

Thickness - Total thickness of the salt deposits should be several hundred feet to buffer thermal and mechanical effects. The desired thickness for a specific HLW repository bed is 50 feet or more to mitigate the thermal and mechanical effects at non-halite units.

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 six miles to the Capitan Reef and one mile to regional Salado dissolution have been established.

Lithology - Purity of the salt beds is desirable to reduce the brine content of the salt. Pending further investigations, three percent brine is established as an acceptable upper limit for the heat-producing waste horizon. Additional geochemical interactions must be considered if significant chemical or mineralogical impurities are present.

Stratigraphy - Continuity of beds, character of inter-bedding and nature of beds over- and underlying the salt are important considerations in construction of the facility and in assessment of possible failure scenarios.

Structure - Relatively flat bedding ($< 3°$) is desirable for operational purposes. Steep anticlines and major faults are to be avoided.

Erosion - While the depth factor reduces concern for erosion, it is desirable to avoid features which would tend to localize and/or accelerate erosion.

Hydrology Criterion: 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.

Factors: Surface Water - Present and future run-off patterns, flooding potential, etc., should not endanger the penetrations into the repository while these openings are unplugged.

Aquifers - For WIPP, the retardation of radionuclides in over- and underlying aquifers represents a secondary barrier if the salt is breached. Consequently, low permeability and transmissivity are desirable. Accurate knowledge of aquifer parameters is important to construction, decommissioning and realistic calculation of the consequences of failure scenarios.

Dissolution - Regional and/or local dissolution must not breach the repository while the wastes represent a significant hazard to man. While there is no general agreement as to an absolute time required, 250,000 years has been adopted as a conservative value in evaluating WIPP sites.

Climatic Fluctuations - Possible pluvial cycles must be considered when estimating the effects of the above factors.

Man-made Penetrations - The effect of drill holes and mining operations on the site selection must be evaluated in considerations of dissolution.

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

Factors: Seismic Activity - The frequency and magnitude of seismic activity impacts facility design and safety of operation. Low levels of seismicity are desirable but facility design and operation can accommodate higher levels if anticipated.

Faulting/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 which can enhance dissolution and hydrologic transport. Major faults and pronounced linear structural trends should be avoided.

Salt Flow/Anticlines - Major deformation of salt beds by flow can fracture brittle rock and create porosity for brine accumulation. Major anticlines resulting from this phenomenon should be avoided or evaluated to check on brine presence and anhydrite facturing.

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

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 long-term integrity of the repository.

Regional Stability - Areas of pronounced regional uplift or subsidence should be avoided since such behavior makes anticipation of future dissolution, erosion and salt flow more uncertain.

Igneous Activity - Areas of active or recent volcanism or igneous intrusion should be avoided to minimize these potential hazards to the repository.

Geothermal Gradient - Abnormally high geothermal gradients should be avoided to allow construction and maintenance of openings in salt at 3000 foot depths. High gradients may also be indicative of recent igneous or tectonic activity.

Physico-chemical Compatibility: The repository medium must not interact with the waste in ways which create unacceptable operational or long-term hazards.

Factors: Fluid Content - A three percent brine content is acceptable for the repository bed containing either high-level waste or TRU waste. The upper limit for brine content has not yet been established. Brine content has less significance for TRU waste horizons.

Thermal Properties - No major thermal barriers should exist closer than 20 feet above or below a HLW horizon to avoid undesirable temperature rises.

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 selection of the repository horizon.

Chemical Properties/Mineralogy - Beds of unusual composition and/or containing minerals with bound water should not occur within 20 feet of a HLW horizon. This will lessen the uncertainties with regard to thermally driven geochemical interactions.

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

Permeability - Salt has very low permeability and only the inter-beds and surrounding media are considered for siting with respect to this factor. 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.)

Nuclide Mobility - This is a secondary factor in WIPP site selection since confinement by the salt and isolation from water is the basic isolation premise. Ion sorption must be evaluated to allow quantification of safety analyses and to indicate whether engineered barriers (waste form and/or absorptive overpacks) would be beneficial.

Another criterion, while not totally geotechnical in nature, was important in site selection and is included here for completeness.

Economic/Social Compatibility Criterion: The site must be operable at reasonable economic cost and should not create unacceptable impact on natural resources or the biological/sociological environment.

Factors: Natural Resources - Unavoidable conflict of the repository with actual or potential resources will be minimized to the extent possible consistent with meeting other significant siting factors.

Man-made Penetrations - Boreholes or shafts which penetrate through the salt into underlying aquifers shall be avoided within one mile of the repository. Existing mining activity, unrelated to the repository, should not be present within two miles of the repository. Future, controlled mining, will be allowable up to one mile from the repository. Future studies may permit still closer mining and drilling if properly controlled.

Transportation - Transportation should be capable of ready development. Avoidance of population centers by transportation routes is not a factor in WIPP siting.

Accessibility - The site should be readily accessible for transportation and utilities.

Land Jurisdiction - Siting will be on federally controlled land to the extent possible.

Population Density - Proximity to population centers and rural habitats will be considered in siting. Low population density in the immediate site area is desirable.

Ecological Effects - Major impacts on ecology due to construction and operation should not occur. Archaeological and historical features of significance should be preserved.

Sociological Impacts - Demographic and economic effects should not result in unacceptable sociological impacts.

The siting factors having the greatest impact on actual location of the WIPP site have been rephrased and listed below. The first four factors were accorded higher priority than the last five.

Salt of high purity at a depth between 1000 and 3000 feet.

Avoidance of areas within one mile of any boring through the Ochoan evaporites and into the Delaware or deeper formations.

Avoidance of areas of deep dissolution and where dissolution had advanced at the top of Salado, by establishing a distance of one mile or more from dissolution fronts at the top of Salado.

Avoidance of possible salt deformation in a belt six miles wide and basinward from the Capitan Reef.

Avoidance of pronounced known anticlinal structures.

Avoidance of known oil and gas trends.

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

Minimize existing potash lease rights within the three square mile repository area.

Minimize state and private land in the 30 square mile area to be withdrawn for the site.

In stage 2 of the WIPP site selection these criteria and factors were applied to all areas within the Delaware Basin in New Mexico.[10] Figure 3 illustrates the result of application of the expanded set of criteria. Two sites survived the constraints imposed by the above site selection factors. New field studies specific to these areas were not conducted at this stage of site screening.

The third stage of site selection required detailed evaluation of the area selected in stage 2 on the basis of the initial reconnaissance. It was possible that this detailed study would reveal that some siting factors would not be ideally met. It is unlikely (and unnecessary) that a site will be ideal with respect to all selection factors. Similarly, it is unnecessary and, indeed, impossible to prove that the "best" site has been selected. The detailed extent of investigation in stage 3, site characterization, is such that all prospective sites cannot be examined in this detail. Rather it is sufficient to establish that an adequate, safe, and acceptable site has been identified. This requires that potential failure modes and hazards be recognized and that siting factors take them into consideration.

Since only two alternate sites in the New Mexico part of the Delaware Basin withstood the set of stage 2 siting criteria, the selection of a preferred site was fairly straightforward. The selected site, now known as the Los Medanos site, was clearly the preferred location. Alternate II was considered less desirable because it was restricted in size, the acceptable salt zones were deeper, and the high-purity salt lying between the Cowden anhydrite (in the lower Salado Formation) and the Castile was thought to be absent. The top of the Salado was about 800 feet deep at Los Medanos versus 1500 feet at Alternate II. Other factors that favored the selection of the Los Medanos area were:

Structural interpretation of what seismic data was then available to Sandia indicated the Los Medanos site would be in a synclinal area unfavorable for oil and gas accumulation.

Similarly, if the site were in a syncline, geopressured brine reservoirs would be less likely.

The Alternate II area lay adjacent to the Double X and Triple X shallow oil fields where water flooding for secondary recovery could occur.

Sandia Laboratories selected the Los Medanos alternate as the best candidate area in early December, 1975. Site evaluation and exploration activities were then expanded to focus on obtaining subsurface data at the Los Medanos site. This constitutes stage 3 of the site studies which has been recently summarized.[11]

The area identified for detailed site studies is located approximately 26 miles east of Carlsbad, New Mexico (Fig. 4). The area to be withdrawn if this site is approved is shown in Fig. 5. This site is situated geologically in the northern part of the Delaware Basin, a sub-element of the Permian Basin, which contains extensive, thick evaporite deposits (Fig. 6) of salt and anhydrite of Permian (about 230 million years) age. Extensive geophysical surveys, geologic and hydrologic studies and numerous boreholes have been utilized to evaluate the region with respect to the site selection criteria. The broad scope of geologic information required for site evaluation, both before and after site selection, has and will continue to utilize most of the basic earth science methods of investigation. These investigatory tools fall into the major categories of field geology, geophysics, geochemistry, and rock mechanics.

Field geology, geophysical survey techniques and boreholes were extensively used to map the stratigraphy and structure of the WIPP region. Considerable stratigraphic information already existed for the general region in the form of research publications and proprietary data in petroleum and potash company files. The 54 boreholes drilled as part of the WIPP site characterization have served a variety of purposes and many are multipurpose. About 20 of these holes have been used to acquire hydrologic data and an additional three holes have been principally for dissolution and/or paleoclimatic studies. Ten holes were exploratory borings to acquire stratigraphic and lithologic data related to the site and to evaluate geophysical indications of possible subsurface structures. Finally, 21 holes to obtain samples for potash assay were drilled to supplement about 30 potash industry holes. This allowed a one-mile sample grid to be completed over the proposed site. All these drill holes were logged, and many were cored and drill-stem tested to acquire formation property data.

With the exception of ERDA 9, which was drilled to proposed repository depths at the center of the site, none of the other drill holes within one mile of the three square mile repository zone penetrate to repository depths. A drill hole soon to be completed one mile north of the site center will be the second hole to sample the repository horizon in the vicinity of the eventual repository. Locations of all holes drilled for WIPP as well as prior existing holes within or near the WIPP site area are shown in Fig. 7.

Exploration geophysics techniques have been used at the WIPP site with varying degrees of usefulness. Among the useful methods are those described in the following paragraphs.

Seismic reflection techniques have been extensively used to provide information on the structure and depth of subsurface formations at WIPP. Early in the preliminary site evaluation, 1500 line miles of existing petroleum company seismic reflection data and 26 line miles of a newly acquired seismic reflection survey were examined for evidence of major faults and other structures. The nature of the data limited its usefulness for examination of shallow (less than 4000 ft) horizons. Information on shallow horizons was subsequently acquired by instituting 48 line miles of special seismic reflection surveys. Conventional vibroseis equipment was used with closer geophone spacing and with vibroseis source and recording adjusted to provide better resolution at depths less than 4000 ft. Experience has shown this technique can provide good information on reflectors in the Castile and below, but must be used with a great deal of caution when attempting to define the attitude of the top of the Salado. Reflections from this horizon and depth are erratic. An additional 65 line miles of reflection data is now being acquired to provide engineering definition at depths of potential repository horizons.

Surface electrical resistivity proved to be a valuable tool to search for dissolution related features in the Delaware Basin. Resistivity surveys over known deep solution features, such as roughly cylindrical collapse chimneys or "breccia pipes", give characteristic signatures. Consequently, closely spaced resistivity surveys were made over the site to examine it for these anomalies. Indicated anomalies were then confirmed or denied by test drilling. The surveys, using a modified Werner electrode array, were run along lines 500 ft apart over the entire 30 square miles of the site area and resulted in about 9000 data points. An "expander" or Schlumberger array was used to investigate changes in resistivity with depth at a given location. The latter configuration was used to determine whether low resistivities were associated with the presence of the brine aquifer. One resistivity signature typical of local dissolution was observed at the WIPP site. Drilling at this location indicated the resistivity "anomaly" was not due to dissolution but rather to greater porosity in redbeds near the surface.

Magnetic methods were employed to search for both regional and local features expected to show magnetic contrast. Existing aeromagnetic surveys of the Delaware Basin were examined for indications of major faulting or igneous intrusives. A known igneous dike nine miles northwest of the site was the only intrusive observable in these data; a higher resolution survey will be used to examine the region near the WIPP site for similar but less evident intrusives. Samples from the intrusive body northwest of the WIPP site have been dated at nearly 35 million years old.

Gravity data for the Delaware Basin were examined for indications of major geologic structures and for their utility in detecting collapse features. The absence of the former in the WIPP site and the failure of collapse features to exhibit significant density differentials limited the usefulness of the gravity technique.

Other geophysical measurements are being used to aid in investigation of present and future tectonic activity. Seismological earthquake monitoring has been conducted on and near the WIPP site to help establish the pattern of tectonic-related seismic activity. A single station has operated at the Los Medanos area for four years to document local seismic activity. This station will be expanded to an array which will continue throughout the operational life of the facility. A seismic array has been operating near Kermit, Texas, on the Central Basin Platform, to establish whether seismic events originating there are natural or are induced by oil-field flooding operations.

First-order level line surveys, tied into the national grid established by the National Geodetic Survey (NGS), were made by NGS within the regional and local area of the WIPP site. These permanent stations will be periodically reoccupied to detect tectonic movements and subsidence due to natural dissolution and potash mining.

Physical and geochemical properties required for WIPP site evaluation have been obtained from laboratory tests on core samples. Rock mechanics and thermal properties have been characterized for the repository horizons. Brine content and halite impurities have also been established.

Hydrologic considerations are important to site selection for WIPP from the standpoint of current and future dissolution of salt and because, if the salt is breached by any mechanism, hydrologic transport is the most likely means of moving radionuclides into the biosphere. The objective of the hydrologic testing is to allow development of an adequate model to permit calculation of both dissolution and nuclide transport. The parameters important to the model are head or reservoir pressure, the water-yielding potential of the rock strata and the chemistry of formation waters. Complementary laboratory measurements are developing ion exchange (retardation) coefficients for the transport model. At the present time, hydrologic data is available from 20 holes drilled for the WIPP project. Two of these sample the aquifers below the evaporite beds, and deep aquifer data from other nearby holes will become available in the next two years. The regional hydrology of the deep formations is adequately characterized by previous investigations.[12]

The methodology applied in developing the hydrologic model is to characterize the hydrologic system in detail at the repository and develop data at larger intervals as the distance from the repository increases. There are four triangular nests of three hydrologic holes each with spacings of 50 to 100 feet between holes. The next larger scale employs spacings of 0.5 mile between test points. These holes in turn form part of a still larger grid of hydrologic holes which surround the site at a spacing of two to three miles. These data have permitted development of a model to be used in calculating the consequences of postulated breaches of the repository. The hydrology at the site is relatively favorable in that the quantities and flow rates are very low, and the quality of the water is so saline it is not potable.

## SUMMARY OF SITE EVALUATION

Information gathered on the geotechnical aspects of the proposed site has been evaluated with respect to the siting factors previously listed. Studies by various investigators have been useful in indicating the possible geologic features in the Delaware Basin that could pose threats to long-term repository integrity.[13,14] Site selection was structured to search for and avoid these features. Those factors with greatest potential impact on WIPP site selection will be briefly discussed.

The factors for depth, thickness and lithology are well met by the present site. Brine content in the lower horizon to be used for HLW experiments is less than 0.5%. The structure and stratigraphy indicated by borehole and seismic data are acceptable.

The hydrologic regime in the WIPP site is also favorable. Potential heads in the overlying and underlying aquifers are not greatly different so the driving force, if they are connected, is slight. The region is near a hydrologic divide so recharge to the aquifers over the site is moderate. These aquifers have relatively low transmissivities and flow velocities are low. Nuclide retardation coefficients in these aquifers are significant for most radionuclides of concern. Future climatic changes should not lead to unacceptable hydrologic conditions or erosion rates for this site.

Since the most plausible natural mechanism for breaching the repository is through dissolution of the salt barrier by groundwater, this aspect was given extensive study. Regional geologic studies in the Delaware Basin have revealed areas of past and present dissolution activity.[13,14] Knowledge of these regional dissolution fronts and of local collapse features due to salt dissolution has allowed implementation of geophysical investigations to assure that such features do not exist in, or near enough to, the site to present a hazard to long-term repository integrity. Geologic studies indicate the regional dissolution front west of the site area (Fig. 4) is progressing eastward at a rate of less than six to eight miles per million years and is moving downward at a rate of less than about 500 feet per million years.[15,14,6] These conservative values assure the repository beds will not be breached by regional dissolution for many million years. Since these are average rates covering the past 600,000 years, the effect of previous pluvial cycles is included, and, consequently, the forecast also incorporates the effect of similar future pluvial cycles.

Rb-Sr isotope geochronology of samples from the bedded salt deposits of the WIPP area indicates no significant recrystallization or formation of brine within the Salado salt since early in its diagenesis over 200 million years ago. Examination of petrographic structures and mineral relationships support these observations. It is evident, however, that some beds such as those containing sylvite or polyhalite, did experience mineral replacement and recrystallization during diagenesis. The natural long-term stability of the site and avoidance of those local dissolution features, which have the potential for jeopardizing the long-term integrity of the repository, provide a high confidence in the ability of the site to isolate wastes from the biosphere for very long times.

Local dissolution features are recognized in the Delaware Basin. These may be of either shallow or deep origin, and it is the latter which may pose the greater potential hazard to the repository. These features, often called collapse chimneys or breccia pipes, form when localized dissolution occurs deep in the evaporite section, possibly at the base of the salt beds, resulting in a void into which overlying beds collapse. These collapse chimneys are known to exist in portions of the basin which have seen extensive dissolution activity. Seismic and resistivity surveys reveal these features, and application of these techniques to the site area indicate the site area is free of them. Studies are in progress to better understand the genesis of collapse chimneys and to evaluate the age, chronology, permeability and the dissolution consequences to adjacent salt beds for a known chimney.

Dissolution may also occur through man-made boreholes if these holes penetrate through the salt and establish water circulation by connecting water-bearing rocks above and below the salt beds. To mitigate this concern, a conservative buffer of one mile between the repository and any such holes has been required. When an adequate borehole plug has been demonstrated, it may be possible to relax this restriction.

Geologic features such as anticlines and faults have been considered in site selection. Salt flow structures, which are known to be present in portions of the Delaware Basin, may distort the rock units sufficiently to make mining operations difficult and may also lead to fracture of the more brittle anhydrite beds occurring within the salt. This fracture porosity may allow brine to accumulate and, in some instances, form brine reservoirs of significant volume. These features may be detected and examined by seismic surveys and by drilling exploratory holes when indicated. The WIPP site is believed to be free of unacceptable salt flow structures. Likewise, should major recent faulting exist near the repository it could be a concern for long-term repository integrity if it should lead to increased rates of dissolution. Open faults or fractures within the salt are not observed or anticipated due to its plasticity, but overlying aquifers and aquitards could be affected by faulting. Techniques used to search for faults at the WIPP site are field geologic mapping, aerial and satellite imagery, and the geophysical investigatory techniques of seismic reflection, resistivity, aeromagnetics and gravity. No active or Quaternary faults of tectonic origin have been detected within the WIPP site. Instrumental monitoring since 1974 confirms very low seismicity at the WIPP site and surroundings; caliche formation and position indicates tectonic stability for more than a half million years. No recent igneous activity has occurred in the region and the normal geothermal gradient does not forecast future igneous or tectonic activity.

Natural resources within any major salt basin are an ever-present potential. In preliminary siting of WIPP, known hydrocarbon trends and potash deposits were avoided by the three-square mile repository area. Some potash and potentially some hydrocarbons exist within the buffer zones established for WIPP. The estimated amount of these resources within WIPP zones I, II and III (Fig. 5), which might not be exploited if WIPP is developed, are 13.1 million tons of potash product ($K_2O$); 23.5 billion cubic feet of gas and 42.5 thousand barrels of oil. The gas could be developed by deviated drilling if the economics were sufficiently attractive. Many of these potash resources may not be economically recoverable depending on many economic and mineralogic factors. For example, the United States Bureau of Mines studies indicate as much as 5.5 million tons of potash product may be presently "economic" out of the total 13.1 million ton resource.[16] The hydrocarbon resources are those estimated to be presently "economic." These resource values are small compared to the total United States resources but must be considered as a potential target or inducement for future generations. Studies now underway may show that these resources can be developed without jeopardy to the repository. The issue of future penetrations by man is one that cannot, however, be ruled out. This is true for any geologic repository, but the probability of such penetration may be somewhat greater for sedimentary and/or salt basins. This eventuality is considered in the repository safety analyses by determining the consequences of such penetrations if they should occur.

Future penetration of the repository by man is one class of potential failure scenarios which has been calculated. One particular scenario which will be described assumes an open, unplugged borehole penetrates through the repository and connects aquifers above and below the salt. This case is of much greater concern than for a hole which terminates within the salt. In this latter instance, there is no mechanism to continue dissolution of salt and the hole will gradually be squeezed closed. Using the hydrologic parameters experimentally established for the WIPP site, the dissolution of salt by water flow in the borehole and transport of the various radioisotopes through the aquifers has been calculated and concentrations and/or possible body burdens of radioactivity determined. Figure 8a illustrates results of calculations for the case where the penetration occurs 1,000 years after sealing a repository which has been filled with both TRU and high-level defense waste. Conservative (worst case) assumptions have been used for this particular calculation. For example, it is assumed that the waste dissolves as rapidly as the salt and that the maximum permeability of the measured range of values exists throughout the site area. Transport of transuranic isotopes through the Rustler aquifers to the exit point at Malaga Bend on the Pecos River, about 14 miles away, is such that it requires about 100,000 years for uranium isotopes to reach their maximum concentration. At this time, a hypothetical man who daily ingested the amount of radioactivity contained in 20 liters of Pecos River water would, over a 50-year lifespan, accumulate a whole body dose less than the annual whole body dose acquired in one year due to natural causes. (The fact that the salt content in this water would soon be lethal is being ignored for these calculations.) There is negligible contribution to the radioactive burden from plutonium isotopes due to their high sorption and retardation in the aquifer system. During the 100,000 years following the postulated repository breach, plutonium concentrations in the Pecos River, as indicated by the calculations, would not exceed $10^{-20}$ μCi/liter. Thorium isotopes also have a high adsorption coefficient but show greater discharge concentrations than plutonium because they represent daughter products of the more rapidly transported uranium isotopes.

One may also examine the concentration in the aquifers at points closer to the repository. Figure 9 illustrates the concentration profiles at a distance of either 1.0 or 0.83 miles from the repository breach for the three isotopes which attain the highest concentration relative to present maximum permissible concentrations (MPC) in water. None of these three isotopes, $^{129}I$, $^{226}Ra$

and $^{236}U$, reach their current MPC in this scenario. The fluctuations in the $^{129}I$ curve represent the engulfment of successive HLW rooms by the solution front.

Similar calculations have been performed for a more severe but much less plausible scenario (Scenario II) which assumes the repository failure occurs at 100 years after decommissioning by massive ($3 \times 10^6$ liters/year) flow of water down into the repository at one edge and back out to the same aquifer at another point in the repository, dissolving only the salt and waste in the repository horizons. The isotopes of significance for this time frame which were not important in the 1,000 year breach are $^{90}Sr$ and $^{137}Cs$. The time for transport to the biosphere at Malaga Bend on the Pecos River is long enough that neither isotope represents a significant hazard. The transuranic concentrations shown in Fig. 8b are higher for this scenario than for scenario 1 due to the solutioning mode, not the earlier time frame at which the repository breach was postulated. For this scenario, intercepting the aquifer with a drill hole at a distance of one mile would find concentrations, 200 years after the breach, above current MPC's for $^{90}Sr$ and $^{137}Cs$. The case for $^{137}Cs$ (Fig. 10) shows that concentrations at three miles remain about four orders of magnitude below MPC. These calculations also assumed the upper values of measured permeability and that the waste leaches as rapidly as the salt dissolves. More realistic leach rates for the 100 year time frame are being determined and will be applied to this calculation. Significant reduction in the calculated near-field aquifer concentrations are expected from this refinement and the near-field concentrations are not expected to exceed current MPC's.

## CONCLUSIONS

Geotechnical studies of the WIPP site over the past three years have examined the site with respect to factors listed in the first part of this paper. The data available to date indicate the WIPP site satisfies all the desirable features with the exception of some conflict with natural resources. While it is possible that future repository mining or improved understanding of geologic processes could reveal aspects undesirable for a repository, these prospects are unlikely and a recommendation can now be made to proceed with WIPP planning based on a site in the Los Medanos area of southeast New Mexico. A potential breach of the repository through penetration by human activity cannot be dismissed and is believed to be more likely to occur than natural failures of the geologic barriers. Calculations have been made to evaluate the consequences of such violations of the repository. These calculations indicate, even when adopting extremely conservative assumptions, that the potential hazard to the general population due to human penetration of the repository in the distant future is very slight - less than that due to naturally occurring radiation.

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Figure 1 Artist's Concept of WIPP. The WIPP will be constructed at two different levels. HLW experiments and high gamma TRU will be placed in the lower horizon. The bulk of the TRU waste will be on the upper level. New waste disposal corridors will be mined as existing rooms are filled.

Figure 2 Distribution of Rock Salt Deposits in the United States

Figure 3 Application of Site ~~Section~~ Selection Factors to the to Delaware Basin

Figure 4 Location Map for Proposed WIPP Site. WIPP is located 26 miles east of Carlsbad, New Mexico. Other features of interest to site selection shown on this map are the salt dissolution front and the 1976 location of the potash leasing area.

Figure 5 WIPP Site/Zone Map. Zone I contains surface facilities and Zone II encompasses the repository. Zone III is a buffer zone in which deep drilling and mining are not allowed. Zone IV is a control zone in which prescribed drilling and mining may occur.

Figure 6 Geologic Cross Section at the WIPP Site. Depths to the Salado horizons proposed for the repository are about 2100 and 2600 feet. Any potash mineralization, if it exists, is within the McNutt Unit, several hundred feet above the repository horizons.

Figure 7 WIPP Drill Hole Locations. Both pre-existing and WIPP investigatory holes are shown.

Figure 8a Transuranic isotope body burdens for a Scenario 1 failure of repository containing both HLW and TRU wastes. Integrated total body dose by isotope for a 50 year "Malaga Man" is shown and compared to existing standards and yearly natural exposures. Event initiation at 1,000 years after sealing.

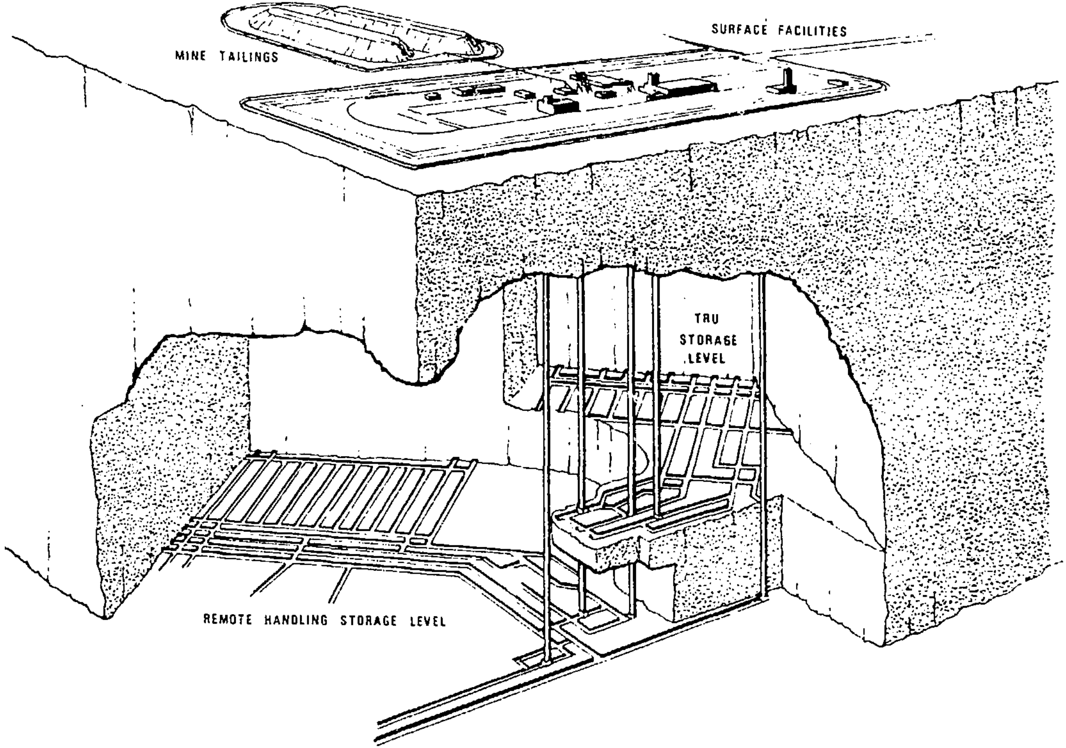
Figure 8b Transuranic isotope body burdens for Scenario 2 failure of repository. Integrated total body dose for 50 year "Malaga man" is shown and compared to existing standards and yearly natural exposures. Event initiation at 100 years from sealing.

Figure 9a $^{129}I$ Concentration Profile in Rustler Aquifer at 1 mile from a Scenario 1 repository breach. Maximum measured permeability used in the transport calculation. Breach initiation at 1,000 years after sealing.

Figure 9b $^{226}Ra$ Concentration Profile in Rustler aquifer at 0.83 mile from a Scenario 1 repository breach. Maximum measured permeability used in the transport calculation. Breach initiation at 1,000 years after sealing.

Figure 9c $^{236}U$ Concentration Profile in Rustler aquifer at 0.83 mile from a Scenario 1 repository breach. Maximum measured permeability used in the transport calculation. Breach initiation at 1,000 years after sealing.

Figure 10 $^{137}Cs$ concentration in the Rustler aquifer at 0.14, 1, and 3 miles from a Scenario 2 breach initiated 100 years after sealing. Repository contains 1000 canisters of spent fuel. Maximum measured permeability used in the transport calculation.




Waste Isolation Pilot Plant

Figure 1

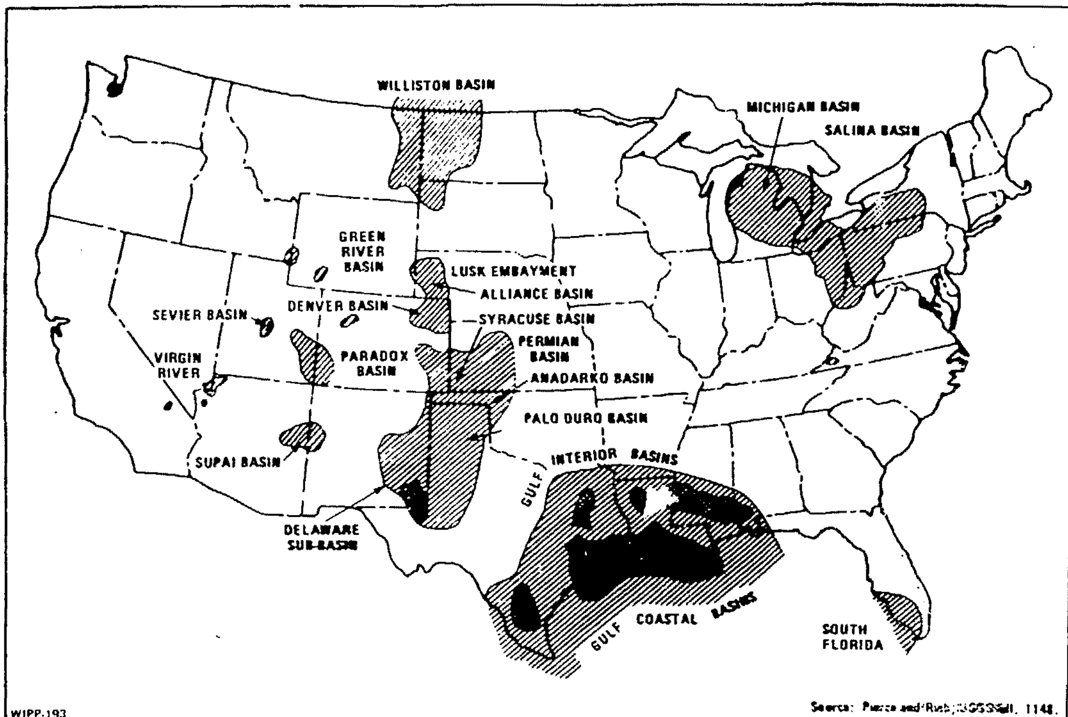

WILLISTON BASIN
MICHIGAN BASIN
SALINA BASIN
GREEN RIVER BASIN
LUSK EMBAYMENT
ALLIANCE BASIN
DENVER BASIN
SEVIER BASIN
SYRACUSE BASIN
PERMIAN BASIN
VIRGIN RIVER
PARADOX BASIN
ANADARKO BASIN
PALO DURO BASIN
GULF INTERIOR BASINS
SUPAI BASIN
DELAWARE SUB-BASIN
GULF COASTAL BASINS
SOUTH FLORIDA
WIPP-193

Figure 2

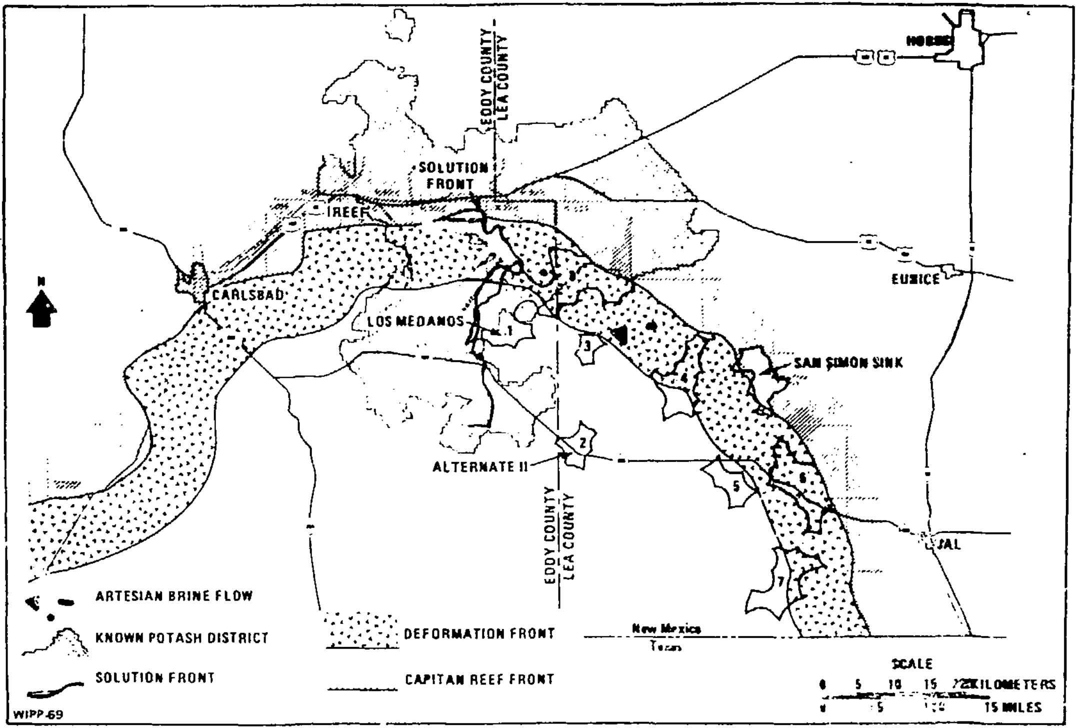

EDDY COUNTY
LEA COUNTY
SOLUTION FRONT
REEF
CARLSBAD
N
LOS MEDANOS
1
2
3
4
5
6
7
8
SAN SIMON SINK
EUNICE
JAL
ALTERNATE II
ARTESIAN BRINE FLOW
KNOWN POTASH DISTRICT
SOLUTION FRONT
DEFORMATION FRONT
CAPITAN REEF FRONT
New Mexico
Texas
SCALE
KILOMETERS
MILES
WIPP-69

Figure 3

MARCH, '77

Sandia Laboratories

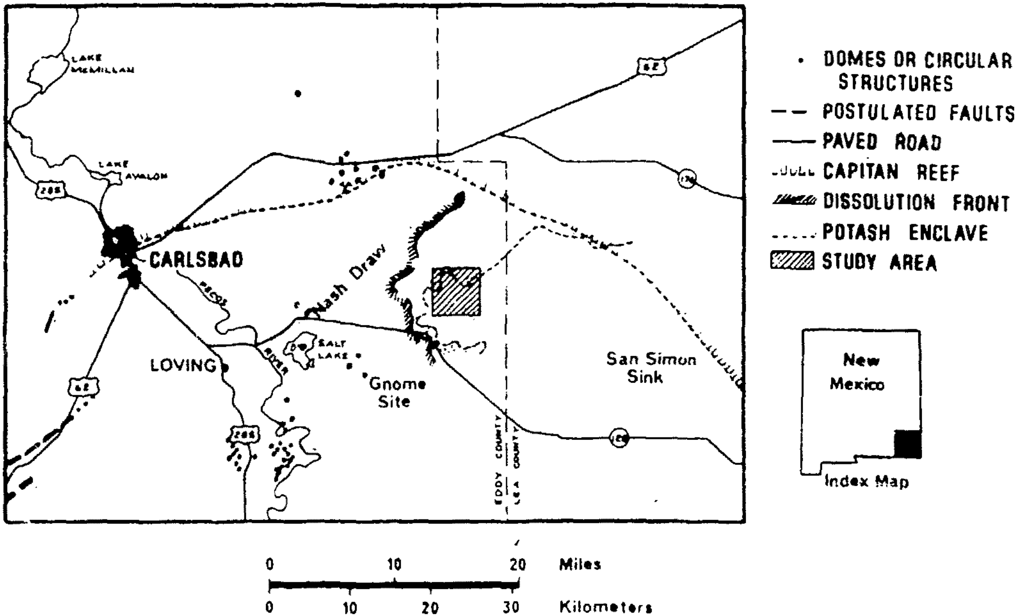
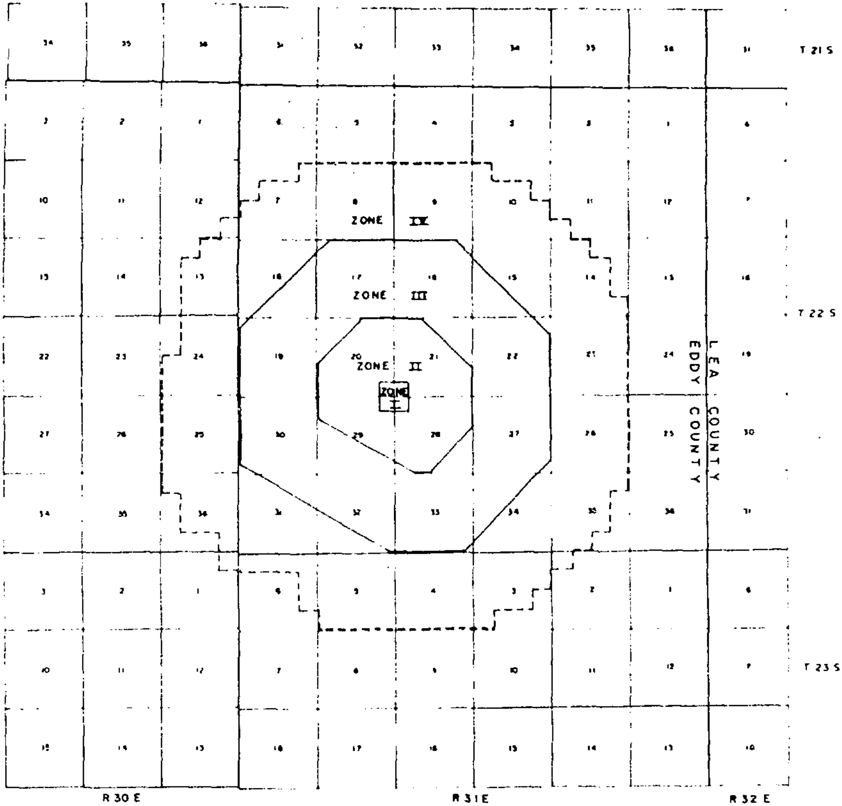



Figure 4




**ZONE ACREAGE**

ZONE I - 60-100

ZONE II - 1880

ZONE III - 6230

ZONE IV - 10,810


WIPP SITE ZONATION

FIGURE 5

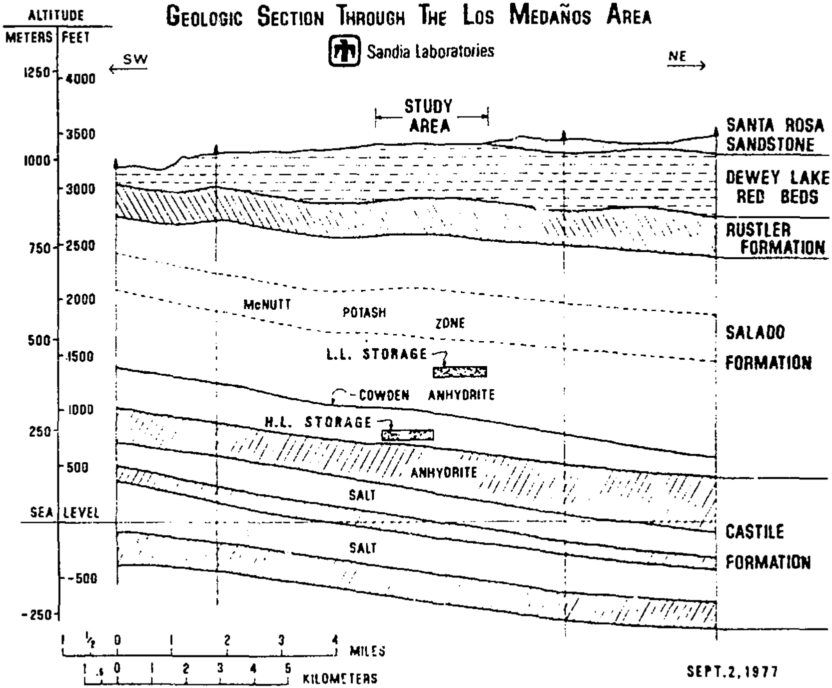

GEOLOGIC SECTION THROUGH THE LOS MEDAÑOS AREA
Sandia Laboratories
ALTITUDE
METERS
FEET
SW
NE
1250
4000
3500
1000
3000
750
2500
2000
500
1500
1000
250
500
SEA LEVEL
-500
-250
STUDY AREA
SANTA ROSA SANDSTONE
DEWEY LAKE RED BEDS
RUSTLER FORMATION
McNUTT
POTASH
ZONE
SALADO FORMATION
L.L. STORAGE
COWDEN ANHYDRITE
H.L. STORAGE
ANHYDRITE
SALT
SALT
CASTILE FORMATION
MILES
KILOMETERS
SEPT.2,1977

Figure 6

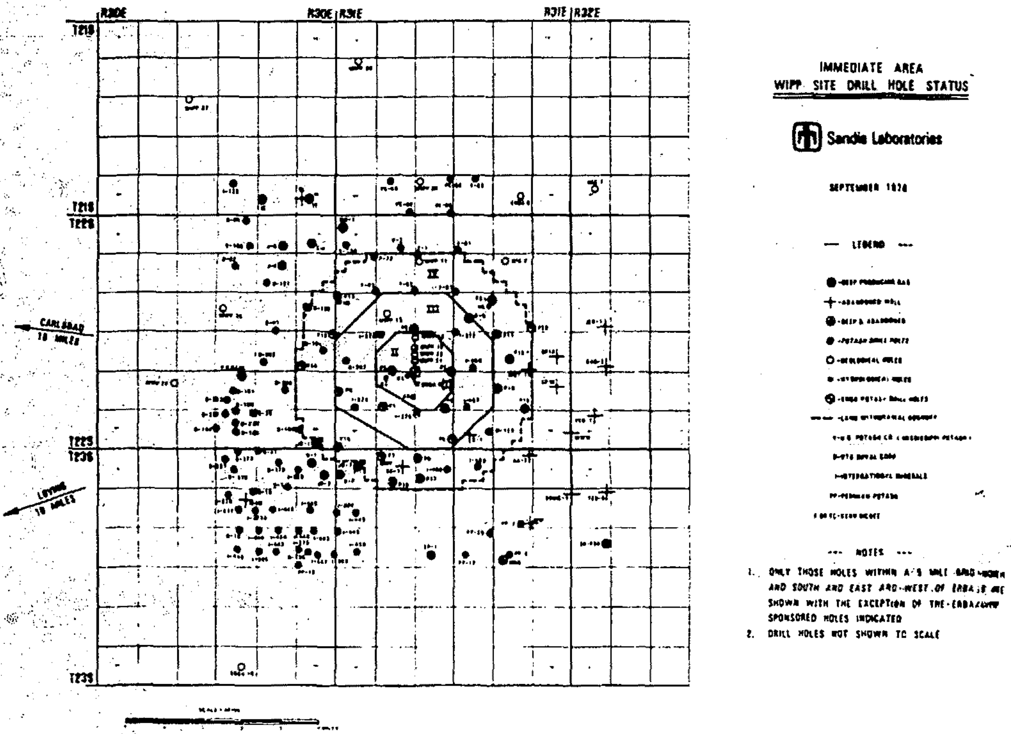

R30E
R30E
R31E
R31E
R32E
T21S
T21S
T22S
T22S
T23S
T23S
CARLSBAD
18 MILES
LOVING
18 MILES
IMMEDIATE AREA
WIPP SITE DRILL HOLE STATUS
Sandia Laboratories
LEGEND
NOTES
2. DRILL HOLES NOT SHOWN TO SCALE

Figure 7

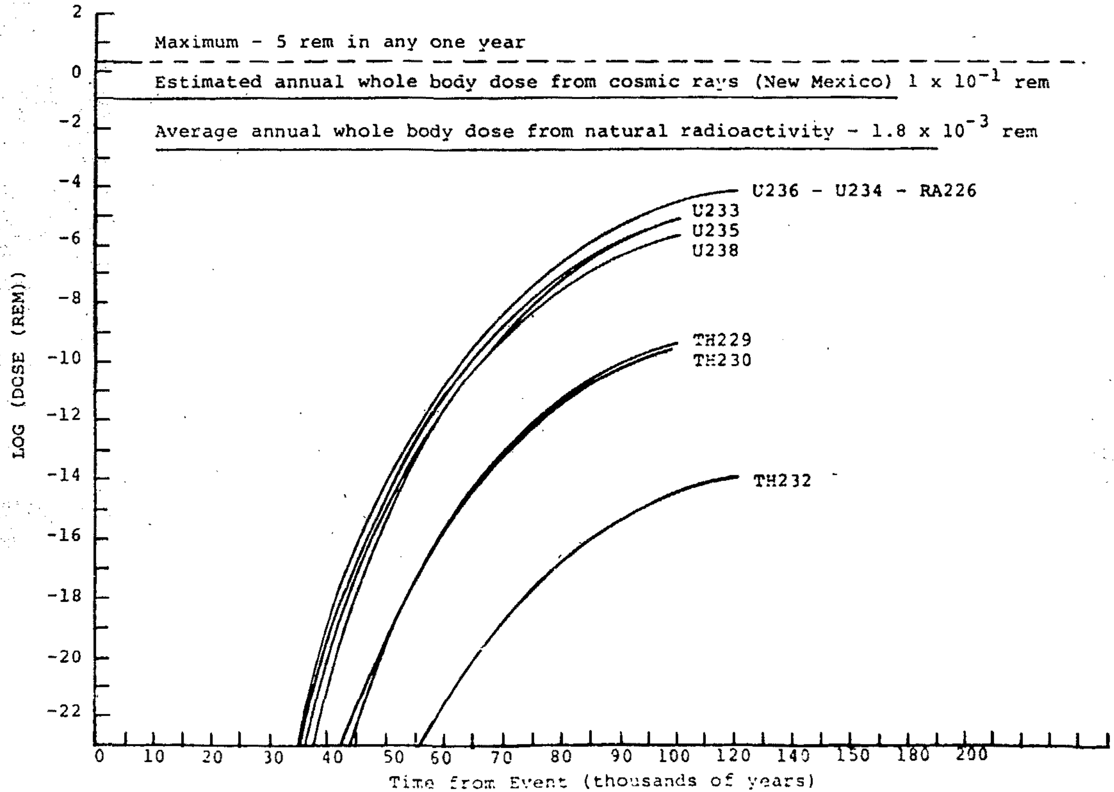

Maximum - 5 rem in any one year
Estimated annual whole body dose from cosmic rays (New Mexico) 1 x 10^-1 rem
Average annual whole body dose from natural radioactivity - 1.8 x 10^-3 rem
U236 - U234 - RA226
U233
U235
U238
TH229
TH230
TH232
LOG (DOSE (REM))
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-22
0 10 20 30 40 50 60 70 80 90 100 120 140 150 180 200
Time from Event (thousands of years)

Figure 8a

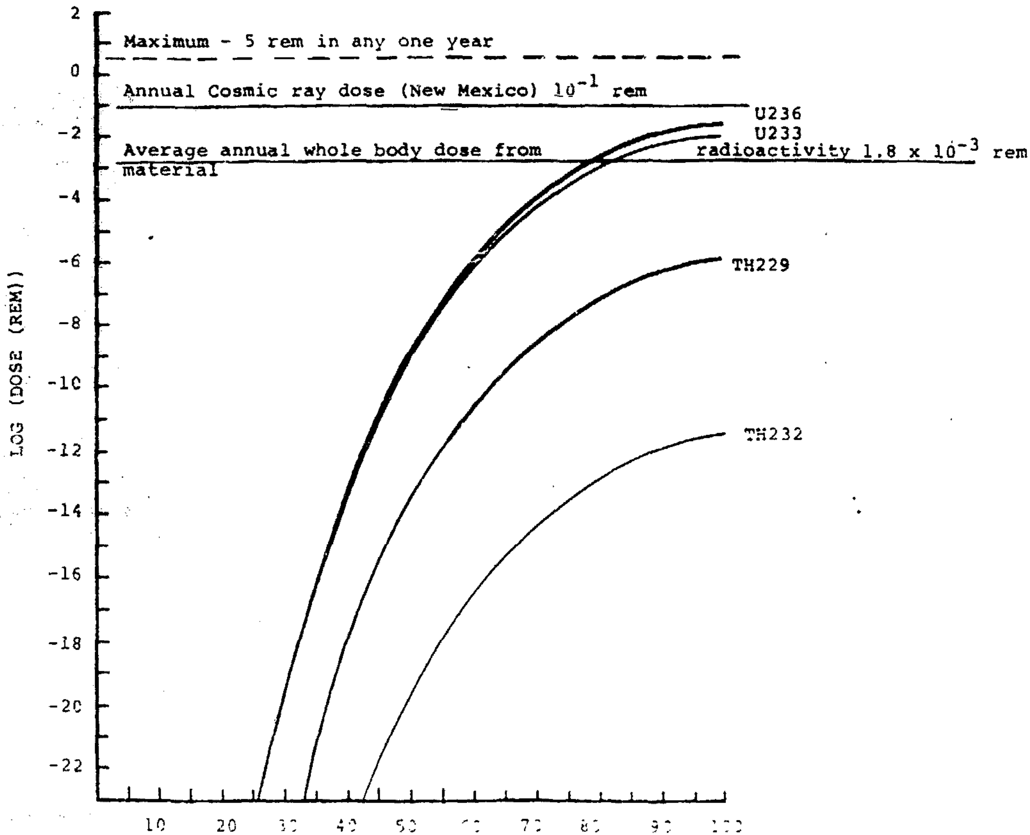

Maximum - 5 rem in any one year
Annual Cosmic ray dose (New Mexico) 10^-1 rem
Average annual whole body dose from radioactivity 1.8 x 10^-3 rem
material
U236
U233
TH229
TH232
LOG (DOSE (REM))
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-22
10
20

Figure 8b

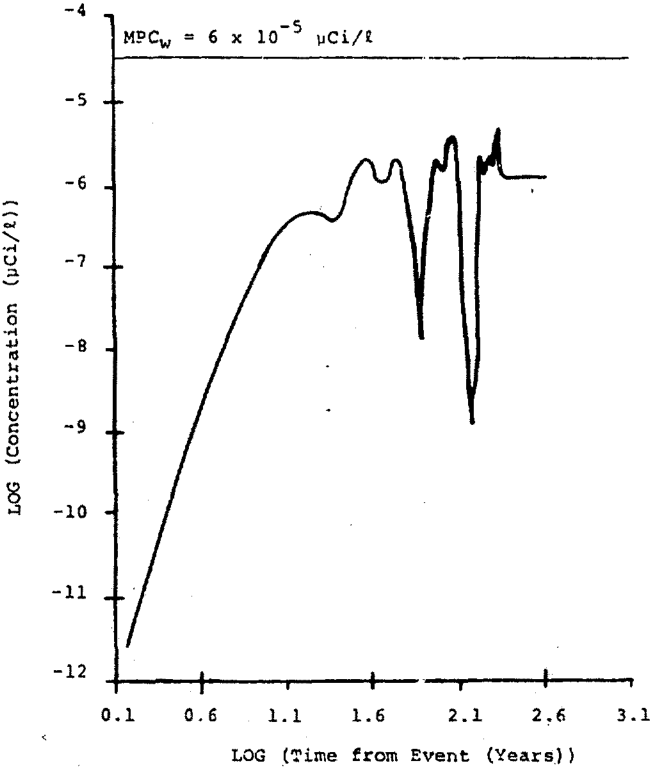
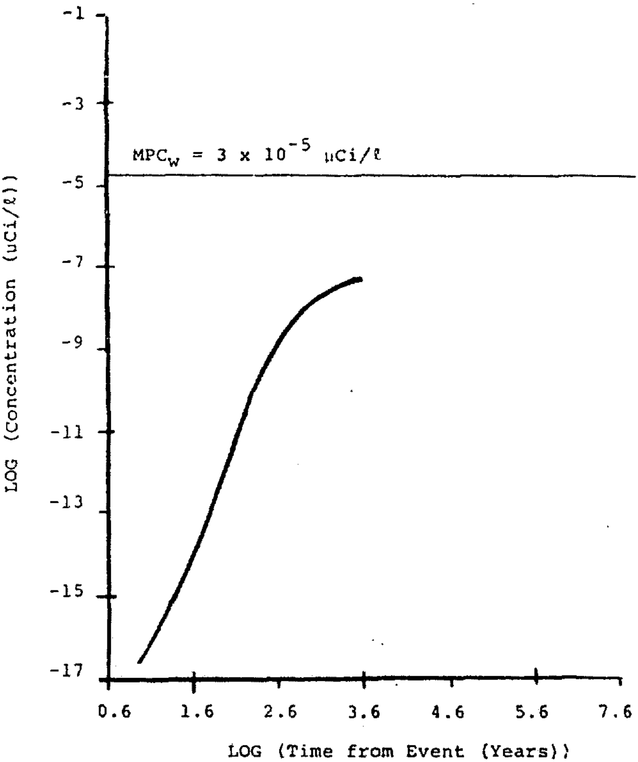

MPC$_w$ = 6 x 10$^{-5}$ μCi/ℓ
-4
-5
-6
-7
-8
-9
-10
-11
-12
LOG (Concentration (μCi/ℓ))
0.1
0.6
1.1
1.6
2.1
2.6
3.1
LOG (Time from Event (Years))

Figure 9a



-1
-3
-5
-7
-9
-11
-13
-15
-17
$MPC_w = 3 \times 10^{-5}$ µCi/ℓ
LOG (Concentration (µCi/ℓ))
0.6
1.6
2.6
3.6
4.6
5.6
7.6
LOG (Time from Event (Years))


Figure 9b

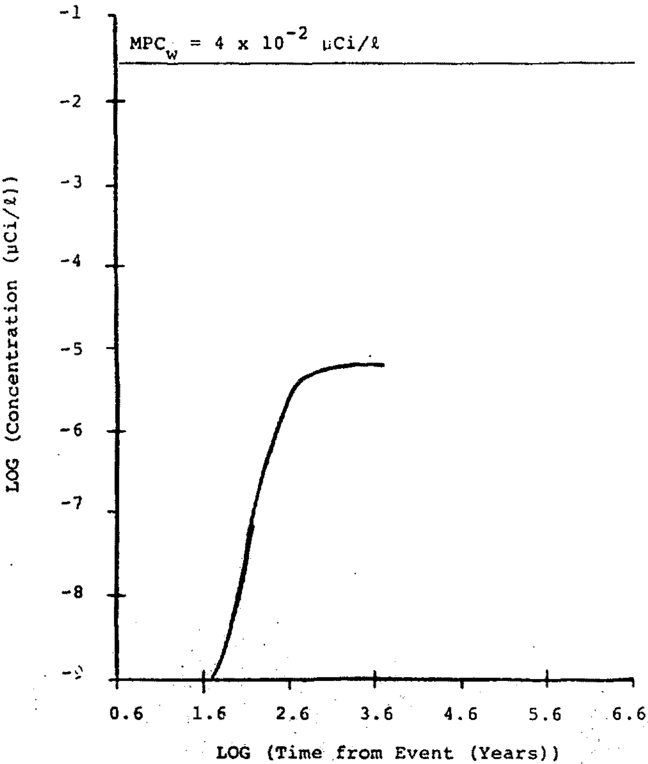
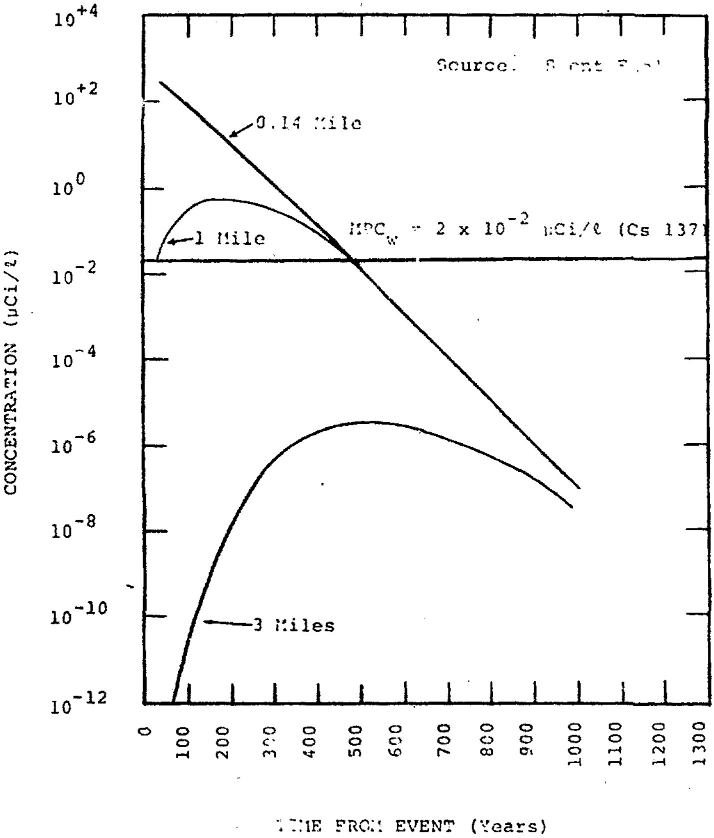

MPC$_w$ = 4 x 10$^{-2}$ μCi/ℓ
-1
-2
-3
-4
-5
-6
-7
-8
LOG (Concentration (μCi/ℓ))
0.6
1.6
2.6
3.6
4.6
5.6
6.6
LOG (Time from Event (Years))

Figure 9c



Source.
0.14 Mile
1 Mile
3 Miles
$MPC_w = 2 \times 10^{-2}$ µCi/ℓ (Cs 137)
$10^{+4}$
$10^{+2}$
$10^{0}$
$10^{-2}$
$10^{-4}$
$10^{-6}$
$10^{-8}$
$10^{-10}$
$10^{-12}$
CONCENTRATION (µCi/ℓ)
0
100
200
400
500
700
800
900
1000
1100
1200
1300
EVENT (Years)


**Figure 10**