February 26, 1998

Citizens for Alternatives to Radioactive Dumping (CARD) submits the following research papers as our current submission to the Environmental Protection Agency:


Snow, David T., General Hydrological Conditions at the WIPP Site. 11 pages.


Reade, Deborah, WIPP Waste Storage at Los Alamos National Laboratory (LANL). 5 pages.

Reade, Deborah, Human Error and the Department of Energy. 4 pages.

Frost, Harold M., Nuclear Transmutation as a Means of Reducing the Menace of Plutonium and Radioactive Wastes. 2 pages.


These papers are in addition to our submittal of January 20, 1998 of the following papers:

Snow, David T., Comments on DOE's Compliance Certification Application, 1996, for the Waste Isolation Pilot Plant, New Mexico, 15 pages.

Phillips, Richard H., Cavernous Zones at the WIPP Site, 13 pages.

Phillips, Richard H., Rainwater Recharge at the WIPP Site, 13 pages.


Snow, David T., Reply to DOE Comment Responses, 18 pages.

Phillips, Richard H., Rebuttal to DOE Response to "CARD Comments 7 to 22", 32 pages

In summary, our concern is that the Waste Isolation Pilot Plant (WIPP) site is not an appropriate permanent repository for radioactive wastes for many reasons, the primary one being that the WIPP site is a portion of one of the world's largest karstlands. Underground water constantly dissolves the surrounding rock resulting in a highly unstable geologic environment. Our knowledge of advancing technology lends us to believe that monitored, retrievable, secure storage close to where the wastes are generated is the wisest course of action at this time. That the Department of Energy cannot accurately assess their current transuranic waste inventory and that the department casually mentions possible expansion of WIPP's mission (Refer to Draft Environmental Impact Statement on Management of Certain Plutonium Residues and Scrub Alloy Stored at the Rocky Flats Environmental Technology Site) further exacerbates our concerns. Thank you for your consideration of our work.

Sincerely,

[Signature]

Janet Greenwald
CARD

jg/lcm
CONCEPTUAL MODEL FOR CONTAMINANT TRANSPORT
IN KARST AQUIFERS AT THE WIPP SITE

by Richard H. Phillips, Ph.D.
and David T. Snow, Ph.D.

INTRODUCTION

The Department of Energy (DOE) seeks permission from the Environmental Protection Agency (EPA) to open the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico for permanent disposal of radioactive waste from nuclear weapons production. Geologic characterization of the overburden at the WIPP site has proceeded on the unwarranted assumptions that: (1) karst hydrology does not occur within the WIPP site; (2) dissolution of evaporites has not occurred at the WIPP site; (3) rainwater recharge to the Rustler Formation is negligible; (4) groundwater flow is confined to the Culebra dolomite; and (5) heterogeneous transmissivity data can be treated as random variables with little or no spatial control. The result has been a hydrologic model which bears no resemblance to reality. CARD has already disproven these assumptions in papers previously submitted to the EPA (see Appendix for complete list).

It is not international practice to consider disposal of radioactive or toxic waste in karstic regions. The reason was well stated by Franklin et al. (1981), in a paper prepared for and published by the Nuclear Regulatory Commission (NRC). They warned that "filtration, which acts in porous media to remove many contaminants from the water, is virtually absent in the karst environment" (p. 57). In the vicinity of WIPP there are large underground caverns sometimes filled with flowing water. Under such conditions, the conservative assumption is that radionuclides will travel at the average speed of water. DOE's conceptual model, which relies upon matrix diffusion and sorption to retard the migration of radionuclides in groundwater, is neither realistic nor conservative.

The purpose of this paper is to present an alternative conceptual model which treats the WIPP site and vicinity as a karstland. We begin with a synthesis of the geologic literature pertaining to karst hydrology in general, as background information to familiarize the reader with concepts and terminology. We then summarize the work of Palmer (1986), who has published a methodology for the prediction of contaminant flow paths in karst aquifers based upon geologic structure and stratigraphy. We then apply these concepts to the WIPP site and vicinity based upon field observation and measured data from WIPP boreholes and test wells, supporting our conclusions with tables, maps, and schematic diagrams. Finally, we use a variety of methods to estimate, within an order of magnitude, the ground-water travel time from the WIPP site to the accessible environment, a task impeded by the paucity of relevant data.

TYPES OF AQUIFERS

A rock formation which can hold and transmit significant quantities of water is called an aquifer. A formation which allows little or no movement of water is called an aquiclude. Karst aquifers, like those of other rocks, may be classified into three principal types -- confined, unconfined, or perched.

In an unconfined aquifer the level of saturation is free to rise and fall in response to variations in recharge. Its upper boundary is a free surface where the fluid pressure is atmospheric. This is known as the water table. The saturated zone below the water table is the phreatic zone; the unsaturated zone above the water table is the vadose zone.

\[ \text{AQUIFER} \]

\[ \text{AQUICLIDE} \]

\[ \text{WATER TABLE} \]

\[ \text{PHREATIC ZONE} \]

\[ \text{VADose ZONE} \]
In a confined aquifer the saturated zone is overlain by an aquiclude and therefore has no free water surface. The level to which water rises in a cased well is called the piezometric or potentiometric surface. If the level of the potentiometric surface lies above the confining layer, the well is said to be artesian. If it lies above the land surface, water will flow spontaneously from the well; this condition is known as flowing artesian.

Water infiltrating from the land surface through the vadose zone toward the underlying aquifer moves downward under the influence of gravity. Impediments to downward flow are sometimes provided by localized impermeable layers. Ponding may occur above these layers, producing a localized saturated zone known as a perched aquifer, suspended above the main, lowest water table.

VADOSE AND PHREATIC ZONES

Karst groundwater systems may be divided into three hydrologic zones:

(1) An upper vadose zone -- a "dry" zone with downward drainage under the influence of gravity, traversed by feeder channels through which water flows freely, analogous to surface watercourses.

(2) An intermediate high-water zone -- a zone through which the water table rises and falls; caves are sometimes dry, and sometimes flooded to capacity; water sometimes flows freely, and is sometimes under pressure.

(3) A lower phreatic zone -- a permanently saturated zone, with lateral drainage; water is under hydrostatic pressure and can flow upward; all caves are continuously water-filled; springs occur where this zone intersects the land surface.

Over time, as the karst is progressively developed, the three hydrologic zones migrate downwards. Flows in closed conduits under pressure are replaced by flows in open channels. Groundwater flow in the open channels of the intermediate zone can attain higher velocities than in the perennially water-filled conduits of the phreatic zone, due to conduit enlargement. For the water to move from the point of recharge to the point of discharge, open channels offer the shortest paths with the least resistance and are therefore preferred. It is a mistake to assume that the most effective flow paths occur beneath the water table.

POROSITY AND PERMEABILITY

Porosity is defined as the total proportion of the spatial volume which is comprised of voids, and is commonly expressed as a percentage. Permeability is the ability of a rock to transmit fluid. To be permeable a rock must be porous, but its pores must also interconnect so that fluid can move between them. For a system of perfectly interconnected pores, the conservative transport or advective velocity is the specific discharge divided by porosity. Since pores that are imperfectly connected or have preferred orientations may influence transport, the ratio of specific discharge to advective velocity is called effective porosity, smaller than porosity.

Measurements of porosity and permeability are normally performed on small samples in the laboratory. These are usually determinations of primary porosity and primary permeability resulting from voids between the grains in the rock. Most rocks, such as carbonates and some evaporites, are transected by fractures such as joints, sheared bedding planes, and faults. The percentage of the volume of the rock occupied by such fractures and any enlargements of them is the secondary...
porosity. Commonly, fractures greatly enhance the permeability of the rock mass, and the difference due to fractures is the secondary permeability.

The solubility of carbonates and evaporites renders them different from other rocks because fracture dissolution causes permeability changes with time. The very process of ground water flow alters the porosity of karstified rocks. This is important because ground water velocity varies inversely with the effective porosity.

HETEROGEGITY AND ANISOTROPY

The ability of an aquifer to transmit water is defined by its transmissivity, which is equal to the thickness of the aquifer multiplied by its hydraulic conductivity. Some aquifers (well sorted sands and gravels, for example), have consistent values for transmissivity nearly independent of position within the formation, and the aquifer is said to be homogeneous. In other aquifers (notably those with significant secondary porosity, carbonate and evaporite rocks, for example), transmissivity varies greatly with location, and the aquifer is said to be heterogeneous. If transmissivity is the same regardless of the direction of measurement, the aquifer is said to be isotropic. If transmissivity varies with direction, the aquifer is said to be anisotropic.

Ground water flows through an aquifer in relation to its hydraulic conductivity and its hydraulic gradient. The level to which water rises in a cased well is the hydraulic head at the open end of the casing. When a number of cased wells tap the same aquifer, the measured head values can be plotted on a map, and potentiometric contour lines can be drawn connecting interpolated points of equal value. The drop in hydraulic head from one contour to another, divided by the shortest horizontal distance between the contours, is the hydraulic gradient. In an isotropic aquifer, the flow paths parallel the gradient, always perpendicular to the potentiometric contours. However, where fractures or solution conduits cause an aquifer to be anisotropic, the flow direction will reflect a balance between the path of least resistance (maximum hydraulic conductivity) and the steepest gradient. It may, in places, be almost parallel to the potentiometric contours, but the water can never flow upgradient.

Karst aquifers are heterogeneous and anisotropic, and become more so with time as the flow of water through the aquifer enlarges the most effective flow paths through preferential solution. Limestones may have very high values of conductivity along joints, faults, and bedding planes, extremely high conductivity within solution conduits, and virtually zero conductivity within the unfractured wall rock. It is simplistic to assume that transmissivity remains constant over a large distance. According to White (1988, pp. 187-188):

The well bore is a very small object on the scale of the heterogeneities of a karst aquifer, and one does not know what component of the subsurface drainage system is being probed. Values obtained from pump tests vary widely over short distances, depending on exactly where the wells are drilled. A well that taps a connection with the conduit system can produce very large quantities of water with negligible drawdown, leading to extremely large calculated transmissivities. A well drilled a few meters away in an unfractured block of limestone may have negligibly small yields.
Darcy's Law

The hydraulic conductivity of porous media was first measured by Henri D'Arcy in 1856. By passing water through a vessel filled with saturated sand, D'Arcy found that the discharge per unit cross-sectional area is proportional to the hydraulic gradient. The resulting equation for specific discharge (with units of velocity) is known as Darcy's law:

\[ \frac{Q}{A} = K \left( \frac{\Delta h}{\Delta l} \right) \]

where \( Q \) = discharge, \( A \) = cross-sectional area, \( K \) = hydraulic conductivity, and \( \Delta h / \Delta l \) = the hydraulic gradient. Darcy's law can also be used to calculate the average fluid particle velocity.

\[ v = \left( \frac{K}{\Theta} \right) \left( \frac{\Delta h}{\Delta l} \right) \]

where \( v \) = average fluid velocity, and \( \Theta \) = average effective porosity.

Darcy's law assumes flow to be laminar. This means that individual "particles" of water move subparallel to conduit walls with friction varying in a linear manner with velocity. In karst, groundwater flow may be dominated by caves and large solution conduits, wherein turbulent mixing provides additional friction. Karst flow is generally unsteady, attaining very high rates following recharge episodes, interrupted by prolonged periods of nearly stagnant conditions. Thus, fluid resistance varies from turbulent to laminar, and average flow rates bear little relationship to measured gradients. The laws of groundwater flow are not readily applicable to rocks containing dissolution channels, as in limestone or gypsum, because sufficient data to evaluate the transient behavior as well as the heterogeneity and anisotropy are invariably lacking.

The flow properties of parallel-walled fractures can be accurately described. However, modeling of a full-scale fractured aquifer is difficult because: (1) the apertures of fractures vary along the length of the flow path; (2) flow in dissolution-enhanced fractures may be turbulent; (3) flow in fractured aquifers is anisotropic, dominated by the largest fractures; and (4) for the entire assemblage of fractures to be characterized, the orientations, spacings, and extent of the fractures must be known. All of these problems in groundwater modeling are compounded in karst terrains where the dominant fracture sets have been enlarged by solution.

Laminar Flow

To characterize flow in fractured rock, the discharge of a single fracture follows the derivation of Hele-Shaw (1898):

\[ q = \left( \frac{w^3}{12} \right) \left( \frac{g}{u} \right) \left( \frac{\Delta h}{\Delta l} \right) \]

where \( q \) = discharge per unit slice, \( w \) = the width (aperture) of the fracture, \( g \) = gravitational acceleration, and \( u \) = kinematic viscosity of the water. If \( n \) parallel fractures of different apertures \( w_n \) cut a unit area \( A = 1 \) of the fractured rock, normal to the flow, then the total discharge per unit area of the medium \( Q = \Sigma q_n \), and effective porosity \( \Theta = \Sigma \Theta_n = \Sigma w_n \).
The average fluid velocity $\bar{v} = (Q / A) (1 / \Theta) = \Sigma q_n / \Sigma \Theta_n =$

$$(\Sigma w_n^3 / \Sigma w_n) (g / 12 u) (\Delta h / \Delta l),$$

showing that the largest fractures have a dominant effect on transport. Similarly, the discharge $q$ of a single tubular conduit follows the Hagen-Poiseuille equation:

$$q = (\Pi d^4 / 128) (g / u) (\Delta h / \Delta l),$$

where $d =$ the diameter of the tube. If $n$ parallel tubes of different diameters $d_n$ cut a unit area, then total discharge $Q = \Sigma q_n$, and effective porosity

$$O = O_n = (\Pi / 4) (\Sigma d_n^2).$$

Average fluid velocity $\bar{v} = (Q / A) (1 / \Theta) = (\Sigma q_n / \Sigma \Theta_n) =$

$$(\Sigma d^4 / \Sigma d^2) (1 / 32) (g / u) (\Delta h / \Delta l),$$

similarly showing the dominance of large-aperture conduits. In both fractures and dissolution channels, transport is sensitive to the progressive enlargement that occurs with maturity of the karst. As the above summations indicate, the addition of solution channels of 3-meter dimensions to a medium otherwise comprising 1000 0.1-mm fractures, the effective porosity will diminish greatly.

Without the channel: $\Sigma w^3 / \Sigma w = 1000 (.0001)^3 / 1000 (.0001) = 10^{-8}$

With the channel: $\Sigma w^3 / \Sigma w = 1000(.0001)^3 + 3^3 / 1000 (.0001) + 3 = 8.7$

One may neglect the fractures altogether, giving 9.0. Transport is dominated by the large-aperture dissolution channels.

TURBULENT FLOW

Turbulent flow occurs in caves and solution pipes when recharge-induced flow is rapid or the conduits are of large diameter. Within a single channel or pipe of a given size, the flow will become turbulent if the velocity is increased above a certain critical value, specific to that criterion -- the Reynolds Number -- which is proportional to velocity and diameter. In general, the flow will be laminar when the Reynolds Number is below 500 and fully turbulent at values greater than 2000. Where flow in a pipe or channel is fully turbulent, the velocity $v$ may be determined by the Darcy-Weisbech equation:

$$v^2 = (2 d g / f) (\Delta h / \Delta l)$$

where $d =$ diameter of the pipe, and $f =$ friction factor. Under turbulent conditions, the square of the discharge is proportional to the hydraulic gradient, so velocity increases less rapidly than the gradient because of additional friction.
CONDUIT FLOW

Karst aquifers differ from others in that they contain systems of solution pipes or conduits that act as connected underground drains for highly localized and transient transport. Though such secondary conduits are few in number, their volume is small in comparison with the primary porosity of the area drained, which reflects the efficiency of the karst drainage system.

The active conduits in karst aquifers often have more in common with surface channels than with other types of ground water aquifers. Above the phreatic zone, velocities are only slightly less than that of surface rivers. Normally flowing at very low gradients, the velocity in karst conduits increases markedly with increasing recharge. Large increases in cross-section occur with small rises of the water table. The largest caves, or master caves, are normally joined by underground tributaries, in much the same manner as surface stream networks. However, there are important differences between the pattern of underground drainage and that of surface rivers. In karst, flow paths may cross each other without mixing, which is only possible if flow is confined to discrete conduits. Explorations of caves have shown that underground streams remain confined within the caves, even when they are filled with water. Diving at karst springs has shown that underground streams are confined to conduits there as well. The master caves become waterfilled close to the level of the springs that they feed.

Karst springs occur at the lowest elevation, the site of minimum hydraulic head, in the karst system. Most of the largest springs in the world are karst springs. Only those from volcanic rocks (such as basaltic lavas) rival their discharge.

KARST WATER TABLE

In karst, the importance of ground water flow in caves and conduits is so great that there is no water table in the sense of a single surface below which the rock is entirely saturated. The rapid flow velocities, the crossing of flow paths, and the lack of mixing between karst conduits demonstrates that they are generally watertight, and that the rocks surrounding them are almost dry, acting as an aquifuge. Outside the caves and conduits there may be almost no circulation. Dry cavities may exist alongside periodic and perennial springs. Tunnels cut through limestone reveal water-filled fissures overlying empty ones. Perched water tables occur in the unsaturated zone. Cavern formation is thus not restricted to any particular zone within the karst, and not every free-surface stream seen in a cave can be related to a local water table.

In many cave systems, large chambers alternate with narrow siphons. Ground water circulates through permeable fissures and is under hydrostatic pressure which activates the siphons and can make the water move upward. These fissures exist throughout the karst down to the impermeable rock beneath it such as shale; water flows in fractures to the level of the impermeable rock regardless of regional base level. Submarine springs have been observed at 700 m (2300 ft) below sea level. Water circulating through fissures has been observed at 800 m (2600 ft) below sea level.

Karst water flows anisotropically through narrow fissures and large caves which may be independent of one another and can be regarded as separate aquifers. The cave systems operate like rivers but in three-dimensional space rather than over a single surface. Above the phreatic zone, open-channeled flow occurs, with streams only partly filling the caves with water. Water levels observed in caves should be considered as static pools at rest, controlled by spill-point levels, rather than coincident with the local water table during flow periods. Within the phreatic zone, groundwater flow is driven by the hydraulic gradient, flowing from places with higher hydraulic heads to places with lower ones. If a large conduit traverses the phreatic zone, it may be a zone of relatively low hydraulic head as
dictated by its outlet, in which case groundwater flow will converge upon it. The water table above such a submerged conduit will be depressed, and the course of the conduit will be marked by troughs or valleys in the water table. In fully developed karst, water flows almost horizontally in the closed conduits of the phreatic zone and in the open-channel conduits at the water table.

LACK OF SURFACE RUNOFF

The most obvious geomorphic characteristic of karst regions is the lack of surface runoff. Rainwater infiltration is rapid and substantial. Overland flow rarely reaches stream channels, but disappears into sinkholes to enter the subsurface drainage system. This is true even in arid and semiarid climates. Apart from dune fields, deserts on impervious rocks rarely lack stream courses, however ephemeral they may be. But karst in arid and semiarid regions is usually without them, as in the Nullarbor Plain of Australia and the Pecos River valley of New Mexico. Rapid infiltration means that water escapes the surface heat and is protected from evaporation, so that karst regions discharge more of the precipitation falling on them than does impervious terrain.

RAINWATER INFILTRATION

In karst groundwater systems, infiltrating rainwater enters the bedrock through open fractures and other planes of secondary permeability, particularly at joint intersections. As these openings are enlarged by solution they become able to transmit increasing quantities of runoff. Over time they may become sufficiently enlarged near the surface to cause gradual subsidence or collapse of the uppermost bedrock. The repeated subsidence of joint blocks toward central solution pipes creates closed topographic depressions known as dolines or sinkholes, where funneling of rainwater occurs. A perforated impermeable caprock will funnel water into the karst in much the same way. The flow may come from a retreating overlying caprock, or from the updip margin of an impermeable formation that is tilted.

EVAPORITE KARST

Not all karst terrains are found on carbonate rocks (limestone or dolomite). Highly soluble evaporite rocks (gypsum, anhydrite, halite) can be sculpted into karst landscapes and aquifers. Anhydrite is comparable with carbonates, usually undergoing alteration by hydration to gypsum due to diffuse intergranular flow before rapid conduit evolution can occur. Gypsum is 10 to 30 times more soluble than limestone, and halite more soluble still. The high solubility of gypsum and halite means that karst systems are not only developed and destroyed at faster rates than in less soluble carbonate rocks.

Because surface outcrops of gypsum survive only in arid climates, sinking streams tend to be small dry arroyos that end either in swallow holes or in short open cave passages. Sinkholes may be broad and shallow or, because of rapid solution at depth in the bedrock, may exhibit collapse at the land surface. Some collapse sinks in gypsum are quite large, such as the Santa Rosa sinks and the Bottomless Lakes of the Pecos River valley in New Mexico.

Gypsum is formed when anhydrite comes into contact with fresh water. Hydration of anhydrite to gypsum is often localized, and results in a change in volume of 35% to 39%. The pressure developed by volume expansion is sufficient to buckle overlying beds, creating joints and fractures which provide pathways for surface water to dissolve evaporites at depth.
The time scale for gypsum dissolution, as determined in the laboratory, is 100 times shorter than that for limestone dissolution. Gypsum solutions become nearly saturated within a few minutes and almost completely saturated within an hour. For this reason, groundwater reaches saturation in much shorter distances in gypsum than in limestone. Therefore, unsaturated water capable of dissolving gypsum must be supplied by vertical seepage from overlying beds. Once initiated, however, gypsum caves should enlarge more rapidly than limestone caves because of the higher solubility.

**COVERED KARST**

Gypsum and salt beds also give rise to karst when covered by a thick deposit of non-carbonate rocks such as sandstone. This form of covered karst is sometimes termed interstratal karst to distinguish it from that developed beneath a soil cover. The term can be misleading, however, as evaporite karst development is three-dimensional and is not confined to the evaporite beds. The classic covered karst region in North America is the Pecos River valley in New Mexico, where the Santa Rosa sandstone and the Dewey Lake Red beds overlie limestone and gypsum deposits of Pennsian age.

A feature that seems unique to the gypsum plains and covered karst of southeastern New Mexico and west Texas is the solution-subsidence trough. These are narrow, elongated depressions that range from 100 to 1500 m (300 to 5000 ft) in width and from 1 to 15 km (0.5 to 10 miles) in length. Generally they are only 4 to 6 m (15 to 20 ft) deep. The troughs run parallel to the regional dip and are formed by collapse of surface rocks into caverns dissolved by underground waters moving along fractures. The collapse debris forms barriers across the channels and causes the underground streams to establish new channels along nearby fractures. Thus the troughs are probably not the result of the collapse of a single cavern but of several.

**WATER BALANCE**

Precipitation falling onto the land surface divides into three parts. One part infiltrates into the soil, penetrating the underlying bedrock, where it continues downward through the vadose zone to the water table. A second part flows overland as runoff into small water courses and ultimately into the master base level stream. The third part returns to the atmosphere by evaporation and transpiration. For any rainstorm the water budget, or water balance, can be expressed in the following equation:

\[ P - E = I + R \]

where \( P \) = precipitation, \( I \) = infiltration, \( R \) = runoff, and \( E \) = evapotranspiration. In karst landscapes there is virtually no surface runoff; drainage is almost entirely underground. Thus the water balance in a karst terrain can be expressed as:

\[ P - E = I \]

where \( I \) is the total amount of water flowing through the underground system. The problem with water balance analysis by this equation is that evapotranspiration and infiltration are difficult to measure.

In most drainage basins, the ultimate discharge point for groundwater is the master base level stream. At the lowest point, the master stream flows into a larger river, which in turn flows to the sea. However, especially in desert regions, closed drainage basins exist, where all flow is centripetal. The lowest point in the drainage basin, both topographically and poentiometrically, is typically a
...lak... which has no outlet either at the land surface or underground and loses water only by evaporation. In this case the water balance equation can be expressed as:

\[(E - P) I = 1\]

where \(E\) = evaporation from the lake surface, \(P\) = precipitation falling directly onto the lake surface, and \(I\) = surface and subsurface inflow to the lake. If there is no surface runoff, then \(I = \) the total amount of water flowing through the ground water system to the lake. The advantage to water balance analysis by this equation is that lake evaporation and direct precipitation are relatively easy to measure. This equation does not take into account changes in storage in the groundwater system, and so it is only useful in long-term calculations. Water balance calculations are inherently imprecise, but they do provide an order of magnitude estimate of groundwater fluxes. If the karst system volume can be independently estimated, recharge rates and groundwater flow times can be approximated.

**PREDICTION OF GROUNDWATER FLOW PATHS**

The traditional method for locating groundwater flow paths in karst aquifers is through the use of fluorescent dyes or other tracers. The dyes are injected into the aquifer at a known sinkhole, and are observed where they emerge at a karst spring. Tracer tests do not actually reveal the groundwater flow paths; they only demonstrate a hydraulic connection between the sinkhole and the spring. Nor do tracer tests reveal the actual groundwater velocity, because the flow path is never a straight line. Nor do tracer tests yield immediate results; in arid regions, where groundwater velocities may not be as fast as in humid regions, it may take longer for the injected tracers to arrive at the karst spring than the amount of time allotted for scientific investigation.

Arthur H. Palmer (1986) has written a landmark paper which presents an alternative methodology for detecting probable groundwater flow paths in karst aquifers, without the use of tracers or even data from boreholes and test wells. Palmer used detailed geologic maps of approximately 75 km of cave passages in a variety of geologic settings, derived from personal exploration and published sources. Palmer found that cave passage gradients and directions could be related to the local geologic structure and stratigraphy. The data show such consistent and easily explained relationships, and cover a broad enough range of geologic conditions, that the results can be extrapolated, with caution, to the prediction of ground water flow paths in karst aquifers elsewhere.

Palmer found that flow in the vadose zone tends to follow the dip of the strata, while flow in the phreatic zone tends to follow the strike of the strata. The difference is crucial in predicting flow paths in karst aquifers. The dip is the angle at which a stratum (sedimentary bed or layer) is inclined from the horizontal; the greater the inclination, the more steeply dipping the bed. The strike is the direction or bearing of a horizontal line in the plane of an inclined stratum; the strike is independent of the angle of the dip, but is always perpendicular to the direction of the dip.

In the vadose zone, flow is controlled by gravity, so the channels descend as vertically as possible toward the phreatic zone. In bedrock, most of these channels are far from vertical. Vadose conduits tend to be concordant to the strata, following the dip of the beds, especially in undeformed rocks. Deviations from the direction and inclination of the dip can generally be attributed to the deflection of flow paths by fractures.

No vadose conduit was found to have a gradient less than the dip of the strata. However, stratigraphic perching above relatively impermeable layers in the vadose zone is common even in highly jointed rocks. Some water-filled passages occur in the vadose zone in cascading, stair-step
profile, with thresholds or rest levels perched above the water table, confusing the distinction between vadose and phreatic zones; boreholes cannot distinguish between them. Perched water can flow laterally as much as several kilometers before reaching the water table. Over this distance, the water flow is entirely independent of the head distribution within the underlying phreatic zone.

The gentler the dip, the more important it is to take the dip into account in predicting the directions of vadose flow paths. Long-distance perching is most common in gently dipping, strongly bedded rocks. Furthermore, the gentler the dip, the more influential the subtle variations in dip direction.

In the phreatic zone, conduits follow the paths of greatest hydraulic efficiency between the vadose infeeder and the valley outlets. The jump at the very downstream end of the vadose section, where the conduit continues submerged within the phreatic zone, is usually no more than a few meters above the spring outlet. Some conduits are never fully submerged, but continue partially air-filled along the water table with very low gradients at approximately the level of the spring.

Phreatic conduits in bedded rocks tend to be oriented at nearly 90° to the dip, roughly along the strike. The strike direction is favored because it offers the shallowest routes without requiring discordance to the strata. The steeper the dip, the less the deviation of the flow path from the strike direction. In a thin soluble rock stratum bounded by insoluble rocks this might seem like a foregone conclusion, because the steep dip provides less leeway for the flow to deviate from the strike.

Phreatic conduits have extremely low hydraulic gradients because of their efficiency in transmitting ground water to springs. They acquire relatively low hydraulic heads with respect to the surrounding (intergranular or fracture-controlled) ground water, causing flow to converge toward them.

Tracer tests have shown that most karst ground water follows convergent flow paths. The predominance of caves with dendritic patterns, at least 75% of those known, supports this observation. This convergence generally concentrates contaminants in the major active conduits. There are some areas of divergent flow, which tends to disperse contaminants throughout the aquifer. This divergence is greatest in the vadose zone. However, contaminants that enter the diffuse-flow portion of a karst aquifer will leak slowly into the major active conduits over a long period of time.

APPLICATION OF KARST MODEL TO WIPP SITE

1. The Rustler aquifer, as a whole, is unconfined. It is one complex aquifer with five members and can only be understood in three dimensions. Water levels in some WIPP test wells are free to rise and fall in response to variations in recharge. This is the hallmark of an unconfined aquifer. In the Magenta dolomite at test wells H-2 and H-3, and in the Culebra dolomite at test wells H-1, H-3 and H-4, water levels rose steadily between mid-1977 and mid-1981, a period during which precipitation at Carlsbad was 17.14 inches per year, compared to an average of 10.85 inches per year during the previous 25 years. While the rise in Magenta and Culebra water levels cannot be correlated with individual rainstorms, it can be correlated with short-term trends in precipitation. Such a short-term response can only occur due to downward infiltration of rainwater through all overlying strata. All must be transmissive to recharge. DOE has made no measurements of rainwater recharge, and relies instead on measurements of permeability to estimate vertical transmissivity.

2. The Magenta and Culebra dolomite members of the Rustler Formation may be considered partially confined. The Magenta is overlain by Forty-Niner anhydrite, and the Culebra is overlain by Tamansk anhydrite, both of which are considered to be confining beds in most places. In actuality,
because anhydrite is a brittle, fractured rock, confinement is more likely to be occasioned by intervening claystones that do not support fractures without closing. In all WIPP test wells the Magenta and Culebra water levels rise into or above the overlying confining beds, except at H-7, WIPP-26 and WIPP-28 where the Magenta is dry, and at WIPP-29 near Laguna Grande de la Sal where the Culebra dolomite is overlain only by surficial deposits. There are consistent encounters of mudstones in the Tamarisk member, 6 to 22 feet above the Culebra, and in the Forty-Niner member, 13 to 25 feet above the Magenta, suggesting that vertical hydraulic connections to the Magenta and Culebra are infrequent. However, anhydrite fractures need not be numerous to be significant for groundwater transport. DOE should have located and characterized the connecting channels throughout the Tamarisk, but has not done so. At WIPP-13, in the northwestern part of the WIPP site, the Tamarisk is described as having a zone of mudstone/gypsum breccia and steeply-dipping fractures throughout; the Culebra and Magenta hydraulic heads are believed to be equal at WIPP-13, but the Magenta head was not measured. At H-6, in the northwestern corner of the WIPP site, the Culebra and Magenta hydraulic heads are known to be equal, indicating a hydraulic connection through the Tamarisk member, but the geophysical and lithologic logs are unavailable.

3. There are localized occurrences of perched water at the WIPP site, indicating the presence of underlying beds which are impermeable locally, but not generally. DOE has only recently begun to characterize them. In the vicinity of the WIPP shafts, and at H-5 in the northeastern corner of the WIPP site, there is perched water in the Santa Rosa sandstone; its hydraulic gradient (28 ft/100 ft) is steep and its hydraulic conductivity (up to 15.5 ft/day) is high. Where the Santa Rosa sandstone is absent in the central and southwestern parts of the WIPP site and south of the site there is perched water in the Dewey Lake Redbeds; attempts to correlate the elevations of these occurrences with cementation of fractures, fluid levels during logging, and loss of circulation of drilling fluid have failed. Perched water in both the Santa Rosa and Dewey Lake formations is fresh enough to be attributed to rainwater recharge, and its inconsistent occurrence indicates that, elsewhere, the water drains to the water table.

4. The position of the water table at WIPP is unknown. For this reason, it is not known where the Magenta and Culebra are confined and where they are unconfined. When the saturated zone is reached during the drilling of a test well, it takes time for the water level in the well to adjust to the level of the water table. Because drilling was not stopped long enough for such adjustment to occur, there is no record of the water table undisturbed conditions. Neither the high-water level nor the low-water level is known, and therefore the vadose zone and the phreatic zone cannot be defined with certainty. The nature of groundwater flow is completely different in the air-filled channels of the vadose zone than in the water-filled channels of the phreatic zone. Over time, as the karst becomes more developed and the water table migrates downward, abandoned air-filled channels remain in the vadose zone, and when these channels carry ground water following torrential rainstorms, the travel times to the water table may be extremely short. Failure to define the water table is a fatal flaw in hydrogeologic characterization.

Under the circumstances, the best we can do is to treat the water levels in the earliest WIPP test wells as though they represented undisturbed conditions. Gonzalez (1983) presents water levels in 13 test wells under supposedly undisturbed conditions, before the sinking of the WIPP shafts, and the highest levels represent the best estimate of the water table before disturbance by drainage into the WIPP shafts. Silva (1996) presents water levels in 33 test wells before the unexplained rise in Culebra water levels which began in January 1988; the data do not represent undisturbed conditions, but the data are synoptic (Table 1). From the data provided by Silva the position of the water table in the stratigraphic column can be approximated (Table 2) and plotted on a map (Figure 1). From this it can be deduced that the water table is in the Dewey Lake Redbeds across the WIPP site, dropping closer to the top of the Rustler as one moves southwestward toward test well P-15, and into
successively lower members of the Rustler as one moves toward Nash Draw. At P-15, perched water was found in the Dewey Lake at 225 feet below the surface, 6 feet above the Rustler. Our conceptual model, therefore, considers that the phreatic zone at the WIPP site includes the entire Rustler Formation, and that the primitive water table is mainly in the Dewey Lake Redbeds.

5. Effective porosity in the Rustler Formation is unknown. Fracture pores and solution channels are not well described, nor do we know their orientations. Porosity in the Culebra dolomite, measured on small samples in the laboratory, ranges from 3% to 30%. DOE averages this to 16%, and assumes that fracture flow is represented by 1% porosity and matrix diffusion is attributable to 15% porosity. In karst, the secondary porosity is the effective porosity, due to the large apertures produced by dissolution. DOE has no measurements of porosity in regions of the Rustler transected by solution conduits, and therefore does not know the effective porosity, nor therefore the velocity of transport. Nor has DOE demonstrated the effectiveness of matrix diffusion in karstified areas; the conservative assumption is that radionuclides will travel at the speed of water in channel flow.

East of Nash Draw, the largest open karst channels found in boreholes are at WIPP-33, where five water-filled caverns, measuring 7.0 ft, 9.5 ft, 6.0 ft, 2.0 ft and 5.0 ft from top to bottom, were found in the Dewey Lake Redbeds and in the Forty-Niner and Magenta members of the Rustler Formation. At WIPP-33 the fluid level during logging was 274 ft below land surface, and the Rustler-Salado contact is 677 ft below land surface; therefore, the thickness of the aquifer cannot be greater than 403 ft. The five caverns, totaling 29.5 ft, were found within a 110.0-ft stratigraphic section; therefore, the thickness of the karstic aquifer cannot be less than 110 ft. The WIPP-33 borehole is 16 inches in diameter, and is therefore traversed by at least 40 ft² of caverns. If the caverns are circular, then they measure 160 ft² in cross-section. If the caverns are lens-shaped along bedding and underlie the deepest part of the WIPP-33 sinkhole (the 3324-ft. contour line), then they are 135 ft wide and measure 4000 ft² in cross-section.

There is a solution-subsidence trough trending westward from SW 1/4 sec 30, T 22 S, R 31 E in the southwestern part of the WIPP site. The western boundary of the WIPP site is 4 miles long. If we assume that WIPP-33 marks the only major solution channel in the northwestern part of the WIPP site, then the aquifer penetrated by the WIPP-33 caverns is 2 miles wide and 110 ft to 400 ft thick, or 1,200,000 ft² to 4,200,000 ft² in cross-section. It follows that the effective porosity of the Rustler/Dewey Lake aquifer could be as low as 0.095% (4000 ft² / 4,200,000 ft²) but not greater than 0.33% (4000 ft² / 1,200,000 ft²), unless there are major undetected karst channels within one mile of WIPP-33.

6. Karst aquifers are heterogeneous and anisotropic. Transmissivity varies with position and direction. Within the WIPP site, measured Culebra transmissivity varies by nearly three orders of magnitude, from 0.1 ft²/day to 88.0 ft²/day. Within one mile of the WIPP site, Culebra transmissivity varies by more than five orders of magnitude, from 0.003 ft²/day to 324 ft²/day. The highest transmissivities have distinct directional orientation in the northwestern and southeastern portions of the WIPP site, as indicated by interference tests. The data cannot be treated as random variables, as DOE has done in its stochastic performance assessment. Values obtained from pump tests at the WIPP site and vicinity vary widely over short distances; wells that tap connections with the karst conduit system show values for transmissivity which are orders of magnitude higher than wells drilled into the unfractured wall rock a short distance away. Transmissivity data in karst cannot be averaged or interpolated between data points. The discontinuous nature of the conduit system violates the mathematical assumption that transmissivity (T) is continuously verifying.
Calculated transmissivities have varied by one to two orders of magnitude at the same WIPP test wells. The most common reason for the discrepancy has been the manner of testing. Transmissivities calculated from multi-well pump tests have tended to be much higher than those calculated from single-well tests. DOE, in its performance assessment (CCA, Table TFIELD-2) has selectively used calculated transmissivities at the low end of the scale, especially within one mile of the center of the WIPP site [Table 3]. The result of such selective presentation of data is to completely misrepresent the transmissivity field at the WIPP site. DOE's model assumes a continuous swath of low transmissivity across the WIPP site [Figure 2], when the highest calculated transmissivities show a continuous swath of high transmissivity across the WIPP site [Figure 3]. Use of the highest measured values of transmissivity is both realistic and conservative. It is realistic because the highest measured values are real; they represent the ability of the rocks to transmit water along discrete, localized flow paths at rates which are orders of magnitude higher than elsewhere in the drainage basin. It is conservative because these are the paths of least resistance, the actual ground water flow paths that will occur during recharge transients. Our conceptual model, therefore, utilizes the highest calculated transmissivities along recognized ground water flow paths.

7. The hydraulic gradients along the ground water flow paths at the WIPP site are unknown. DOE has never collected synoptic data for the varying hydraulic heads in the Culebra. Thus the measurements of gradients cannot be reliably compared to each other, and neither the flow directions nor the hydraulic gradients can be stated with certainty. Moreover, the data set for hydraulic heads in the Magenta is incomplete, because DOE does not recognize the importance of the Magenta to ground water flow in the Rustler. DOE has proceeded on the assumption that the Culebra is a confined aquifer, bounded above and below by impermeable anhydrite beds. Consequently, we do not know where the Culebra is confined and where it is not, nor what is the full extent of the aquifer.

Under the circumstances, the best we can do is to utilize hydraulic heads that we do not know to be in error. In analyzing the hydraulic head data [Table 4] used in DOE's performance assessment (CCA, Table TFIELD-3), we have found eight examples of test wells where DOE's assumed values are clearly in error, six examples of test wells where DOE's assumed values are unsubstantiated, five examples of test wells where DOE has selected values which would steer the southeasterly flow path away from H-7 in Nash Draw [Figure 4], and two examples of test wells (H-16 and WIPP-29) which are not included in DOE's performance assessment even though they are located close to demonstrated ground water flow paths. One of these wells, WIPP-29, is located 0.6 miles from Laguna Pequena and 1.4 miles from Laguna Grande de la Sal, the most copious discharge points for Rustler ground water. At WIPP-29 the Culebra is overlain only by surficial deposits; the water level is the hydraulic head -- 2968 feet above sea level. As one would expect, this is the lowest hydraulic head measured at any WIPP test well. Inclusion of WIPP-29 in performance assessment flow models would have steered ground water flow paths to Laguna Grande de la Sal. Our conceptual model considers all, not merely most, of the data. The CCA also reports uncertainty in Culebra hydraulic heads due to measurement error. Along the southeasterly flow path, the margin of error is greater than the assumed drop in hydraulic head. Our conceptual model incorporates a range of hydraulic head values, which necessarily results in a range of calculated ground water travel times.

8. Groundwater flow in karst, especially in the phreatic zone, tends to be convergent. A large conduit will be a course of relatively low hydraulic head, and groundwater flow will converge upon it. The course of the submerged conduit will be marked by troughs in the water table. This can be seen along the southeasterly flow path, where the Culebra heads reported by Lappin (1989) at H-11, H-17, P-17 and H-7 are equal (2995 ft) and are lower than the Culebra heads in the surrounding test wells [Figure 4].
Sinkholes, or dolines, are present in every karstland. They are the quintessential feature, the surface expression of subsurface dissolution, subsidence, and collapse. However, in a covered karst, sinkholes may be less frequent. Thick beds of sandstone exposed at the surface may not fully reflect the disruption of subsurface strata, and where the bedrock is covered by windblown sand, all but the largest karst features may be obscured. However, there will still be a lack of surface runoff. This is the telltale sign of karst, even in and regions, where running water is generally the most effective geomorphic agent shaping the landscape. Within the WIPP site, most of the infiltrating rainwater is funneled not through sinkholes, but through a perforated caprock of Mescalero caliche. Once beneath the caliche, the water is protected from evaporation and finds its way to vadose feeder channels in the Dewey Lake Red beds.

Flow in the vadose zone is controlled by gravity, and is entirely independent of the hydraulic head distribution in the underlying phreatic zone. In bedrock, flow in the vadose zone is downward but not vertical, and tends to follow the dip of the strata, especially in gently dipping, undeformed rocks such as the Dewey Lake Red beds. The gentler the dip, the more it controls the direction of vadose flow, and the more influential the subtle variations in dip direction. Within the WIPP site there is no persistent dip at the top of the Dewey Lake Red beds [Figure 5]. Instead there are mounds and depressions. The mounds are centered around test well H-18 in the northwestern part of the site, and test wells H-1 and H-3 in the central part of the site. There are two structural depressions: one of them, 15 feet deep, centered around test well WIPP-12, is overlain by Santa Rosa sandstone, the other one, 24 feet deep, centered around test well WQSP-6, is not. We have demonstrated in a previous paper that the absence of Santa Rosa sandstone is the controlling factor in determining the area of greatest rainwater recharge. At WQSP-6 the Dewey Lake Red beds produced 25-30 gallons per minute of potable water, the largest amount reported anywhere in the vicinity of the WIPP site. This is entirely consistent with the concept of vadose flow following the structural dip, collecting as perched water in a structural depression, and finding its way downward through feeder channels under the control of gravity. West of the WIPP site the Dewey Lake Red beds dip westward at about 50 feet per mile (0.50); here the vadose flow would be westward, directly toward Nash Draw.

Flow in the phreatic zone follows the paths of maximum hydraulic efficiency, the paths of least resistance enhanced by dissolution. Phreatic conduits in bedded rocks with interbedded mudstones tend to be oriented at nearly 90° to the dip of the strata, roughly along the strike. The steeper the dip of the beds, the less the deviation of the flow path from the strike direction. Thus the flow path is almost horizontal. Phreatic conduits have extremely low hydraulic gradients because their large dimensions provide efficiency in transmitting water to karst springs. Within the recharge area at the WIPP site the dip is east-northeastward; the top of the Rustler [Figure 6] dips about 80 feet per mile (0.50); the top of the Culebra [Figure 7] dips about 75 feet per mile (0.80); and the top of the Salado [Figure 8] dips about 90 feet per mile (1.00). In the northwestern part of the WIPP site is a region where dissolution has affected the top of the Salado. From the WIPP shafts, the flow paths through the Culebra dolomite would be almost horizontal, along the 2700-foot structural contour line, north-northeastward to WIPP-13 and south-southeastward to the west of H-11 and H-17 [Figures 4 & 7]. This is consistent with the concept of karstic phreatic flow primarily through the Rustler dolomites, and secondarily above the Rustler mudstones, not because the flow is fully confined, but because these are the most permeable strata, the paths of least resistance.

When flow along the northwesterly path reaches WIPP-13 it becomes unconfined. The Culebra hydraulic head at WIPP-13 (3064 ft) is believed to be equal to the Magenta hydraulic head. Flow from the Culebra and lower unnamed members rises through the vertically fractured Tamarisk member to the Magenta and Forty-Niner members; there is no hydraulic separation between the members of the Rustler. From WIPP-13 the flow path turns westward, under proven karst conditions, passing by H-6, where the Culebra and Magenta heads are known to be.
equal (3057 ft), and continuing through the caverns beneath the WIPP-33 sinkhole to WIPP-25 in Nash Draw, where the Culebra and Magenta heads are also known to be equal (3054 ft). Although this portion of the flow path is still in the phreatic zone, flow no longer follows the strike of the beds. The existence of this flow path has been demonstrated by the multi-well pump test centered in the Culebra at WIPP-13. Unfortunately, the pump tests were performed under the assumption that flow is confined to the Culebra, and were not designed to assess the importance of other members of the Ruster. The calculated transmissivity along the flow path between WIPP-13 and WIPP-25 was much higher (650 ft³/day) than the transmissivities calculated at the individual wells (69.0 ft³/day at WIPP-13, 270 ft³/day at WIPP-25. This reflects the presence of a zone with extremely high transmissivity between WIPP-13 and WIPP-25, most likely the caverns at WIPP-33, all of which are higher than the Culebra. The hydraulic gradient between WIPP-13 and WIPP-25 is low (2.5 ft per mile) due to the efficiency along this flow path to Nash Draw.

13. When flow along the southeasterly path reaches H-11 the hydraulic gradient is essentially zero. The Culebra hydraulic heads at H-11, H-17, P-17 and H-7 are equal (2995 ft). This implies a fairway of such high transmissibility that a gradient is not evident between flow events. The WIPP site air photos reveal this region to be pockmarked with sinkholes and indistinguishable in character from Nash Draw. Along this path the groundwater flow is west-southwestward, opposite to the east-southeastward direction of the regional dip. Accordingly, the water table truncates stratigraphic column, dropping from the Dewey Lake Red beds at H-11 within the WIPP site to Tamarisk gypsum at H-7 in Nash Draw. When viewed in profile, the flow path during dry periods would have stagnant pools of perched water, not associated with the local water table, with sills or spill-points at every impermeable bed. After torrential rainstorms, rapid recharge would flush through the channels, creating cascades of waterfalls, in a step-by-step fashion, wherever vertical pathways exist. Perched water was reported at P-17 in the Dewey Lake Red beds, 265 ft below land surface, 117 ft above the Rustler; water was also reported at P-17 in the lower unnamed member, 600 ft below land surface, 17 ft below the Culebra. Thus the observations are consistent with the karst model.

14. Flow in Nash Draw is under water table conditions. Conduits may not be fully submerged. Flow is unconfined along the water table all the way to the karst springs at Laguna Pequena (2959 ft). Hydraulic gradients are apparently higher (13.0 ft/mile from WIPP-25 to Laguna Pequena, 4.5 ft/mile from H-7 to Laguna Pequena), probably due to cascading conditions. Transmissivities are high (650 ft³/day at WIPP-25, 1450 ft³/day at H-7, 1000 ft³/day WIPP-29). Inflow from Laguna Pequena to Laguna Grande de la Sal is about 18.5 ft³/sec (6320 gal/min, or 5.8 x 10⁶ ft³/yr) as a long-term average, as determined by a regional water balance analysis, and can be as high as 394 ft³/sec (177,000 gal/min) as measured on September 5, 1984 after a four-inch rainstorm (Phillips, 1987, Chapter VIII). Large, transient groundwater discharges from a few springs is one of the classic characteristics of a karstland.

15. DOE, in its performance assessment, assumes that all flow is through a confined Culebra dolomite aquifer with only steady matrix and fracture flow. All of DOE's data collection was based upon this assumption, adequate for the purpose of modeling because it neglects the extreme heterogeneity and transient behavior of a karst. DOE has never characterized the orientations, spacings, and apertures of fractures in the Ruster Formation or they would have discovered the dissolution conduits. As shown under the heading of Laminar Flow, transport is very sensitive to such parameters that determine effective porosity. Without knowledge of the apertures of fractures or solution conduits it is not possible to make reliable calculations of transport of radionuclides. However, if we were to seek an average steady velocity using D'Arcy's Law as DOE has done, we would still find different results in the presence of karst.
16. The multi-well pump test at WIPP-13 demonstrated an existing hydraulic connection with the WIPP exhaust shaft located 8000 ft (1.52 miles) to the southeast, and with WIPP-25 located 20,420 ft (3.87 miles) to the west in Nash Draw. The calculated hydraulic conductivities, assuming a confined aquifer 7 m (23 ft) thick, are 1.32 ft/day between the exhaust shaft and WIPP-13, and 26.0 ft/day between WIPP-13 and WIPP-25. In calculations derived from single-well pump tests, hydraulic conductivity is 11.0 ft/day at WIPP-25, and 33.3 ft/day at WIPP-29. As indicated in paragraph 5, above, average effective porosity could be as low as 0.1% and should not be greater than 0.33%, although our calculations will also consider DOE's assumed value of 1.0%. The hydraulic gradient is the most difficult parameter to assess since we have only apparent, steady gradients. At the WIPP exhaust shaft the Culebra hydraulic head, as determined from DOE/WIPP 97-2278, Figure 3.31, is 2992 ft, which is lower than the water levels in Nash Draw and is therefore reflecting temporary drainage into the repository. The Magenta hydraulic head, as determined from DOE/WIPP 97-2278, Figure 3.29, could be as high as 3096 ft or as low as 3068 ft. At WIPP-13, where the Culebra and Magenta heads are believed to be equal, Lappin (1989) gives a value of 3064 ft. At WIPP-25, where the Culebra and Magenta heads are known to be equal, Lappin (1989) gives a value of 3054 ft. At WIPP-29, where the Magenta is absent and the Culebra is overlain only by surficial deposits, Lappin (1989) gives a hydraulic head of 2968 ft. WIPP-29 is located near the karst springs at Laguna Pequena, 35,200 ft (6.67 miles) from WIPP-25.

Under Darcy's law, the average fluid velocity is inversely proportional to the effective porosity, and directly proportional to the hydraulic conductivity and the hydraulic gradient. Therefore, the highest velocity will result from low porosity, high conductivity, and high gradient; the lowest velocity will result from high porosity, low conductivity and low gradient. Our calculations assume a hydraulic gradient of 0.0005 (3064 ft - 3054 ft / 20,421 ft) between WIPP-13 and WIPP-25, and 0.0025 (3054 ft - 2968 ft / 35,205 ft) between WIPP-25 and WIPP-29. After the heads in the WIPP shafts recover, the hydraulic gradient between the WIPP exhaust shaft and WIPP-13 could be as high as 0.004 (3096 ft - 3064 ft / 6004 ft) or as low as 0.0005 (3068 ft - 3064 ft / 8004 ft). If the average effective porosity is 0.1%, the hydraulic gradient between the WIPP exhaust shaft and WIPP-13 is 0.004, and the hydraulic conductivity between WIPP-25 and WIPP-29 is 33.3 ft/day, then the travel times (t) along the segments of the northwesterly flow path are as follows:

\[
V = \frac{K \cdot \Delta h}{\Delta l}
\]

\[
V_1 = \left(\frac{1.32 \text{ ft/day}}{(0.001)}\right) \times \left(0.004\right) = 5.28 \text{ ft/day}
\]

\[
t_1 = \frac{(8004 \text{ ft})}{(5.28 \text{ ft/day})} = 1,515 \text{ days}
\]

\[
V_2 = \left(\frac{26.0 \text{ ft/day}}{(0.001)}\right) \times \left(0.0005\right) = 13.0 \text{ ft/day}
\]

\[
t_2 = \frac{(20,421 \text{ ft})}{(13.0 \text{ ft/day})} = 1,571 \text{ days}
\]

\[
V_3 = \left(\frac{33.3 \text{ ft/day}}{(0.001)}\right) \times \left(0.0025\right) = 83.25 \text{ ft/day}
\]

\[
t_3 = \frac{(35,205 \text{ ft})}{(83.25 \text{ ft/day})} = 423 \text{ days}
\]

\[
t = 1,515 \text{ days} + 1,570 \text{ days} + 423 \text{ days} = 3,509 \text{ days} = 9.6 \text{ years}
\]

If the average effective porosity is 1%, the hydraulic gradient between the WIPP exhaust shaft and WIPP-13 is 0.0005, and the hydraulic conductivity between WIPP-25 and WIPP-29 is 11.0 ft/day, then the travel times (t) along the segments of the northwesterly flow path are as follows:
Thus the groundwater travel time along the northwesterly flow path from the WIPP shafts to Laguna Grande de la Sal could be as short as 10 years using our estimates of karst geometry, or as long as 400 years using DOE's geometry, but never 10,000 years.

17. Multi-well pump tests have demonstrated a rapid hydraulic connection between test wells H-3, DOE-1 and H-11 in the southeastern part of the WIPP site. This flow path, acknowledged by DOE, crosses the WIPP site boundary near H-11, passing through a zone of high transmissivity between test wells H-17 and P-17. It may extend farther, turning westward toward H-7 in Nash Draw. Palmer (1966) provided support for the logical contention that many diffuse conduits are generally tributary to a large, master conduit, while a master conduit seldom distributes its flow to an array of diffuse conduits. Thus a karst channel on-site must continue to a point of discharge at Nash Draw. The hydraulic heads at H-11, H-17, P-17 and H-7 are reportedly equal (2995 ft), which demonstrates the difficulty in applying Darcy's law to a karstland characterized by episodic flows interrupted by long stagnant intervals. If velocity were proportional to the apparent hydraulic gradient, then the velocity would be zero and the travel time would be infinite. A more reasonable interpretation is that the region between H-11 and H-7 is so highly transmissive that a measurable gradient is not needed to drive groundwater flow. This interpretation is supported by the Culebra transmissivity of 1430 ft²/day measured at H-7, the highest transmissivity ever reported for any of the forty-two WIPP test wells.

This southeasterly flow path is primarily through the Culebra dolomite and on the mudstone immediately beneath the Culebra. There has been a consistent lack of core recovery in this mudstone unit, yet no hydrologic data have been taken in this unit at any of the WIPP test wells. There are no reliable measurements of the Culebra hydraulic head in any of the WIPP shafts; the nearest test well is H-1, where Lappin (1989) reported a head of 3024 ft. Gonzalez (1983) reported an undisturbed water level of 3025 ft at H-1; Mercer (1983) reported fluid density of 1.016, and the CCA reports 1.022, so the corrected freshwater hydraulic head should be 3030 ft or 3032 ft. Lappin (1989) reported heads of 3008 ft at H-3, 3001 ft at DOE-1, and 2995 ft at H-11. These heads are reasonable given the reported water levels and fluid densities, and we will use them in our calculations.

The highest measured hydraulic conductivities, assuming a confined aquifer 7 m (23 ft) thick, are 1.32 ft/day at the WIPP exhaust shaft, 0.86 ft/day at H-3, 1.5 ft/day at DOE-1, and 1.7 ft/day at H-11. The extrapolation of borehole measurements beyond the immediate vicinity of the borehole is inappropriate in a heterogeneous, anisotropic aquifer, but given the paucity of data we have no other way to estimate the travel time. The hydraulic gradient is 0.0013 (3008 ft - 3001 ft / 5224 ft) between H-3b3 and DOE-1, and 0.0015 (3001 ft - 2995 ft / 3992 ft) between DOE-1 and H-11b3. It is another 1501.7 ft from H-11b3 to the WIPP site boundary. If we assume a hydraulic head of 3024 ft at the WIPP exhaust shaft, then the hydraulic gradient is 0.006 (3024 ft - 3001 ft / 3852 ft) between the shaft and H-3b3; if we assume a hydraulic head of 3032 ft, then the hydraulic gradient between the shaft and H-3b3 is 0.008 (3032 ft - 3001 ft / 3852 ft).
If the hydraulic gradient between the WIPP exhaust shaft and H-3b3 is 0.006, and the effective porosity is 0.1% (as derived at WIPP-3), and if we assume that the hydraulic conductivity between two test wells is equal to the lesser of the two measured values, then the travel times (t) along the segments of the southeasterly flow path are as follows:

\[
V_1 = [(1.32 \text{ ft/day}) \times (0.001)] \times (0.006) = 10.6 \text{ ft/day}
\]
\[
 t_1 = (3652 \text{ ft}) / (10.6 \text{ ft/day}) = 363 \text{ days}
\]

\[
V_2 = [(1.5 \text{ ft/day}) \times (0.001)] \times (0.0013) = 1.95 \text{ ft/day}
\]
\[
 t_2 = (5224 \text{ ft}) / (1.95 \text{ ft/day}) = 2679 \text{ days}
\]

\[
V_3 = [(1.7 \text{ ft/day}) \times (0.001)] \times (0.0015) = 2.55 \text{ ft/day}
\]
\[
 t_3 = (5494 \text{ ft}) / (2.55 \text{ ft/day}) = 2155 \text{ days}
\]

\[
t = 363 \text{ days} + 2679 \text{ days} + 2155 \text{ days} = 5197 \text{ days} = 14.2 \text{ years}
\]

Thus the travel time along the southeasterly flow path from the WIPP shafts to the WIPP site boundary could be as short as 15 years using our estimates of karst geometry, or as long as 200 years using DOE's geometry, but never 10,000 years.

The preceding calculations are crude but conceptually sound. Because we do not know the aperture of the karst conduits, or their hydraulic conductivity, or the position of the water table during flow periods, or where the Rustler flow is confined and where it is not, an adequate performance assessment cannot be undertaken by anyone. Had the DOE engaged in a genuine effort to investigate and characterize the karst hydrologic system at the WIPP site and vicinity, more meaningful calculations would have been possible.

We have applied Darcy's law along pre-conceived flow paths made evident by the interference testing results and fortuitous placement of wells. We predict travel times of 10 to 400 years. Conversely, DOE has computed travel times over shorter paths (just to the compliance boundary, not Nash Draw) that are two to three orders of magnitude greater. The reasons are: (1) that they have used synthetic head data that reflect much of the drawdown to the shafts, giving low gradients; (2) that they have used minimum values of conductivity, instead of the highest values appropriate to karst conditions; and (3) that they have used recharge rates commensurate with the minimized conductivities, 0.2 to 2.0 mm/yr, whereas evidence given below suggests recharge rates close to 18 mm/yr. DOE's
recharge rate was determined by what would calibrate their distorted model. We have a more rational estimate based on a hydrologic balance.

18. The WIPP site lies within a closed drainage basin. The lowest point in the basin, both topographically and potentiometrically, is Laguna Grande de la Sal in Nash Draw. It is a salt lake with no outlet either at the land surface or underground; it loses water only by evaporation. The karst springs which drain the Rustler Formation reach the surface at Laguna Pequena, the most copious inlet to Laguna Grande de la Sal. There is no other apparent surface runoff into either lake, and so the regional water balance may be expressed as follows:

\[(E - P)I = I\]

where \(E\) = evaporation from the lake surface, \(P\) = precipitation falling directly onto the lake surface, and \(I\) = ground-water inflow to the lake. The USGS estimates that brine evaporation equals 90 inches (7.5 feet) per year in the vicinity of Laguna Grande. Precipitation at Carlsbad averages about 14.4 inches (1.2 feet) per year. The natural extent of Laguna Grande, as mapped by Robinson and Lang in 1934, when potash mining began in Nash Draw, was about 2,120 acres \((9.23 \times 10^7 \text{ ft}^2)\). Net evaporation from Laguna Grande would equal \(5.8 \times 10^8 \text{ ft}^3\text{yr}\). At least this amount of water drains from the Rustler aquifer into the salt lake, and an equal amount of infiltrating rainwater must reach the Rustler Formation.

In a karst terrain such as the Nash Draw watershed, there is almost no surface runoff; drainage is almost entirely underground. Thus the regional water balance may also be expressed this way:

\[P - I = E\]

where \(P\) = precipitation, \(I\) = infiltration, and \(E\) = evapotranspiration. From analysis of USGS topographic maps the size of the Nash Draw watershed may be estimated at 226,000 acres, or \(9.84 \times 10^9 \text{ ft}^2\). Potentiometric contour maps indicate that this topographic divide approximates the ground water divide. If precipitation equals 1.2 ft/yr, then precipitation falling on the watershed is \(1.18 \times 10^{10} \text{ ft}^3\text{yr}\). The infiltration rate of \(5.8 \times 10^8 \text{ ft}^3\text{yr}\) would equal about 5% of annual precipitation, and so the rate of evapotranspiration would be about 95%.

DOE, in its performance assessment, assumes that rainwater recharge to the Rustler Formation equals 0.2 to 2.0 mm/yr. If precipitation at Carlsbad averages nearly 40 cm/yr, then DOE is assuming an infiltration rate of only 0.05% to 0.5% per year, and an evapotranspiration rate of 99.5% to 99.95% per year. Based upon these unwarranted assumptions, DOE concludes that thousands or tens of thousands of years are required for infiltrating rainwater to reach the Rustler Formation and, consequently, that an equivalent amount of time is necessary to drain the Rustler aquifer. These assumptions are not based upon measured data, are inconsistent with the regional water balance, and cannot account for the \(5.8 \times 10^8 \text{ ft}^3\text{yr}\) of naturally occurring ground water evaporating from Laguna Grande de la Sal. Such water balance calculations provide an order of magnitude estimate of ground-water fluxes consistent with the higher values of hydraulic conductivity. Any calculations of infiltration or ground-water travel times which are inconsistent with these magnitudes based on a water balance must be wrong.

19. The standard methodology for identifying flow paths and measuring travel times in karst aquifers is through the use of fluorescent dyes or other tracers. This method should have been used, and still could be used, at WIPP. The WIPP-33 drill hole intercepted a nested sequence of five water-filled caverns — two in Magenta dolomite, two in Forty-Niner gypsum, and one in Dewey Lake siltstone.
At the WIPP-33 sinkhole, following a ten-inch rainstorm in September 1985, five feet of standing water was observed to infiltrate into the ground. If the WIPP-33 drill hole were converted into a test well, and enough water were pumped into the sinkhole to simulate this rainstorm, then tracers in the water might be detected at the WIPP-25 test well in Nash Draw, where gypsum deposits containing bones and teeth of extinct species of horse and camel record the presence of karst springs during the Pleistocene. However, it is not certain that WIPP-25 intercepts the modern-day karst conduits; tracers might not be observed until they arrive at the karst springs at Laguna Pequena. The same problem pertains to ground water monitoring in karst aquifers. Unless monitoring wells intercept the karst conduits, contaminants in ground water can bypass an array of monitoring wells and remain undetected until discharging at distant springs. In the case of WIPP, this could mean that failure of containment would go unrecognized until much of Nash Draw is contaminated.

20. As previously stated, the conservative assumption is that, under karst conditions, if there is effectively no filtration or retardation of dissolved contaminants, that radionuclides will travel at the speed of water. Plutonium entering the Rustler aquifer would begin to arrive at Laguna Grande de la Sal as soon as the fastest ground water can carry it there. Plutonium would concentrate in the lake sediments until flushed out by major flooding. Laguna Grande de la Sal is in a closed drainage basin, with no perennial outlet to the Pecos River either at the surface or underground; its water level fluctuates with rainfall. There is a low, but discernible topographic divide between Laguna Grande de la Sal and the Pecos River. This topographic divide is partly breached by an irrigation canal which extends southwestward from a bench mark (1100 ft FNL, 200 ft FWL, sec 19, T 23 S, R 29 E). The elevation of the bench mark is 2964 ft, and the elevation of the irrigation canal is 2960 ft. Field observations adjacent to another bench mark (2314 FSL, 2203 FEL, sec 4, T 23 S, R 29 E), with an elevation of 2959 ft, indicate that the evaporite crust of Laguna Grande de la Sal has killed all vegetation up to an elevation of 2960 ft, the same elevation as the irrigation canal. The top of the evaporite crust records the high-water level for the salt lake. Thus the irrigation canal can be a conduit for overflow discharge from Laguna Grande de la Sal to the Pecos River in times of major flooding. The irrigation canal is 0.4 miles long and reaches the Pecos River 3.25 miles east of the town of Loving, New Mexico; hence it is known informally as the Loving Canal. If this canal should carry plutonium contamination from the salt lake to the Pecos River, it is here and downriver that actual victims would be affected.
FIGURE 1: POSITION OF WATER TABLE IN STRATIGRAPHIC COLUMN

CONTOUR INTERVAL * 50 FEET
ABOVE OR BELOW TOP OF RUSTLER
WATER LEVELS FROM SILVA (1996)
MEASURED JANUARY 1988
FIGURE 2: CULEBRA TRANSMISSIVITIES ASSUMED IN CCA

- Greater than 10 ft²/day
- Less than 10 ft²/day
FIGURE 3: HIGHEST MEASURED CULEBRA TRANSMISSIVITIES

- Circles represent transmissivities greater than 10 ft²/day.
- Squares represent transmissivities less than 10 ft²/day.

Legend:
- GREATER THAN 10 ft²/day
- LESS THAN 10 ft²/day
FIGURE 4: COMPARISON OF GROUNDWATER MODELS

DIRECTIONAL ARROWS FROM SAND97-0194, FIGURE 1-9. USED WHERE CONSISTENT WITH HYDRAULIC HEADS IN CCA.

MILES
FIGURE 5: STRUCTURE CONTOURS ON TOP OF DEWEY LAKE REDBEDS

CONTOUR INTERVAL = 20 FEET
DATUM BASE: MEAN SEA LEVEL
FIGURE 6: STRUCTURE CONTOURS ON TOP OF RUSTLER FORMATION

CONTOUR INTERVAL = 20 FEET
DATUM BASE: MEAN SEA LEVEL

MILES
FIGURE 7: STRUCTURE CONTOURS ON TOP OF CULEBRA DOLOMITE

CONTOUR INTERVAL = 20 FEET
DATUM BASE: MEAN SEA LEVEL
FIGURE 8: STRUCTURE CONTOURS ON TOP OF SALADO FORMATION

CONTOUR INTERVAL = 20 FEET
DATUM BASE: MEAN SEA LEVEL
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The water table, as indicated by water levels in wells cased to the Culebra, measured in January 1988 (Silva, 1996), is given relative to the top of the Rustler Formation. These data are not undisturbed conditions, but the data are synoptic.

Note: Bedrock surface at WIPP-29 is Culebra dolomite.
TABLE 3. COMPARISON OF HIGHEST MEASURED TRANSMISSIVITIES (ft²/day)
IN CULEBRA DOLOMITE WITH THOSE ASSUMED IN CCA, TABLE TFIELD-2

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<tr>
<td>* Exhaust Shaft</td>
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</table>

* Test wells located within 1.5 miles of waste panels.
DOE considers that 10 ft<sup>2</sup>/day is a high transmissivity. In the Culebra dolomite, measurements higher than 10 ft<sup>2</sup>/day have been reported at ten of fifteen locations within 1.5 miles of the waste panels. These include the ERDA-9 test well (22.0 ft<sup>2</sup>/day) and the WIPP exhaust shaft (28.0 ft<sup>2</sup>/day) at the center of the WIPP site, and the H-1 test well (30.0 ft<sup>2</sup>/day) directly above the waste panels. Yet the DOE assumes low transmissivities, no greater than 2.2 ft<sup>2</sup>/day, at all but one of these fifteen locations, the lone exception being DOE-1 (11.0 ft<sup>2</sup>/day), located 1.1 miles southeast of the waste panels, where transmissivity of 33.0 ft<sup>2</sup>/day has been reported.

The net effect of such selective presentation of data is to completely misrepresent the transmissivity field at the WIPP site. When DOE's assumed transmissivities are plotted on a map (Figure 2), it is shown that DOE's model assumes a continuous swath of low transmissivity from the southwest corner to the northeast corner of the WIPP site, two miles wide, bounded on the southeast by test well DOE-1 (11.0 ft<sup>2</sup>/day) and on the northwest by test wells WQSP-1 (31.0 ft<sup>2</sup>/day) and WQSP-2 (11.0 ft<sup>2</sup>/day), whose sources of measurement, reported in Table T7FIELD-2 of the CCA, are not disclosed. Within this two-mile-wide swath of assumed low transmissivity, the highest assumed measurement is at test well H-3 (22.0 ft<sup>2</sup>/day), located 0.15 miles south of the waste panels, where transmissivity of 19.0 ft<sup>2</sup>/day has been reported. Closer to the WIPP shafts the assumed transmissivities range from 0.25 ft<sup>2</sup>/day at test well WIPP-21, where transmissivity of 22.0 ft<sup>2</sup>/day has been reported, to 0.90 ft<sup>2</sup>/day at test well H-1, where transmissivity of 20.0 ft<sup>2</sup>/day has been reported. The Culebra dolomite is 23 feet thick at H-1; when divided into the assumed transmissivity, the result is an assumed hydraulic conductivity of 0.04 ft/day, or 14 feet per year, in the vicinity of the WIPP shafts.

A truly conservative performance assessment should utilize the highest reported transmissivities at WIPP test wells. When the highest reported transmissivities are plotted on a map (Figure 3), it is shown that a continuous swath of high transmissivity, two miles wide, extends from the northwest corner to the southeast corner of the WIPP site, bounded on the east by test well H-15 (7.1 ft<sup>2</sup>/day) and on the southwest by test well H-14 (0.3 ft<sup>2</sup>/day), where higher transmissivity was implied but not definitively measured during the multi-well pump test centered in the Culebra at H-11. Within this two-mile-wide swath of reported high transmissivity are a number of test wells located within or alongside potential groundwater flow paths, including H-6 (88 ft<sup>2</sup>/day); DOE-2 (89.0 ft<sup>2</sup>/day); WIPP-13 (12.0 ft<sup>2</sup>/day); the WIPP exhaust shaft (28.0 ft<sup>2</sup>/day); H-1 (20.0 ft<sup>2</sup>/day); H-3 (19.0 ft<sup>2</sup>/day); DOE-1 (33.0 ft<sup>2</sup>/day); H-11 (43.0 ft<sup>2</sup>/day); H-17 (13.0 ft<sup>2</sup>/day); and P-17 (21.0 ft<sup>2</sup>/day). The Culebra dolomite is 21.2 feet thick at the WIPP exhaust shaft; when divided into the transmissivity, the result is a hydraulic conductivity of 1.32 ft/day, or 480 feet per year. The WIPP exhaust shaft was shown by the WIPP-13 multi-well pump test to be hydraulically connected to test well WIPP-25 in Nash Draw. Neither the exhaust shaft nor WIPP-25 were included in DOE's performance assessment.

Altogether there are sixteen WIPP test wells where DOE's assumed transmissivity and the highest reported transmissivity differ by one to two orders of magnitude (H-1, H-2, H-3, H-4, H-15, H-17, P-17, P-18, WIPP-12, WIPP-18, WIPP-19, WIPP-21, WIPP-22, WIPP-27, D-268, and ERDA-9). Such a consistent pattern could not have happened by accident.
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<th>-- water levels --</th>
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ERRORS IN HYDRAULIC HEADS ASSUMED IN CCA:

H-1: Assumed head in CCA is 3024 ft. Undisturbed water level is 3025 ft (Gonzalez, 1983). Correction factor is 5 ft @ fluid density of 1.016 (Mercer, 1983). CCA reports fluid density of 1.022. Correction factor should be 7 ft. Head is at least 3032 ft.

H-3: Assumed head in CCA is 3011 ft. Undisturbed water level is 2998.3 ft (Gonzalez, 1983). Correction factor is 8 ft @ fluid density of 1.024 (Mercer, 1983). CCA reports fluid density of 1.035. Correction factor should be 12 ft. Head is at least 3010 ft.

H-4: Assumed head in CCA is 2990 ft. Undisturbed water level is 2993.5 ft (Gonzalez, 1983). Correction factor is 4 ft @ fluid density of 1.024 (Mercer, 1983). Head is at least 2997 ft.

H-5: Assumed head in CCA is 3065 ft. Undisturbed water level is 3028.1 ft (Gonzalez, 1983). Correction factor is 46 ft @ fluid density of 1.106 (Mercer, 1983). Head is at least 3072 ft.

H-6: Assumed head in CCA is 3058 ft. Undisturbed water level is 3053.3 ft (Gonzalez, 1983). Correction factor is 12 ft @ fluid density of 1.040 (Mercer, 1983). Head is at least 3065 ft.

H-9: Assumed head in CCA is 2974 ft. Undisturbed water level is 2981.6 ft (Gonzalez, 1983). Head is at least 2982 ft.

H-10: Assumed head in CCA is 3023 ft. Undisturbed water level is 3003.0 ft (Gonzalez, 1983). Correction factor is 31 ft @ fluid density of 1.044 (Mercer, 1983). CCA reports fluid density of 1.047. Correction factor should be 33 ft. Head is at least 3036 ft.

P-17: Assumed head in CCA is 2983 ft. Undisturbed water level is 2976.5 ft (Silva, 1996). Correction factor is 19 ft @ fluid density of 1.082 (Mercer, 1983). Head is at least 2995 ft.

WIP-26: Assumed head in CCA is 3014 ft. Undisturbed water level is 3014.9 ft (Silva, 1996). Head is at least 3015 ft. Mercer (1983) reports fluid density of 1.013. Correction factor should be 4 ft. Head should be at least 3019 ft.
SELECTIVE USE OF HYDRAULIC HEAD DATA IN CCA:

H-7: Assumed head in CCA is 2995 ft. This corresponds with Lappin (1989) who reports hydraulic head of 2995 ft. Undisturbed water level is 2994.8 ft (Silva, 1996). Mercer (1983) reports fluid density of 1.001. CCA reports fluid density of 1.000. Freshwater head must be 2995 ft. However, heads of adjacent wells to the east should not be lower than 2995 ft, because water does not flow eastward out of Nash Draw.

H-4: Assumed head in CCA is 2990 ft. Lappin (1989) reports hydraulic head of 2995 ft, the same as H-7. As shown above, head is at least 2997 ft.

H-11: Assumed head in CCA is 2994 ft. Lappin (1989) reports hydraulic head of 2995 ft, the same as H-7. Undisturbed water level is 2970.7 ft (Silva, 1996). CCA reports fluid density of 1.078.

H-17: Assumed head in CCA is 2989 ft. Lappin (1989) reports hydraulic head of 2995 ft, the same as H-7. Undisturbed water level is 2942.5 ft (Silva, 1996). CCA reports fluid density of 1.100.

P-17: Assumed head in CCA is 2963 ft. Lappin (1989) reported hydraulic head of 2995 ft, the same as H-7. As shown above, head is at least 2995 ft.

Cabin Baby: Assumed head in CCA is 2989 ft. Undisturbed water level is 2983.2 ft (Silva, 1996). CCA reports that fluid density is not available (NA). Therefore, the assumption of a hydraulic head lower than that of H-7 is unwarranted.

The net result of the selectively low hydraulic heads assumed for five wells (H-4, H-11, H-17, P-17, Cabin Baby) all located east of H-7 is to create a groundwater model that does not allow the southeastern flow path (H-3, DOE-1, H-11, H-17, P-17) to turn westward toward the H-7 collapse sink in Nash Draw.
The CCA reports that measurements of fluid density are not available (NA) for eleven WIPP test wells (H-16, P-18, WIPP-12, WIPP-18, WIPP-21, WIPP-22, WIPP-27, AEC-7, Cabin Baby, D-268, and ERDA-9). Without measurements of fluid density, freshwater heads cannot be calculated even if undisturbed water levels are available. Therefore, the freshwater heads assumed in the CCA for WIPP-12 (3063 ft), WIPP-18 (3053 ft), WIPP-27 (3078 ft), AEC-7 (3058 ft), Cabin Baby (2989 ft), and D-268 (3003 ft), are unsubstantiated.

The CCA reports substantial uncertainty in Culebra heads due to measurement error. The following represents the range of values acknowledged in the CCA:

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From the previous discussions it may be seen that the true hydraulic heads for eleven WIPP test wells (H-1, H-3, H-4, H-5, H-6, H-9, H-10, H-17, P-17, WIPP-26 and Cabin Baby) fall outside the margins of error assumed in the CCA.

Finally, we note that three WIPP test wells for which hydraulic heads have previously been reported (H-8, H-16 and WIPP-29) are not included in performance assessment. Mercer (1983) reports hydraulic heads of 2991 ft at H-8 and 2975 ft at WIPP-29. Lappin (1989) reports hydraulic heads of 2995 ft at H-8, 3005 ft at H-16, and 2968 ft at WIPP-29. Admittedly, H-8 is irrelevant to performance assessment, being located far outside the potential flow paths from the WIPP site to the accessible environment. However, H-16 is located 1667 ft northwest of the center of the WIPP site, and the anomalously low hydraulic head in the Culebra at H-16 indicates a flow path northwesterly from the WIPP shafts, which DOE has not considered in performance assessment. WIPP-29 is located in Nash Draw near Laguna Pequena, the inlet to Laguna Grande de la Sal, which is the ultimate discharge point for contaminated water from the WIPP site. DOE's failure to incorporate WIPP-29 into its performance assessment, together with DOE's selective use of low hydraulic head data at test wells H-4, H-11, H-17, P-17 and Cabin Baby, steers groundwater flow away from Nash Draw, and thus does not approximate reality.
GENERAL HYDROLOGICAL CONDITIONS AT THE WIPP SITE

David T. Snow, Ph.D.

Introduction

The basic elements of the regional hydrology near the WIPP site have not been established in a conventional way. A casual, but trained observer, seeing the abundant white precipitates in Laguna Grande de Sal, and the pitted, streamless plain upslope to the east would quickly hypothesize that he was seeing the respective discharge and recharge areas of an unconfined karst system that traverses the east-dipping Dewey Lake and Rustler clastics and evaporites as well as the underlying Salado salt beds. A few bore holes disclosing thicknesses that decrease westward should have indicated that dissolution has removed from the WIPP site the Forty-Niner and Tamarisk salt beds, and that it has thinned the Unnamed Member salt to a pinch-out west of the site. Consistent with that understanding, dissolution has left clay residuum where the above-mentioned salt beds have been reduced, as well as at the top of the Salado Formation, well into the site.

The first bore holes disclosed the 7m thick Culebra Dolomite to be the most consistent aquifer, increasing in transmissibility westward by five orders of magnitude, consistent with greater fracture permeabilities due to dissolution of infillings of gypsum and karst channelization. Rustler anhydrites and siltstones generally tested low in transmissibility, raising the question of confinement for flows in the Culebra, a potential path for contaminants escaping the repository. Pumping tests were analyzed as though the Culebra were fully confined, an advantage for safety if it could be relied upon to convey contaminants almost horizontally to a distant accessible environment.

The hydrologists responsible failed to follow the classical approach to resolving the apparent inconsistency and uncertainty: they should have asked, where along the basin margin is the Culebra confined or unconfined, or to what degree is it both? The hallmark of an unconfined aquifer is a water table, but in fine-grained rocks, the water level in bore holes is slow to equilibrate to the water table level. Once the zone of saturation is reached in drilling, the work has to be stopped long enough to allow the water level to adjust, sometimes a matter of days. No such observations were undertaken, so the original water table was left undefined, a fatal procedural flaw. Water levels were only recorded consistently in wells cased to the Culebra, on the premise of confinement. Had there been an effort to define the water table, a systematic study of the relative levels of the water table and the Culebra heads would have revealed areas of full confinement west of the WIPP, local confinement within the LWA and unconfinement west of the site and on to Nash Draw. Because confinement along flow paths of concern was a premature conclusion of DoE, the efforts necessary to resolve the nature and causes of variations were not undertaken. Nested piezometers should have been installed. The geochemistry, apparent age distributions and measures of local recharge and discharge for the flow system could have been analyzed to resolve alternative hypotheses of flow control features and recharges, from which a more defensible model could have been conceived and implemented, a model consistent with all, not merely most of the data.

From an organizational point of view, DoE’s hydrological consultants have emphasized
hydrostratigraphic modeling, but they have neglected the implications of dissolution, less amenable to modeling, features arguably first in importance in terrain as novel as that at WIPP. Alternative geological conditions and hydrological implications were certainly debated over the years, but the numerical inclinations of the many prevailed over the qualitative preferences of the few, to favor a layer-cake model they were capable of solving, given the paucity of data.

Too little credence was given to the implications of field observations, such as the obvious sinkholes in and west of the LWA, as well as in Nash Draw., or to deductions from the discontinuous Mescalero Caliche. The techniques of drilling, coring and logging were inherited from potash explorations requiring only rock composition, so the geologists and hydrologists were inattentive to the need for and feasibility of obtaining data relevant to the hydrology. The geometry of Rustler and Dewey Lake fractures and dissolution features varying across the site were neglected, to the detriment of the hydrological testing and modeling efforts that followed.

Warnings of the implications of karst by such observers as Ferral and Gibbons (1979), Anderson (1978), and especially Phillips (1987) were discounted because they didn’t fit the hypothesis of Culebra confinement so favorable to the applicant, DoE. With objectivity compromised, the realization of the important role of karstification in determining flow and transport properties of the entire overburden sequence has been lost. If the result of an impartial assessment is a conclusion that the Culebra and other non-Salado strata fail to provide a barrier to transport, then the applicant must re-apply on other grounds for compliance.

In absence of exploration data focused on karst hydrology, a model proposed herein for groundwater transport of radionuclides has to rely on the available site observations, and upon literature, experience and reasoned speculation about the dissolution-enhanced conduit system at and near WIPP.

Characteristics of Evaporite Karst. With Reference to the WIPP Site, Carlsbad, NM

The following description of evaporite karst terrain has been formed from observations in several countries and especially from underground exposures in salt and potash mines that have experienced inflows. Reasonable speculation and logic support conclusions of cause and effect. A model of evaporite karst system geometry would have been a good starting position for the design of field explorations and the testing of a site, such as the WIPP environment. A revised assessment of the travel time in the Rustler Formation from a point near the repository to the accessible environment is a necessary derived result.

1. Whereas carbonate terrain has frequent fractures of tectonic origin, evaporites have few because creep closes them in salt, and low rock strength leads to large spacings in the associated argillaceous clastics. Consequently, dissolution channels that form in youthful stages of evaporite karst tend to be widely spaced. Anhydrites and dolomites found with evaporites, being strong, brittle rocks, develop youthful dissolution systems resembling those in limestone terrain.
2. Dissolution proceeds more rapidly in evaporites and associated anhydrites and soft clastics than it does in carbonates because great solubility, low erosive strength and rapid alteration processes favor channel enhancement. Anything that changes the hydrology can quickly change the medium.

3. There are chemical processes peculiar to evaporite terrain that influence its karst development.
   a. Fresher waters alter anhydrite slowly to gypsum, accompanied by about 10% swelling which effects fracture zones in adjacent rocks.
   b. Salt and gypsum may re-precipitate, filling fractures in nearby anhydrites and carbonates. Several generations of infillings represent regional geochemical changes over time.
   c. Small physical changes, such as temperature, pressure and dilution can have strong consequences for the rate and direction of dissolution or deposition.

4. Volume changes in evaporite bodies, especially the thinning of salt members dissolved at their surfaces, exert profound physical changes on overlying brittle rocks, while carbonates are usually dissolved from within, maintaining the thickness of the member.
   a. Dissolution at a horizon, such as the top of salt, produces subsidence of the overburden, random and non-uniform in plan. This leads to normal-displacement fracturing with random strikes in anhydrites and carbonates, less frequently in soft clastics.
   b. Gypsification heaves the overburden non-uniformly, producing extensional fractures. It also distends anhydrite beds, producing compressional fractures and some anticlinal folds.

5. Dissolution of a fracture in evaporites tends to concentrate flow, causing rapid evolution to a single passage, while an enlarged conduit following a network of fractures through carbonates or anhydrites tends to retain multiple branches into maturity. This results from the absence of frequent tectonic fractures in evaporites, most conduits requiring other causes of initiation, such as subsidence or faulting.

6. Abundant insolubles liberated from salt and materials eroded from associated soft clastics give rise to abundant detrital materials that fill conduits by channel transport processes, especially during waning stages of recharge events.

7. Field evidence of sedimentary structures in residual clay beds indicates that its materials have been transported by running water. There may develop clay films at salt contacts by diffusion of salt through the interstices of the clay, resulting in structure-less accumulation, but the majority is transported. Laminae of clay bordering anhydrite beds, top and bottom, seem ubiquitous, suggesting advective removal of salt through the anhydrite beds, more permeable than the salt. Concentrated flow parallel to a contact occurs at the intersection of a fracture abutting the salt, but thereafter, it migrates over the salt surface. In order to concentrate flow persistently, such a conduit must connect downstream, to other conduits. If egress is cut off, flow and dissolution of conduit walls slows down, facilitating closure by salt creep. Similarly, a conduit roof of residual clay may close plastically, or fall abruptly. Thus, if a conduit is found, open, it is probably connected downstream to others. Lateral conduit displacement is the mechanism of development of a continuous bed of residuum, mainly by bend migration and point-bar deposition of transported detritus. Dissolution at a conduit wall depends upon boundary layer shear more than upon brine
concentration, so turbulence, discharge and conduit dimensions are directly related in some complex way. Because discharge has to depend upon the porous media hydraulics of beds contributing to the conduit flow, the spacing of conduits is another dependent variable. If something happens in the overburden and in the beds upstream to limit supply, the system of open conduits changes by increasing spacing to maintain aperture. Consequently, there may develop large areas of residuum without open conduits if a cut-off pipe has diverted flows to a lower stratum. Residuum in the unsaturated zone may retain continuity as barriers to percolation, forming perched water bodies, or in the saturated zone as supporting beds below more conductive karstic levels.

Proceeding down-gradient along the top of a salt bed (if it were possible to explore it), one would find the first residual clay accumulation to be associated with some channels eroded into the salt. Further downstream, chance intersection by lateral migrations develops a dendritic pattern of larger channels with greater spacings. Where close-spaced channels are occasionally pinched off by creep, new ones form nearby. The establishment of a laterally persistent clay is a dynamic channel replacement process along a band downstream of the leading (upstream) edge of the residual deposit. If drilling discloses a layer of residual clay upon some remaining salt, there may be channels nearby, missed by the drilling, that are both upstream and downstream of that well site. If residuum is found, but no salt remains, the responsible channels may have closed, flow pirated to lower strata along steep conduits initiated by fracture flow across anhydrite, carbonate or clastic beds. Nevertheless, if one could follow the residuum upgradient, an edge of the parent salt bed would be found, upon which open channels persist. The occurrence of residuum implies karst upstream.

In the unsaturated zone, a continuous layer of residuum is a barrier that may locally perch groundwater flowing down dip either in intergranular clastic rocks, fractured carbonates or anhydrite, or in channels formed in them. If no recharge were to occur over a prolonged period, the perched water would disappear. But if recharge is recurring, a water table may develop and persist upsection of the edge of salt beds. The confinement of flow upon impermeable residuum or salt, whose structural dip is opposite to the flow direction, results in a cascading water table. Flat segments of the water table interrupted by steep segments between confined channels represent the static situation between recharge events, while a higher, more continuous water table is a transient recharged condition. Widely separated drill holes without synoptic head measurements cannot distinguish between the static and transient conditions, recording only an apparent water table.

8. By reason of high evaporite solubility, singular channels observed in continuous salt cut rapidly towards base level, the discharge elevation. The prevalence of anhydrite and clay layers in salt formations typically supports flat channel segments, interrupted by steep segments where the channels cut across the strata, stair-stepped in profile.

9. Unlike karst development in carbonates, dissolution of evaporites tends to go rapidly to completion. As long as salt remains and flow can contact it, salt will be removed until only residual materials remain between less soluble beds. If a salt bed is represented elsewhere by residuum only, there is an intermediate region where salt, residuum and solution channels co-exist. Since
residuum is due to coalescence of channel fillings, the persistence of open channels in residuum is fortuitous. Even gypsum after anhydrite eventually vanishes from the stratigraphic sequence, leaving residuum. Between residuum and equivalent anhydrite are intermediate regions of anhydrite, gypsum and channels with variable degrees of infilling. The most likely terminal horizon to find open channels is at the base of a sulfate rock unit perched on residuum. Progressive differential subsidence resulting from irregular dissolution disrupts the overlying clastic or brittle beds, promoting the formation of erosion channels that follow fractures across the poorly-cemented clastics. The apertures of conduits so eroded across clastics are much smaller than those that form within or upon the soluble rocks. Conduit cross-sections across clastics tend to be circular or elliptical, while conduit cross-sections at bedding planes of soluble rocks tend to be lens-shaped. The mature evaporite karst is likely to have a small frequency of large bedding-controlled conduits on the clay residues of the original salt beds, and a like frequency of smaller steep conduits crossing the coarse muddy sandstones.

10. In the presence of both evaporites and carbonates, the carbonates serve as horizons of resistance to down-cutting. Therefore, large dissolution channels convey water on the carbonates, feeding a system of more frequent solution-enlarged fracture conduits within the carbonate rocks, originally two orthogonal sets normal to bedding. Thus, pervasive or diffuse dissolution features in carbonates and anhydrites, such as partial openings in fractures otherwise gypsum-filled, suggest the presence of larger solution channels in overlying evaporite rocks.

11. Weakly cemented clastics only develop sinkholes at the surface by sapping action above the cavities, in this case where underlain by dissolved evaporites. Tubular conduits are eroded along fractures cutting the clastics. These extend upwards, not only to the water table, but also to the surface, because the subsurface conduit concentrates flow, just as topographic irregularities concentrate runoff. During recharge events, the sapping process proceeds upstream to connect the cavity with the point of ingress, such as an arroyo floor. As structural support is removed from below by erosion, deflection of strata may form a sink, concentrating more surface flow at a swallow. When concentric graben fractures form, displacements lead to a collapse. A sink may partially fill with collapse breccia or stream-transported debris. A sinkhole or chain of sinkholes signifies a prior, large-aperture dissolution conduit traversing beneath them. There is no certainty that the furthest upstream sinkhole marks the upstream end of the parent conduit, which may have its source more remote where recharge is collected at uneroded, distributed fractures. An alignment of sinks indicates fracture control of the underlying bedding-plane solution channel. Such aligned sinkholes have long been known on the Gypsum Plain of New Mexico and Texas (Melton, F.A., 1934, Linear and dendritic sink-hole patterns, Science, 80:123-124).

12. If sinkhole formation occurs from the bottom upwards, we need to know what controls the development of the parent conduit. Gypsification does not cause flexure downwards, but subsequent dissolution of gypsum may develop a cavity to promote sapping of overlying clastics. At the WIPP site, cavities form either by salt or gypsum dissolution by water that percolates slowly through the overburden of argillaceous clastics. The most shallow salt bed nearest the outcrop of the Rustler was the locus of the earliest dissolution, following a feature that could supply a concentrated flux, such as the trace of a steep tectonic fracture abutting salt from above. If
fractures ever cut salt, they are healed by creep but not in the clastics, so dissolution starts along the strike of its intersection with the top of salt. The flow develops by a component of the regional gradient acting in the fracture. The tectonic pattern of NW and NE-striking joints of the Delaware Basin has elements in the Rustler clastics at WIPP as well as in the carbonates and anhydrites.

A second control is similar, conduits that form by dissolution of the gypsum that forms in matrix adjacent to water-bearing fractures in otherwise insoluble anhydrite. A reticulated pattern of primary fracture conduits in clastics or anhydrite, where they abut underlying clay, will develop larger solution conduits in the direction of the tectonic fracture set closest to the regional gradient. Conversely, a salt-bounded conduit rapidly evolves channels more nearly aligned with the gradient, since it loses fracture control as it incises the salt.

13. Size-evolution of conduits in salt is influenced by creep closure. If several channels in salt were to occur, the channel carrying the least brine will pinch off, so discharge becomes concentrated in a few, widely-spaced conduits which follow the gradient and enlarge at the expense of others.

14. Not all percolating water is collected through sinkholes directly into dissolution channels of the uppermost salt. Upslope of a sinkhole area, water recharged percolates slowly through the intervening fractured non-salt units, eventually concentrating along fracture-controlled salt bed intersections. This is the argument for conduit extension up-gradient of sink holes. Retrograde growth is envisioned.

The salt bed controlling a conduit may act as an aquiclude for some time. But if the channel encounters a defect in the salt, such as a clastic-filled paleo-channel, or a fracture in salt that is newly-formed or clastic-filled, it can flow to lower stratigraphic horizons, such as the next deeper salt bed. The concentrated flow traversing and dissolving the upper salt will erode a steep conduit across the clastics by traction of the weak clays and sands, some structural detail responsible for its course. In time, the major dissolution channels form a stair-step profile, down to the salt bed or residuum closest to the outlet. Likewise, gypsum dissolution localized along fractures in anhydrite define other cross-cutting conduits.

Channels in the plane of bedding are generally larger in cross section than needed for steady system flow. Consequently, they remain full-conduit but stagnant most of the time if the dip of bedding has a component opposite to the flow direction. If the dip is in the direction opposite to flow, it will develop a cascade over the edge of each impermeable bed that supports channels, where a steep conduit along a structural defect forms across intervening beds to each successive supporting bed. If dip is towards the discharge end, incision of conduits through salt will form vertical chasms bounded by salt, and floored by underlying beds. Open-channel flow will prevail, since air entry from the outcrop will cause the channels to drain, or to be partially filled much of the time.

15. Flow concentration in the discharge region of a system enhances dissolution rates and cavern formation. Topographic control of discharge, say, to a spring occupying a reentrant of the surface, concentrates cavern formation nearby and near the water table, enlarging headward. Jointing,
subsidence fracturing, solubility contrasts and perhaps fault occurrence influence the details of formation.

16. If karst system flow is to the outcrop of a sedimentary basin, the major flow component must be essentially up-dip. Each spill point on a confining bed is a persistent point on the water table, while the rest of the conduit system is at atmospheric pressure only in the steep, cross-cutting segments. During most of the time between meteorologic events, a detailed depiction of the water table would show a stair-stepped profile, with effectively stagnant, flat water table segments characterizing the long salt or residuum-bounded legs of the path oriented up-dip. A less-detailed survey of the piezometric surface, as is obtained by wells completed in the wall-rocks, generally cannot reflect the transients, but depicts an apparent water table, defined and controlled mainly by the spill-point elevations. The actual flows in the long conduits occur at much lower gradients, largely unrelated to the apparent gradient. Thus, hydraulic conductivity cannot be deduced from the regional flux and the apparent gradient, as measured between wells completed in the wall rocks. Nor can the velocities be deduced from models of the regional gradient acting on media characterized in the wall rocks.

17. If the karst system penetrated to the same level everywhere in a basin, it would bevel the older strata, progressively as flow approaches the discharge area. Thus, salt beds, as seen at WIPP, have been removed to deeper stratigraphic levels, as the discharge area is approached. However, the retrograde evolution of karst channelization implies more shallow development with distance from the discharge area. It is critical to estimate the depth of penetration of dissolution effects at various positions, when exploration has not specifically defined it. The distribution of residuum, left from the removal of salt, is the primary delineator. The distribution of openings in fractures formerly filled with gypsum provides another measure. There is a karstic region everywhere above and downgradient of such observed features. Where residuum is found, channels have been and may persist. Where only fracture dissolution has occurred, there may be diffuse dissolution without channels of significance. Diffuse dissolution must extend an uncertain distance headward of the most advanced positions of dolines or sinks.

18. One might expect that chance dissolution and structural defects that lead to windows through the confining salt beds headward of the spill-points would produce a boxwork of large solution cavities in a zone having uncertain vertical extent. But dissolution in salt is so rapid that a short-circuit tends to enlarge and to pirate all the flow, forming a new spill point. Predecessor channels above it are left unsaturated. Thus only a single level of major channels is believed to be active at any time, all others at higher levels being inactive, until reoccupied during extreme flood events. A thin level of active channels overlying a deep zone of diffuse dissolution features constitutes the saturated ground, a karstic aquifer traversing the dipping strata. That geometry is far more significant than the classical hydrostratigraphy bounded by formation and member contacts. Recharge to the saturated ground has to be rapid, since large relict channels persist in the vadose zone, riddled with abandoned cavities, partially filled with debris.
Flow and Transport in the Karst

1. The typical major meteorologic event that produces local runoff into sinkholes, including those obscured by eolian sand infillings, develops hydraulic transients in the karst system. Swallow holes and conduits in the unsaturated zone may be blocked by debris or squeeze, providing storage and delaying arrival of the water to the saturated zone. The saturated active channel zone, essentially one layer thick, has such high transmissibility that it can carry the transient flux received with only small changes of gradient and little storage, being saturated by reason of its retrograde dip. To some degree, the piezometric surface rises temporarily to fill in the stair-steps. During periods of years between recharge events, the water table is flat overlying large bedding-confined channels that then carry no water, whereas in the diffuse saturated zone beneath it, there may be slow flow in response to the more regional gradient. Much of the Culebra must be so described.

Events in the region of discharge should be observed, but they may be masked by the surface storm effects, so that when an evaporative basin fills or the river flow suddenly increases, the magnitude of spring discharge remains unrecognized. Whatever storage is provided by changes of the water table, plus the elastic storage due to pressure changes in the saturated zone, the decaying flows carried by the diffuse porous zone and, to lesser degree by the cavernous zone are discharged during years between storm events.

2. Recharged water does not pass through the system without some mixing with ambient water. The average residence time depends, in part, upon the storage volumes in the saturated zone. Transport in the cavernous layer is too rapid to facilitate much matrix diffusion or sorption. Since most of the total water volume is below the cavernous, high-velocity zone, there is ample time for matrix diffusion and sorption to take place in the diffuse zone of fracture and intergranular flow.

3. Only one glimpse has been provided of the part of the cavern system active during storm transients. At WIPP-33, five caverns of large, but uncertain dimensions were found, one in Dewey Lake, two in Magenta and two in Forty-Niner gypsum. There are many other drill holes that provided evidence of former caverns, where now only residual mud is encountered. These occupy several levels in the Dewey Lake, at 14 to 19 ft above the Magenta in the Forty-Niner Member. 6 to 22 ft above the Culebra in the Tamarisk Member, and just below Culebra at the top of the Unnamed Member. The specific surface of the cavern system is uncertain but small. If, for example, there are ten conduits with cross-sections 0.5 X 10 ft each 100 ft of width by 50 ft in thickness, then $S = 0.04$, implying that sorptive and diffusive retardation is small. If there were no other pore system present, all recharge would arrive at and be conducted by this cavernous system in very short travel times. The transmissibility of the cavern system is so enormous that it operates for only a few days after a recharge event, then quickly becomes stagnant. Though it is primarily a saturated confined system, due to the easterly dip, it is an unconfined system close to the spill points, where it may have increasing cross-section as the water table rises. Because the vadose zone contains many abandoned conduits, the water table cannot rise to the surface in pluvial periods, as hypothesized by Corbet and Knupp. Travel time cannot be estimated from hydraulics, since neither conductivities nor transient gradients are known to any degree. Alternatively, residence times in this system can be estimated by its fluid volume and the replacement rate.
factors which may have less uncertainty.

4. We may make an arbitrary distinction between the mature, cavernous saturated karst zone and the thicker zone of more youthful, fine-textured karst below it, and we could speculate on the partitioning of flux between the two systems. If the cavernous karst channels are supported from below by impermeable salt or residual clay beds, then the diffuse aquifers underlying such layers transition from confined to unconfined, receiving whatever small flux can penetrate across bedding and flow up-dip according to the apparent, more regional gradient. In actuality, there are probably all gradations of karstification in the fine-textured zone, but large conduits are so infrequent there that most drill holes have missed them. Due to long-term drainage to the shafts, since 1983, and to pumping during tests since 1979, the water table has remained in the diffuse-conduit zone below its natural level within the cavernous zone, so transmissibilities tested do not reflect the high values that would be relevant during the 10,000 year regulatory period. Tested properties reflect the low end of the scale of the fine-textured underlying zone, since wells have been completed only in the Culebra dolomite where they usually display confinement. To some degree, the computed transmissibilities reflect thicker sections, including dissolved horizons above and below the Culebra, as well as in fractured and dissolved anhydrite. The aquifer tested is locally confined by residuum layers, but it is not restricted to the Culebra, so 7 meter well completions in it have exaggerated Culebra conductivities. Transmissibilities have varied over five orders of magnitude, consistent with the karstic vagaries of the fine-textured system.

5. We take issue with DoE's modeling of flow and transport through the aquifer(s), which has assumed flow only in the 7m Culebra, fully confined, having a T-field based upon measured T's in the mid-range and assuming continuity of values inappropriate for fractured or karstic channelization. Alternatively, one could accept DoE's estimates for that fine karst system because it is, at least, based on some conductivity measures and tracer testing. However, it is our position that the majority of the average annual flux has been neglected because recharge estimated from evaporation in Laguna Grande is an order of magnitude greater than DoE deduced by calibrating its regional groundwater model. Even greater fluxes may occur, that discharge water over the sill of Laguna Grande into the Pecos River. Evaporation estimates indicated that a minimum of 20mm/year recharges the cavernous karst system. At higher than current levels, it is transported without retardation through the cavern system to Nash Draw. Simultaneously, the additional flux via the fine-textured karst system may be taken essentially as proposed by DoE, but with greater transmissibilities to convey 10 mm/year.

6. Transport may be estimated on the assumption that a repository breach is sudden and copious, as would occur if a hydrofracture were driven by repository or Castile reservoir pressure, propagating up-dip and up-section until it intersects the Rustler karst system about 2 miles west of the center of the LWA. Because a hydrofracture in a normally loaded basin would follow bedding weaknesses and have large lateral extent, it would readily intersect a narrow solution channel, feeding its discharge directly into that of the natural flux resulting from episodic recharge over the entire plan of the flow system. Assume that recharge through the vadose zone is uniform along the flow path, 10 miles long, and that the point of injection is 6 miles from the Nash Draw discharge point. If flow paths are roughly parallel, uniform recharge collects and flow increases linearly.
downstream. Typical of maturation of a karst, it is likely that channels enlarge and become less frequent downstream to maintain nearly constant flow velocities. Flow capacity increases downstream to convey the increasing flux. Neglecting any fluid interchange between the large cavernous conduits and the underlying finer-textured karstic and porous media, all that is needed to evaluate transport of a conservative tracer are estimates of the fluid volumes along the karst conduits and the annual recharge, or water volume recharged per unit area per event of period \( t \).

7. Depicted, here, is a coalescing single-layer channel system repeated each 2000 ft of width, inclined from the surface to the discharge point in Nash Draw, 52800 ft distant from the eastern edge of the karst region, a likely groundwater divide.

Recharge of 20mm/year is assumed to be uniform over the area. The channels are smaller and more numerous at the upstream end than at the terminus. It is assumed that the aggregate cross-sectional area increases lineally over the path, to maintain approximately constant velocity, so as to maintain apertures against closure by sedimentation and creep. The discharge increases downstream, as recharge is accumulated. Recharge, \( r \), is assumed to be conveyed, half in transient flows by the cavernous zone, half in steady flow in the fine-textured underlying zone. If the cavernous zone is arbitrarily taken to be 100 ft wide and 50 ft deep at the area overlying the repository, two miles downstream of the divide, the 1% porosity would imply 50 ft² of conduit there, and 250 ft² at the discharge end. The area of pores \( A = ax \), so \( a = .0047 \) is the proportionality constant. Transport velocity is

\[
V = \frac{Q}{A} = \frac{rwx}{ax} = 10(100)/305/.0047 = 700 \text{ ft/year}
\]

The travel time from a point of injection, at \( x = 21120 \) ft to the end, where \( x_0 = 52800 \) ft is

\[
\tau = (52800-x)/700 = 45 \text{ years}
\]
so if waste is injected at 4 miles, i.e., 2 miles west of the shafts, it would emerge in Nash Draw in about 45 years. Note that Laguna Grande is taken as the accessible environment in this exercise, since the LWA boundary is in a region of unlikely water use. Reasonable changes in the interval between conduits or their dimensions, or of the recharge rate could conceivably result in travel times as short as 5 years or as great as 500 years, but never 10,000 years. Convective dispersion due to velocity variations within a solution channel or between channels of differing size would spread the arrival of contaminant molecules, but that would have no effect on the cumulative amount arriving at the compliance boundary.

8. An alternative breach would be along a borehole, either by seal failure or by the E1-E2 scenario. It cannot be assumed that a borehole will discharge directly into the cavern system, but more likely into the finer-textured karst, including the Culebra. So it would be transported more slowly until it reaches the large channels. It is not credible to assume, as did DoE, that flow is confined to the Culebra, but rather, that flow has an up-section component, from Culebra across such units of the Rustler that are unconfined. The first likely residual clay aquiclude is stratigraphically about 6 to 22 ft above the Culebra, where flow may enter the cavernous zone near the water table after about 1500 ft of travel. The travel time is the sum of times in the two zones.

It would be prudent to assume that the system of dissolution conduits in the fine-textured zone becomes increasingly integrated into larger and less frequent channels approaching the arbitrary cavernous zone, but we might estimate the longest possible travel-time on the basis of measured properties that DoE has assumed to be Culebra properties. If injection is so slow as to have no effect on the gradients, the time would be proportional to the shortened path length and the travel times computed by DoE, 5 km to the compliance boundary via the Culebra. On that basis, the maximum travel times would be about .09 as long as those of DoE. Many of the CCDF would fail the EPA criteria, since the additional travel time in the cavernous zone would be negligible. The evidence for karst dissolution in the Rustler suggests shorter travel times along much of the flow paths in the fine-textured karst as well as a cavernous water table zone, suggesting failing CCDF's as a consequence.
TO: Environmental Protection Agency (EPA)  
Office of Radiation and Indoor Air  
401 M Street SW  
Washington, DC 20460  

FROM: Richard Hayes Phillips, Ph.D.  
Citizens for Alternatives to Radioactive Dumping (CARD)  
144 Harvard SE  
Albuquerque, NM 87106  

RE: Supplement to CARD Rebuttal to DOE Response to CARD Comments  

On January 20, 1998, CARD submitted to EPA our Rebuttal to DOE's Response to CARD's Comments on the Compliance Certification Application (CCA) for the Waste Isolation Pilot Plant (WIPP). CARD reserved the option of submitting further comments before the deadline of February 27, 1998. CARD has since discovered further evidence in support of our interpretations, and we submit this evidence now.

EVIDENCE OF KARST AT H-6  

Beginning in June 1973 the DOE drilled the H-6 test wells within the northwestern corner of the WIPP site. H-6 is an array of three test wells. At the time H-6 was drilled, the DOE was interested in three water-bearing units: the Magenta dolomite, the Culebra dolomite, and the "brine aquifer" at the Rustler-Salado contact. Accordingly, the three test wells were completed to these depths. The DOE assumed that ground water flow was confined to these units, and its core samples at H-6 were largely confined to them also. For these reasons, the available lithologic and hydrologic data at H-6 are incomplete. Very brief lithologic descriptions for H-6 were published by Mercer and Orr (1979). Geophysical logs and photographs of core are still unpublished, nearly 20 years after completion. CARD obtained them from the Sandia central files on February 19-20, 1998.

H-6 is of interest for these reasons: (1) the hydraulic heads for the Magenta and Culebra are equal (3057 feet) at H-6, indicating a lack of hydraulic separation between the two units at this location; (2) Culebra transmissivity is high (88.0 ft²/day) at H-6; (3) multi-well pump tests have revealed hydraulic connections between H-6 and other test wells (DOE-2, WIPP-13, P-14, and WIPP-25) with high Culebra transmissivities; and (4) H-6 is located only one mile from Nash Draw, where karst conditions prevail.

The fluid level during logging at H-6 was in the Dewey Lake Red beds, 226 feet below land surface, 201 feet above the Rustler, 3123 feet above sea level, 56 feet higher than the Rustler hydraulic heads, which implies perched water in the Dewey Lake Red beds.

Core in the Magenta dolomite (496-515 feet) is intact, with horizontal fractures (1 per vertical foot) from 496.3 to 509.8 feet, and undulatory fractures along wavy laminae at 512.8, 513.5, and 513.8 feet. It is interpreted that the northwesterly flow path through the Magenta from WIPP-13, where the Magenta is broken and shattered, to WIPP-33, where two open, water-filled caverns were found in the Magenta, largely bypasses H-6.

In the Talamas member, the caliper log shows a small washout at 583-586 feet, the gamma ray log indicates increased clay content at 584-590 feet, and the resistivity log implies a water-bearing zone at 581-588 feet. Core samples were not taken at this interval, but Mercer and Orr (1979) describe this
interval as dissolution residue with a mud matrix. It corresponds stratigraphically with the dissolution residue of mudstone with angular clasts of gypsum found at 16.7-23.8 feet above the Culebra at WIPP-13.

Core in the Culebra dolomite (604-627 feet) is intact from 604-609 feet, with one gently dipping (10°) fracture. There was no core recovery from 609.0-614.0 feet, or from 615.1 to 615.8 feet. The core is broken into pieces from 616.8 feet to the bottom of the Rustler, reportedly 627.0 feet; within this interval, only 1.4 feet of dolomite fragments were recovered. Altogether, intact core recovery was only 7.1 feet, or 30% [Plate 1].

In the lower unnamed member there was 5.5 feet of lost core between 628 and 634 feet, immediately beneath the Culebra; the 0.5 feet of recovered core consists of dark brown dissolution residue with gypsum fragments. There was 3.9 feet of lost core between 634 and 639 feet, the 1.1 feet of recovered core consists of reddish-brown dissolution residue with gypsum fragments. Mercer and Orr (1979) describe these dissolution residues as having a mud matrix. The residue is underlain by 1.0 foot of vuggy gypsum which is broken into pieces [Plate 2]. Core samples were not taken below 640 feet.

In the Culebra and lower unnamed members, taken together, there was 33.9 feet of lost core in a 39.0-foot interval at H-6. Core recovery was only 13%, and this consists mostly of subrounded dolomite fragments or dissolution residue with a mud matrix, all of which are indications of moving ground water. This 39-foot cavernous zone is direct evidence of karst at the WIPP site.

EVIDENCE OF KARST AT H-3

The original H-3 test well was drilled in July and August 1976. Beginning in October 1983, H-3 was expanded to an array of four test wells. They are located 0.6 miles south of the center of the WIPP site, about 400 feet south of the proposed waste disposal area. H-3 is of interest for these reasons: (1) the hydraulic head for the Magenta (3152 feet) is higher than the hydraulic head for the Forty-Niner (3126 feet), indicating upward flow between them at this location; (2) Culebra transmissivity is high (19 ft²/day); (3) multi-well pump tests have revealed hydraulic connections between H-3 and other test wells (DOE-1, H-11) with high Culebra transmissivities; and (4) H-3 is very close to the WIPP repository.

When the H-3 hydropad was expanded, the wells were renamed H-3b1, H-3b2, H-3b3 and H-3b4. The well casings were perforated in Magenta dolomite (559-584 feet) at H-3b1, in Culebra dolomite (676-700 feet) at H-3b2, in Culebra dolomite (673-696 feet) at H-3b3, and in Forty-Niner claystone (537-547 feet) at H-3b4. The geophysical logs, lithologic descriptions, and photographs of core are unpublished. CARD obtained geophysical logs for H-3b1, H-3b2 and H-3b4 from USGS in January 1997, and obtained lithologic descriptions for H-3b2 and photographs of core for H-3b3 from the Sandia central files in February 1998. The evidence is now correlated for the first time.

Core in the Dewey Lake Red beds at H-3b3 reveals that the upper 150 feet (22-172 feet) is highly transmissive to downward infiltration. The upper 18 feet (22-40 feet) was not cored; trench exposures within the WIPP site and outcrops at Livingston Ridge reveal that this horizon is typically broken and crumbled into platy fragments. Between 40 and 172 feet the core is broken and shattered at 22 intervals ranging in thickness from 0.1 to 1.1 feet, there was 33.9 feet of lost core at seven intervals (48.4-51.0, 64.1-69.0, 82.2-83.8, 98.0-99.0, 112.7-117.9, 132.6-142.0, 160.7-169.9) with open, dipping fractures above each interval. It is concluded that downward infiltration through this interval can be rapid. Below 172 feet most fractures are filled with selenite, making the
Dewey Lake Redbeds less permeable to downward infiltration, a moist zone was detected in drill cuttings at 175 feet in H-3b1. However, this does not mean that the lower portion of the Dewey Lake Redbeds is impermeable. At H-3b3, core in the lower Dewey Lake Redbeds (172-502 feet) reveals 14 open, dipping fractures, three of them within one foot of the Rustler; there was 11.1 feet of lost core at five intervals (192.0-194.1, 265.6-268.0, 319.7-320.0, 343.3-346.0, 484.2-486.0); and there are rounded core samples at eight locations, indicative of moving groundwater. Lithologic descriptions for H-3b2 indicate 65.6 feet of lost core in the Dewey Lake Redbeds.

In the Forty-Niner member at H-3b3 the caliper log records washouts at 534 feet and 536-540 feet. Photographs of core at H-3b3 show an interval of mudstone at 533-542 feet, containing brecciated gypsum fragments at 534 feet. Lithologic descriptions at H-3b2 identify a zone of dissolution resulting at this horizon, described as "mud, dark reddish-brown, residue from previously existing argillaceous halite unit" (534.3-539.3 feet and 543.0-544.0 feet), "mud, greenish-gray, interlayered with light greenish-gray gypsum stringers" (544.0-545.1 feet), and "fragments of dark-reddish-brown claystone in gysiferous matrix" (545.1-545.2 feet); there was no core recovery from 539.3 to 543.0 feet. DOE measured the hydraulic head in this unit at H-3b4 (and also at DOE-2, H-14 and H-16), where it is claystone. DOE measured transmissivity in this unit only at DOE-2 (0.011 ft²/day), H-14 (0.071 ft²/day), and H-16 (0.0056 ft²/day), and concluded that, in performance assessment, Forty-Niner claystone could be assigned a permeability of zero. A truly conservative performance assessment would have utilized measurements of Forty-Niner transmissivity at H-3b2, where there is no claystone at all, but a gaping 10.8-foot cavity partially filled with mud and bounded above and below by anhydrite.

Core in the Magenta dolomite (563.8-584.3 feet) at H-3b3 is intact at three intervals (563.8-567.4 feet, 571.6-575.1 feet, and 575.9-584.3 feet), although there are ten horizontal fractures along bedding planes within these intervals. The other 5.0 feet of the Magenta (567.4-571.6 feet and 575.1-575.9 feet) is broken and shattered [Plate 3]. This is especially significant because DOE twice stated to the Peer Review Panel that the Magenta at H-3, specifically, has not "been found to be fractured." (CCA, pp. 9-29, 9-30). The lithologic description for H-3b2, only 100 feet from H-3b3, does not disclose any fractures at all, nor any shattered fragments as seen in H-3b3 core. This could well be true, hydraulic properties can vary greatly over short distances in a karstland. The Magenta could be shattered and highly transmissive at one location, yet intact and impermeable 100 feet away. At H-3b1, also 100 feet distant from H-3b3, Magenta transmissivity was measured at 0.1 ft²/day, which cannot be representative of conditions at H-3b3. A truly conservative performance assessment would have utilized measurements of Magenta transmissivity at H-3b3, where the Magenta provides two preferential pathways for groundwater flow.

In the Tamarisk member at H-3b3 the caliper log records a washout at 640-654 feet. Photographs of core at H-3b3 show an interval of dark-reddish-brown clay with angular anhydrite fragments at 640.8-643.8 feet and 646.0-654.8 feet. Lithologic descriptions at H-3b2 identify this zone, at 648.2-649.2 feet and 650.0-656.2 feet, as "residue from previously existing halite unit;" there was no core recovery from 649.2 to 650.0 feet. The fracturing and disruption of the overlying Magenta dolomite is attributable to collapse into voids caused by dissolution of halite in the Tamarisk.

Core in the Culebra dolomite (668.5-691.6 feet) at H-3b3 is broken into blocks by eight solution-enlarged fractures, 4 per vertical foot, from 668.5 to 670.5 feet. The rest of the Culebra is broken and shattered [Plate 4], the largest intact sections being 4 inches long (above 684 feet), 2.5 feet long (above 689 feet), and 7 inches long (below 690 feet). According to hand writing upon blocks of wood left in the trays, two of these sections were removed by G. Walter of Hydrogeochem to test for matrix diffusion. Thus DOE's methodology is revealed: laboratory analysis was performed upon the few surviving blocks ofuggy dolomite remaining in an otherwise completely shattered interval of

3
the Culebra, and upon this analysis the supposed ability of the Culebra to retard the migration of radionuclides in groundwater is based. Clearly this is not representative of conditions in the field. Lithologic descriptions at H-3b2 disclose only 3.4 feet of core recovery in the Culebra (676.0-677.3 feet, 686.0-687.3 feet, and 691.0-691.8 feet).

In the lower unnamed member at H-3b3 the caliper log records a washout at 692-702 feet. Photographs of core at H-3b3 show broken blocks dark gray shale at 696-697 feet and broken blocks of reddish-brown mudstone at 702.4-703.8 feet, underlain by breccia with gypsum fragments at 703.8-704.2 [Plate 5]. There was no core recovery from 691.6 to 696.0 feet, or from 697.0 to 702.4 feet, which coincides with the washout. The lost core was probably clay residue, as lithologic descriptions at H-3b2 reveal a loss of core from 691.8 to 699.0 feet, immediately beneath the Culebra, and this is underlain by 6.6 feet of clay, grading downward from grayish-black to dark-reddish-brown, containing anhydrite fragments, described as "residue of previously existing halite unit." The fracturing and disruption of the overlying Culebra dolomite is attributable to collapse into voids caused by dissolution of halite in the lower unnamed member.

In the Culebra and lower unnamed members, taken together, there was 17.7 feet of shattered dolomite, 9.8 feet of lost core, and 2.8 feet of dissolution residue in a 33.7-foot interval at H-3b3, and there was 19.6 feet of lost core and 6.6 feet of dissolution residue in a 28.3-foot interval at H-3b2. Intact core recovery in this interval was only 10%.

Thus, in the H-3 test wells, there is a 10.8-foot cavity, partially filled with mud, in the Forty-Niner member; 5.0 feet of broken and shattered Magenta dolomite; 14.0 feet of dissolution residue in the Temisk member; 17.7 feet of broken and shattered Culebra dolomite; and 12.6 feet of dissolution residue in the lower unnamed member. There is direct evidence of karst at the H-3 test wells in every member of the Rustler Formation.

DOE may try to attribute the shattered Magenta and Culebra core samples to its own primitive coring techniques. DOE contractors have been observed using hammers to remove core samples from the tubes. However, at the urging of David T. Snow, the recently completed coring at the H-19 hydropod was done with a triple-tube core barrel, which produces superior samples. This technology has existed for 25 years, but DOE is now using it for the first time. Even at H-19 (where the Culebra is 740.3-764.4 feet below the surface) there were two intervals of crushed dolomite at 749.6-750.8 feet and 755.3-758.5 feet, and another interval described as "intensely fractured" at 754.0-755.3 feet. Holt (1997, SAND 97-0194) states that intact pieces are rare in this interval, the core is typically crushed or unrecovered. Photographs of core at H-19, prior to its removal from the core barrel, show that this interval was intensely fractured, and that the fractures were vertical to subvertical.

The H-6 test wells were drilled in 1978. The H-3 test wells were completed in 1983. The geophysical logs, lithologic descriptions, and photographs of core are still unpublished. Most of this material was not submitted to the Sandia records center until 1995. None of this material is referenced in the CCA, so it is unlikely that the EPA would have asked for it. To our knowledge, none of this material was available for public examination in the Sandia records center until February 13, 1998, two weeks before the EPA deadline for public comments. There are forty-two WIPP test wells, and numerous other WIPP boreholes. It is an affront to the scientific community to be allowed so little time to examine such pertinent records. Until the basic data for all WIPP boreholes and test wells has been examined by independent scientists, the WIPP should not be licensed.
KARST IN THE EXHAUST SHAFT

In our paper entitled "Potential Flow Paths from the WIPP Site to the Accessible Environment," (pp. 12-13) we identify a northwesterly flow path from the WIPP shaft to Nash Draw by way of the WIPP-13 test well, involving all five members of the Rustler Formation. In our "Rebuttal to DOE Response to CARD Comments 7 to 22," (pp. 2-3, 11-12) we describe the WIPP-13 pump test which showed an existent hydraulic connection between the WIPP exhaust shaft (1.50 miles southeast of WIPP-13) and WIPP-25 in Nash Draw (3.87 miles west of WIPP-13) by way of the WIPP-33 sinkhole. In our "Conceptual Model for Contaminant Transport in Karst Aquifers at the WIPP Site" (pp. 16-17) we calculated the travel time along this flow path and conclude that transport of contaminated water from the WIPP exhaust shaft to Laguna Grande de la Sal could take as little as 10 years. We have since discovered additional evidence in support of this flow path.

In a report entitled "Geotechnical Activities in the Exhaust Shaft" (DOE-WIPP-86-006) there are maps of certain intervals of the shaft walls. One of these maps (Figure 11) depicts a "breccia zone" in the lower unnamed member of the Rustler, immediately beneath the Culebra. It is in the shape of a solution channel, 6 feet high and 5 feet wide. The upper half is described as consisting mainly (60%) of angular to subangular clasts of dolomite in an argillaceous dolomite matrix; the lower half is described as soft claystone, nearly fissile, and poorly indurated. The overlying dolomite beds are fractured and trend downward; the surrounding beds thin toward the "breccia zone."

The "breccia zone" is located in the northwestern wall of the exhaust shaft, centered at about 3000 (N 60° W). This points in the direction of test well H-16 (N 64° W) where the Culebra head is anomalously low (3005 feet), indicating a zone of low fluid potential, as one would expect along a submerged flow path in the phreatic zone. It also points in the general direction of WIPP-13 (N 25° W). It is not clear why the "breccia zone" does not appear in the opposite wall of the shaft; either the map is incomplete, or the zone penetrates the shaft wall tangentially. Either way, it is direct evidence of dissolution in the exhaust shaft. If it is a solution channel, it would explain the existent hydraulic connection between the exhaust shaft and Nash Draw by way of WIPP-13 and WIPP-33.

The same report (DOE-WIPP-86-006) identifies three "unstable areas" in the exhaust shaft: (1) the Forty-Niner claystone (575.5-586.5 feet), 16.5 feet above the Magenta; (2) the Tamarisk claystone (689.0-695.5 feet), 16.0 feet above the Culebra; and (3) the claystone of the lower unnamed member (736.0-745.0 feet), immediately beneath the Culebra. These are the same intervals which are karstic at H-3, and which we have correlated to 23 other WIPP boreholes and test wells, and at the ventilation shaft, in our paper entitled "Cavernous Zones at the WIPP Site."

WIPP SITE RESISTIVITY SURVEY

In the early stages of geological characterization, when the WIPP site was still known as the Los Medanos site, an electrical resistivity survey was performed over the entire site, which was then six miles in diameter. The work was performed by Elliot Geophysical Company of Tucson, Arizona. The original study, entitled "An Experimental Detailed Resistivity Survey of Known or Suspected Breccia Pipes and Sinkholes, Eddy County, New Mexico," was transmitted in triplicate to George B. Griswold on December 22, 1976. A follow-up report, entitled "Evaluation of the Proposed Los Medanos Nuclear Waste Disposal Site by Means of Electrical Resistivity Surveys, Eddy & Lea Counties, New Mexico," was transmitted in triplicate to Dennis W. Powers on December 29, 1977, together with 11 maps and resistivity profiles without which the text is not useful.
The reports were never published. CARD was unaware of them until they were referenced in the CCA (pp. DEF-40, DEF-41). On December 24, 1997, we submitted a formal request to Sandia National Laboratories asking for the reports and maps. On January 12, 1998, we were informed by Sandia that: (1) the original study is available in the Sandia central files; (2) the follow-up study is available in the WIPP reading rooms; and (3) the maps and resistivity profiles are not available. CARD has since obtained originals of the maps and resistivity profiles from other sources.

Ironically, we have received two inquiries from DOE contractors wanting to obtain them from us.

On January 19, 1998, the EEG received a copy of a report concerning piezometers installed in the Santa Rosa Formation near the WIPP exhaust shaft (DOE/WIPP 96-2278). This report contains a section authored on October 28, 1977 by Dennis W. Powers. In this section is a map (Figure 15) which shows the outlines of two types of low resistivity anomalies taken directly from a map which accompanied the Elliot survey. CARD inquired about this and was informed that it was known all along that Dennis W. Powers possessed the maps, but that it was not the job of the technical staff at Sandia labs to track down and provide material which is not in the Sandia central files.

It should be noted that Dennis W. Powers was the principal author of the Geological Characterization Report (GCR, 1978, SAND78-1596) which, at the time, was used as the basis for recommending that the site be selected and that underground construction proceed. This report alludes to the resistivity survey without referencing it, falsely states that analysis of the data was not yet complete (p. 2-25), and provides two maps (Figures 2.14 and 2.15) which fail to locate the 9880 measurement stations and the 391 line miles of resistivity profiles which thoroughly covered the WIPP site.

The purpose of the resistivity survey was to locate geological hazards such as collapse structures or breccia pipes within the WIPP site. There was concern that such features might exist but remain unrecognized by surface mapping and aerial photography because the WIPP site is heavily covered with dune sands which would obscure all but the largest structural features. Where dissolution or brecciation has taken place, and subsequent compaction has not occurred, there should be a strong decrease in resistivity, indicating higher porosity, moisture content, clay content, or salinity.

The following conclusions were drawn from the resistivity survey:

(1) The dissolution front at the top of the Salado extends into the northwestern and southwestern portions of the WIPP site, where H-6, WIPP-33, and P-15 are now located.

(2) There is a zone of structural weakness in the Rustler Formation, a possible dissolution front, entering the site from the southeast; this is now known to be a zone of high transmissivity, where Cabin Baby, P-17, H-17, H-17 and DOE-1 are located.

(3) There is a localized, high-amplitude, low resistivity anomaly in sec 17, T 22 S, R 31 E, which was suspected of being a breccia pipe. This feature was later drilled as WIPP-13. The Tamarisk was found to be vertically fractured, the Magenta broken and shattered. Multi-well pump tests have shown a hydraulic connection between the WIPP shafts and Nash Draw by way of WIPP-13.

(4) There is a broader, high-amplitude, low resistivity anomaly in secs 30 & 31, T 22 S, R 31 E, in the largest topographic depression east of Nash Draw shown on the 15-minute USGS topographic map, Nash Draw quadrangle. Subsequent trench exposures have shown this to be a karst valley overlain by perforated Mescalero caliche caprock.
There is a closed topographic depression in sec 9, T22S, R31E which was suspected of being a collapse sink; a low resistivity anomaly was detected only at shallow depths, and it was concluded that this is not a "major collapse structure," but merely an ordinary sinkhole due to solution caverning. This feature was later found to be underlain by a high-amplitude negative gravity anomaly. It was then drilled as WIPP-14, and the Culebra was found to be underlain by 71.4 feet of mud with gypsum and anhydrite fragments.

There is a general increase in porosity and water content in the Rustler Formation and the Dewey Lake Red beds from east to west across the site and toward Nash Draw.

The Culebra and Magenta dolomites are not the only water-bearing units in the Rustler Formation; the mudstones and siltstones of the Forty-Niner, Tamarisk, and lower unnamed members have much lower resistivity than the anhydrite layers.

The siltstone and mudstone layers in the Salado have "extremely low resistivity;" these are water-bearing units, tens of feet in width, in "the supposed dry salt."

We have prepared a contour map (Figure 1) depicting the low resistivity anomalies. The outermost contour lines are 250 ohm-meters, and the contour interval is 25 ohm-meters. The innermost closed contours are filled in black, rather than using hachures which cannot be shown on this scale. The following observations may be made:

1. One of the broadest low resistivity anomalies (<175 ohm-meters) extends northward from the collapse sink later drilled as WIPP-33. Five water-filled caverns were found: one in Dewey Lake siltstone, two in Forty-Niner gypsum, and two in Magenta dolomite.

2. A localized, high-amplitude, low resistivity anomaly (<150 ohm-meters) was found at the P-14 borehole. P-14 was later converted to a test well where the highest Culebra transmissivity east of Nash Draw (233 ft²/day) was measured.

3. A broad, low resistivity anomaly (<175 ohm-meters) is found in the vicinity of test well WQSP-6, in the rainwater recharge area, where 25-30 gallons per minute of potable water was found in the Dewey Lake Red beds, the largest inflow of potable water measured at any of the forty-two WIPP test wells.

4. A localized low resistivity anomaly (<200 ohm-meters) was found at the center of the WIPP site, where evidence of dissolution has been found in the WIPP shafts.
FIGURE 1: LOW RESISTIVITY AREAS

CONTOUR INTERVAL = 25 OHM-METERS

250 OHM-METERS

LOWER CONTOUR LINES

RESISTIVITY LOW CLOSURE

DATA FROM ELLIOT GEOPHYSICAL COMPANY

MILES
February 27, 1998

Air Docket, Docket No. A-93-02
Room M-1500
Mail Code 6102
US EPA
401 M Street SW
Washington, DC 20460

The following is CARD's rebuttal to DOE's response to Breach Scenarios at the WIPP Site by Richard H. Phillips, Ph.D., and David K. Mitchell, P.E., originally submitted to EPA on March 17, 1997. We not only present a point-by-point rebuttal to DOE's response; we also identify passages in our original report which stand uncontested, together with additional evidence to support our findings. As a convenience to the reader, CARD has numbered the arguments made by the DOE, and has numbered the paragraphs of CARD's rebuttal correspondingly.

BREACH SCENARIOS REVISITED
by Richard Hayes Phillips, Ph.D.
and David K. Mitchell, P.E.

1 DOE does not deny that the original site selection criteria were altered in order to accommodate the WIPP site.

2 CARD did offer specific comments concerning the extent of brine reservoirs. We referred the reader to EEG-23 (1983, p. 31), Phillips (1987, Figure 76), and EEG-61 (1996, p.2-3). All three references are in the EPA docket. All three conclude that the WIPP-12 brine reservoir extends directly underneath the WIPP waste panels.

DOE, in performance assessment, assumes that the probability of an oil exploration borehole intercepting a Castile brine reservoir beneath the repository is 8% (CCA, p.9-167). This assumption is based upon a geostatistical analysis by Powers et al. (CCA, Mass Attachment 18-6) of the entire New Mexico portion of the Delaware Basin (CCA, p.DEL-86). Of a total of 3406 well files reviewed, 28, or 0.82%, were found to have notations by the driller indicating an encounter of pressurized brine (CCA, p.DEL-87).

Subsurface exploration at WIPP does not support this assumption. Three exploratory drill holes within the WIPP site (WIPP-12, WIPP-13 and DOE-1) were deep enough to have encountered brine in the Castile, and one of them did (WIPP-12). In addition, a time domain electromagnetic survey was conducted by Earth Technology Corporation (SAND 87-7144) in an attempt to determine the distribution of Castile brine beneath the WIPP waste panels. Based on this data, Borns calculated that Castile brine underlies 10% to 55% of the waste panel area, with a mean of 25% (CCA, Mass Attachment 18-5). Borns constructed a map which depicts brine extending beneath 29% of the waste panel area (CCA, Mass Attachment 18-5, Figure 1). From the same data, the CCA estimates that Castile brine underlies 25% to 57% of the waste panels, with a median of 40% (CCA, p.MASS-105). Thus the weight of geologic evidence dictates that an exploratory borehole within the WIPP site stands a 25% to 40% chance of encountering pressurized brine in the Castile. DOE's assumption of 8% is neither realistic nor conservative.
ERDA-9 is indeed "an existing pathway to the WIPP repository." It is near enough to the repository footprint (CCA, Figure 3-9) to be within the disturbed rock zone (DRZ) and therefore must connect the WIPP excavations to the land surface. CARD never said that ERDA-9 and the Castile brine reservoir are connected; we said that 200 feet of vertically fractured anhydrite is all that separates them.

CARD is aware that DOE plans to plug ERDA-9 in the future. CARD is also aware that DOE attempted to plug ERDA-10 in 1977. There appears to be no record of the success or failure of the attempt.

DOE claims that its borehole plugs will remain effective for 10,000 years. Unless a continuous concrete plug is shown to withstand the pressures encountered in the WIPP-12 brine reservoir, this claim is entirely unsubstantiated.

DOE does not address the implications of reducing the WIPP site boundaries. DOE cannot prevent waterflooding for secondary oil recovery or solution mining for potash, and cannot oversee the eventual plugging of oil and gas drill holes, beyond the current boundaries.

In 1996, according to EEG-62, Figure 2.2-2, there were 139 oil and gas wells within two miles of the WIPP site boundary. According to maps obtained from Midland Map Company, Midland, Texas, there are now 177, and 47 more have been planned and located (Figure 1). In January 1980 there were only 37 (Figure 2). This means that 140 oil and gas wells have been drilled in 48 square mile sections within two miles of the WIPP site within eight years' time. The current drilling rate, therefore, is 36 per mi² per 100 years. This is 30 times greater than the estimate of 120 per mi² per 10,000 years used by DOE in performance assessment (CCA, pp. 6-182, DEL-81). DOE's estimate is derived by averaging the drilling rate throughout the entire Delaware Basin over the last 100 years, as allowed by EPA criteria (40 CFR 194.33(b)(3)). This derives from a baseless assumption by EPA (40 CFR 191, Appendix C) that the drilling rate in sedimentary rock formations cannot exceed 30 per km² per 10,000 years (77 per mi² per 10,000 years). The criterion is clearly in error and should be overturned.

One of the reasons why the current drilling rate is so high is that active institutional controls have been removed. Prior to 1990 much of the area surrounding the WIPP site was being mined for potash, and it is BLM policy not to allow oil and gas drilling in areas where mining is ongoing. The situation is comparable to what will happen at the WIPP site when active institutional controls are lost 100 years after closure. The current drilling rate is the best estimate of what the drilling rate will be at that time. Oil and gas companies would be drilling into the WIPP site today if they were not prevented from doing so. Figure 1 reveals that nine of the recent discovery wells were drilled within one mile of the western boundary of the WIPP site.

According to the CCA (Figure 6-28, p. 6-187) the WIPP waste disposal area is about 173 acres, and the WIPP operations region is about 27 acres, which amounts to 200 acres of underground excavations, not counting the experimental region. Thus the drilling rate into the WIPP waste disposal area, when active institutional controls are lost, should be about 10 per 100 years. If the chances of penetrating a Castile brine reservoir are 25% to 40%, then an E-1 borehole (one which is drilled through the waste panels and intercepts pressurized brine) can be expected once every 25 to 40 years.
WIPP does not meet EPA containment requirements, partly because it is located in a known mineral district and is vulnerable to human intrusion. Anyone can produce a performance consistent with the desired conclusion. This does not explain away the inevitable breach of confinement occasioned by inadvertent drilling or fluid injection.

CARD is pleased that DOE has committed to exercising 100 years of active institutional control over the WIPP site. CARD is also pleased that EPA has awarded DOE no credit for passive institutional controls 100 years after closure, when active institutional control is assumed to be lost.

Under the heading of "potash mining," DOE devotes an entire page to its plans for exercising active institutional control, and never addresses the issue of what happens when active institutional control is lost: (1) potash mining could destroy much of the Salado Formation as a geologic barrier; (2) if water were to flood the potash mines, the water would travel laterally along marker beds in the Salado and could reach the WIPP shafts; (3) the potash mines could serve as preferential pathways for migration of contaminated water from the WIPP repository, and (4) potash mining could cause fracturing, subsidence, and collapse of overlying strata, thereby increasing the hydraulic conductivity of the Rustler aquifer and damaging the casings of oil wells.

The maximum allowable surface dose rate for a canister of remotely handled transuranic waste (RH-TRU) is 1000 rem/hr, compared to 0.2 rem/hr for contact-handled transuranic waste (CH-TRU). DOE says that the isotopes in RH-TRU will decay rapidly enough that its radiological effects will, in several hundred years, be similar to that of CH-TRU. DOE cannot credibly make such a statement because the radionuclide content of the waste scheduled for WIPP is unknown. Moreover, CARD has shown that drilling through the repository is likely to happen much sooner than assumed by DOE.

The hydrologic effects of potash mining beneath the Rustler aquifer are not adequately modeled by assuming an increase in hydraulic conductivity (1 to 1000, applied randomly). Steeply dipping subsidence fractures could provide pathways through the upper Salado to the Rustler, thereby reducing the distance required for hydrofracture from the repository to cause a breach of containment.

It is assumed that, after active institutional control is lost, potash resources within the controlled area will be completely removed within a century. DOE should not be allowed to select, randomly or otherwise, the century in which such mining is calculated to occur. The realistic and conservative assumption is that potash mining will occur during the first century, as soon as active institutional control is lost.

Whether or not a mineral is economically feasible to extract depends upon two conditions: (1) its market value; and (2) the available technology. These conditions are not constant and should not be extrapolated into the distant future.

The WIPP-12 brine reservoir was not "allowed to flow in order to discover information about the Castile brine reservoirs." DOE had considered it "highly unlikely" that brine would be encountered at WIPP-12. DOE was forced to deepen WIPP-12 as a result of a lawsuit filed by Jeff Bingaman, then New Mexico Attorney General, and the WIPP-12 brine encounter was considered an unpleasant surprise. The brine flowed to the surface at a rate of 45 gallons per minute; it filled up the catchment area so quickly that DOE had to dig a new one. Thirteen days were devoted...
exclusively to hydrologic testing, after which time the flow still was not stopped. Altogether, 60,000 barrels (2.5 million gallons) flowed to the land surface during a 40-day period. Similarly, at the Bates #2 well, brine injected two miles away by Texaco flowed to the surface at a rate of 840 gallons per minute (1200 barrels per hour) for 5.5 days before the well was finally brought under control. A total of 298 truckloads were required to haul the salt water away, and a pipeline had to be constructed to help alleviate the problem. The "well established practices" for countering brine flows, alluded to by DOE, are not always successful.

16 DOE states that brine flowing straight up a borehole from a Castile brine "pocket" would entrain little, if any, waste from the repository. Based on this reasoning, the dose to the driller is assumed in performance assessment to be limited to cuttings, cavings, and spallings. DOE assumes that all exploratory boreholes, even those encountering pressurized brine, will be plugged at abandonment, and that the plugs will be effective for 200 years, after which time the plug is assumed to fail completely (CCA, Appendix PEER, p. 3-73). During this time the connection between the reservoir and the repository remains open, and the repository becomes filled with pressurized brine which corrodes the canisters and dissolves the waste, creating a slurry of radioactive brine along with hydrogen sulfide and carbon dioxide gas. It is the second exploratory borehole, in what is known as the E1-E2 scenario, that would tap a pressurized repository and bring radionuclides in excess of EPA standards to the surface. Drillers might indeed abandon such a flowing well, and such an action would release additional radionuclides into the accessible environment.

17 DOE makes this statement: "If PA calculations showed that radionuclides would reach the accessible environment in sufficient quantities to violate the EPA standards, the DOE would not have submitted the CCA." That is exactly the point. DOE has incorporated whatever assumptions were necessary to show compliance (e.g., DOE's assumed recharge rate of 0.2 to 2.0 mm/yr, which gives a groundwater travel time of thousands of years). Phillips and Snow (1998) have shown, by means of a regional water balance analysis, that the recharge rate approaches 20 mm/yr. Using estimates of karst geometry, Phillips and Snow (1998) have calculated groundwater travel times as short as 10 years from the WIPP exhaust shaft to Laguna Grande de la Sal in Nash Draw. Groundwater flow from Nash Draw, and overflow from Laguna Grande de la Sal to the Pecos River, are quite relevant to determinations of dose. In the real world, the Pecos River is where the people live, where actual victims would be affected. Only by ignoring the large amount of water in Laguna Grande de la Sal can DOE justify its assumed recharge rates and travel times.

18 DOE assumes that any radionuclides that enter an intrusion borehole would reach the land surface, bypassing the karstic Rustler aquifer. Even if the hole is not cased during drilling, the predicted dose is not fatal to the rancher or the cow. DOE seems concerned about this point; the statement that "only very small amounts of contaminants would migrate from the point of release over 10,000 years" is made at least twenty times in the comment responses in SEIS-II (pp. 13-4, 13-7, 13-14, 13-23, 13-26, 13-30, 13-34, 13-59, 13-62, 13-63, 13-65, 13-68, 13-69, 13-78, 13-80, 13-82, 13-87, 13-93, 16-8, 16-117. If the karst model of Phillips and Snow (1998) is essentially correct, then this statement by DOE is wholly invalid.
19 DOE chides CARD for not having been familiar with the entirety of the 21 volumes of the CCA. DOE goes on to cite additional material submitted by DOE to EPA after the March 17, 1997 deadline for public comment.

20 Everything CARD said about the Hartman scenario is true and stands unrefuted by DOE. The reader is referred to our original paper, *Breach Scenarios at the WIPP Site*, pp. 4-7. The screening decision referred to by DOE (CCA, Appendix SCR.3.1.3.1) claims that leakage from brine injection wells is "unlikely to occur" near the WIPP for a number of reasons. Let us examine DOE's evidence: (1) DOE argues that oil production near the WIPP takes place in the Brushy Canyon Formation at depths greater than 7000 feet. The truth is that some producing oil wells near the WIPP are tapping the Cherry Canyon Formation at depths of 5100 to 6200 feet. More importantly, brine injection near the WIPP takes place in the Bell Canyon Formation at depths of only 4000 to 5100 feet. Most of the exploratory wells in the Bell Canyon Formation have been plugged and abandoned. Oil recovery currently takes place by secondary methods. (2) DOE argues that the Castile Formation, which is not present at the Bates #2 well where the Hartman scenario took place, would provide potential "thief zones" that would prevent brine injected into the Bell Canyon Formation from rising into the Salado Formation. CARD has already pointed out that recent water level rises in the Culebra dolomite at test well H-9b, located 6 1/2 miles south of the WIPP site, are strongly correlated with brine injection into the Bell Canyon Formation, indicating that the Castile and the Salado are not reliable geologic barriers. (3) DOE argues that oil pools in the vicinity of WIPP are smaller than at the Rhodes-Yates field, where the Hartman scenario took place, and therefore waterflooding on the scale of that undertaken at the Rhodes-Yates field would be "unlikely" at WIPP. The scale of waterflooding is not the concern; what is relevant to containment at WIPP is the pressure and duration of waterflooding. Already there are four brine injection wells within two miles of the WIPP site boundary, one of which is operating at a pressure that exceeds the lithostatic pressure at the repository horizon. The blowout at the Bates #2 well was caused by brine injected by Texaco two miles away. The brine had traveled through an anhydrite marker bed in the lower Salado, one of the same marker beds that exist at the WIPP site. There is no reason why a similar blowout cannot occur at WIPP due to brine injection at one of the 177 (soon to be 224) operating oil and gas wells within two miles of the WIPP site boundary. Brine injection near the WIPP is happening today. It cannot be prevented by DOE. A blowout could occur even while the workers are in the repository.

21 Ultimately, waste containment at WIPP depends upon DOE's ability to seal the WIPP shafts perfectly, forever, because the overlying Rustler aquifer is karstic and cannot be relied upon even to retard the migration of radionuclides. DOE accuses CARD of making "unsupported assertions" concerning the performance of the shaft seals. So does DOE. We predict the seals will fail, and DOE predicts the seals will work. Either argument is equally valid in the absence of supporting data. The "currently envisaged design" does not "demonstrate" compliance with containment requirements. Until it is tested in the field, nothing is demonstrated. CARD agrees that the disturbed rock zone (DRZ) will not heal at the time of emplacement. That 100 years of undisturbed performance will be necessary for salt creep to heal the DRZ (CCA, p. 3-26). CARD is concerned that the DRZ may never heal at all.
22 CARD not only asserts that Rustler groundwater will flow down the WIPP shafts, CARD observes that it does so already. When the WIPP exploratory shaft (now the salt handling shaft) was drilled in 1981, total inflow of Rustler groundwater was estimated at 1.5 gal/min (2160 gal/day), and less than 0.1 gal/min (144 gal/day) after liner plates were installed (TME 3178, pp. 4-3, 4-4). When the WIPP ventilation shaft (now the waste handling shaft) was drilled in 1982, total inflow was estimated at 0.3 to 0.9 gal/min (430-1300 gal/day), some of it from the Rustler, some of it from clay, anhydrite and siltstone beds in the Salado. When the ventilation fans were turned off, and the water was no longer being evaporated, a foot of water collected in the tunnel connecting the exploratory shaft with the ventilation shaft (Phillips, 1987, Plate 24). Even after the ventilation shaft was lined and grouted, leakage was measured at 0.5 to 2.0 liters/min (190-760 gal/day) (SAND88-7002, p. G-7). The WIPP exhaust shaft was drilled in 1983, even after liner plates were installed and grouted, more than 1 liter/min (380 gal/day) of inflow was observed from the Culebra dolomite alone (SAND88-7002, pp. G-5, G-6).

Head measurements are not necessary to show that Rustler groundwater would flow down the shaft seals. In situ observations are enough.

23 Rustler groundwater is everywhere unsaturated. In the ventilation shaft, the Culebra dolomite "produces enough water to wet the underlying shaft walls to the shaft sump, and to begin dissolution of evaporites exposed in the shaft walls below. The shaft wall in the Salado is deeply fluted by dissolution of halite by the seepage" from the Culebra (TME 3177, pp. 4-3, 4-4). CARD is concerned that dissolution of halite in the WIPP shafts will exceed the rate of salt creep, and that the shafts will never seal.

DOE correctly states that dissolution of the Salado at the repository horizon would cease as soon as Rustler water has dissolved enough halite to become saturated. The problem is that Rustler groundwater flow is continuous. Once a pathway exists from the Rustler to the Salado, the supply of fresh water would be continuous, and dissolution would not cease until the WIPP repository is completely flooded.

24 The basic premises of the WIPP were that the salt beds were supposed to be dry, and that salt creep would surround and encapsulate the waste canisters. But the WIPP is not located in a zone of pure salt. At the repository horizon, and in the WIPP shafts, the Salado contains seams of clay and marker beds of fractured anhydrite, both of which are more permeable than halite and contain up to 25% water by volume. It was thought that a thermal gradient was necessary for this brine to migrate into the repository. Now we know that a pressure gradient is sufficient. The brine migrates toward the area of lowest pressure in the Salado -- the WIPP excavations. Brine is now "weeping" into the repository at a slow but significant rate. A ventilating system now evaporates the water, but after closure, the WIPP will be a wet repository. There are no plans for specially designed containers at WIPP. The waste is to be buried in steel drums placed in direct contact with wet salt. When the steel drums corrode, the result would be a slurry of brine and dissolved waste. For more information on this subject, the reader is referred to: Scientists Review Panel on WIPP, Evaluation of the Waste Isolation Pilot Plant (WIPP) as a Water-Saturated Repository, 1988.

When the brine inflow was first discovered, DOE should have accepted the inevitable and abandoned the site. Instead, DOE argues that the hydrogen sulfide and carbon dioxide gas produced by corrosion of the steel drums will produce enough pressure to stop the brine inflow -- that a pressurized repository is a good thing.
There are no reliable measurements of brine inflow to the repository. The Room Q experiments were not conducted in a sealed room; consequently, some of the brine was evaporated. Estimates of brine inflow are derived from measurements of permeability of the clay seams and anhydrite beds, but these measurements may be an order of magnitude low (Scientists Review Panel, 1988, Figure 2).

In SEIS-II (p. 4-22) there are figures, not to say "measured data," on brine inflow to the WIPP repository. It is estimated that 50 to 160 cubic meters of brine, on the average, will seep into each waste disposal room of 3675 cubic meters. This is equivalent to 1.36% to 4.35% of the volume of each disposal room, each of which would be 13 feet high. This would result in 2 to 7 inches of brine in each disposal room, not counting any downward seepage from the Rustler Formation, lateral seepage from brine injection, or upward flow from the pressurized artesian brine reservoir in the Castile Formation.

There are alternatives to radioactive dumping. CARD discussed three of them: (1) transmutation; (2) vitrification; and (3) improved waste containers. DOE claims to have considered them, but DOE is not utilizing them.
BREACH SCENARIOS AT THE WIPP SITE

by Richard H. Phillips, Ph.D.

and David K. Mitchell, P.E.

The WIPP site is located in a known mineral district. Potash resources, including sylvite \([\text{KCl}]\) and langbeinite \([\text{K}_2\text{Mg}_2(\text{SO}_4)_3]\), in the McNutt member of the Salado Formation, extend directly above the WIPP repository (FEIS, 1980, Figures 8-5, 9-1, 9-2). Oil and gas resources in the Delaware Mountain Group (and lower formations) extend directly underneath the WIPP repository (FEIS, 1980, Figure 8-6; EEG-62, 1996, Figure 2.2-6). This has been known since before the WIPP site was selected.

Under the original WIPP site selection criteria, only "areas more than two miles from deep drill holes" were considered (GCR, 1978, Figure 2-3). When a test hole called ERDA-6, drilled at the original WIPP site, encountered a pressurized brine reservoir in the upper anhydrite of the Castile Formation, between the Salado Formation and the Delaware Mountain Group, the site had to be abandoned. Because no other potentially suitable sites in the Delaware Basin could be found, a new map was drawn indicating "areas more than one mile from deep drill holes." (GCR, 1978, Figure 2-8) On this basis, the current WIPP site was selected.

Two test holes, ERDA-9 and WIPP-12, were drilled at the current WIPP site, penetrating 53 feet and 47 feet deep, respectively, into the Castile Formation, stopping short of any pressurized brine reservoir. Thus the FEIS concluded that brine reservoirs "are extremely unlikely near the repository." A Stipulated Agreement was later signed between DOE and the State of New Mexico requiring that borehole WIPP-12 be deepened. (WIPP-12 is located one mile north of the center of the WIPP site).

On November 22, 1981, pressurized brine associated with hydrogen sulfide gas was encountered at WIPP-12 in the upper Castile anhydrite, 240 feet below the Salado Formation. The brine flowed to the land surface at a rate of 45 gallons per minute (1540 barrels per day) for forty days. Total brine outflow was 60,000 barrels, or about 2.5 million gallons (DOE, 1982, TME 3148). Thus a geologic mechanism exists which is capable of flooding the WIPP repository, corroding the steel drums, dissolving the waste, and carrying contaminated water up the WIPP shafts to overlying aquifers or to the land surface (EEG-6, 1980, pp. 47-48).

The total volume of the WIPP-12 brine reservoir was later estimated at between 17 million gallons (EEG-23, 1983, p. 29) and 30 million gallons (EEG-22, 1983, p. 79). By comparison, about 63 million gallons would be necessary to completely fill the WIPP repository (EEG-16, 1982, p. 45). It is likely that the WIPP-12 brine reservoir extends directly underneath the WIPP waste.
emplacement panels (EEG-23, 1983, p. 31; Phillips, 1987, Figure 76; EEG-61, 1996, p. 2-3) Borehole ERDA-9 (located 320 feet from the center of the WIPP site) was never deepened; but less than 200 feet of vertically fractured anhydrite is all that separates the pressurized brine reservoir from ERDA-9, an existing pathway to the WIPP repository. The plan is to plug ERDA-9, but there is no proven technology for plugging boreholes in salt formations, and CARD doubts that it can be done successfully.

In 1983 the boundaries of the WIPP site were reduced, from an approximation of a circle with a three-mile radius (18,960 acres) to a perfect square, four miles on each side (10,240 acres). The DOE thereby relinquished control of 8,720 acres in what had been designated as Zone IV (EEG-23, 1983, Figure 26), within which DOE had intended to prevent secondary methods of oil recovery such as waterflooding or hydrofracturing, to prevent solution mining for potash, and to oversee the eventual plugging of oil and gas drill holes (FEIS, 1980, p. 8-4). The rationale, according to DOE, was that "the minimal amount of crude oil likely to exist within the WIPP site" made waterflooding adjacent to WIPP unlikely (EEG-55, 1994, p. 21; EEG-62, 1996, p. xiv). CARD has long suspected that one of the reasons for reducing the boundaries of the WIPP site was the presence of obvious karst features in Zone IV (e.g. boreholes WIPP-33 and WIPP-14) as described by Barrows (1982, pp. 6-8, reprinted in EEG-32, 1985, Appendix A; see also Barrows to Chaturvedi, 8/6/82, Appendix B; Barrows to Chaturvedi, 4/7/83, Appendix C). Whatever the reasons, there are now, within the old Zone IV, 14 oil wells and 6 gas wells. Altogether, there are now, within two miles of the current WIPP site boundary, 101 oil wells, 18 gas wells, 7 oil and gas wells, 4 brine injection wells, and 9 dry holes (EEG-62, 1996, Figure 2.2-2).

All of this is in direct violation of EPA standards for the siting of repositories for nuclear waste disposal, and with good reason. The very purpose of geologic disposal is to emplace the nuclear waste in an area unlikely to be disturbed during the necessary period of waste isolation. No deep geologic disposal site is more likely to be disturbed than one in a known mineral district. Here is the text of the relevant EPA standard:

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 a significant concentration of any material that is not widely available from other sources, should be avoided in selecting disposal sites. Resources to be considered shall include minerals, petroleum or natural gas ... 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. (40 CFR 191.14e)
DOE claims that because the WIPP site was selected before the EPA standards were promulgated, the natural resources provision does not apply, and thus the WIPP site has been "grandfathered" into existence. CARD agrees with Neill et al. (EEG-61, 1996, p. xvi) that there is no "grandfather" provision in 40 CFR 191, and that there has been no formal acceptance of WIPP as a repository.

It is worth noting that langbeinite potash, unlike sylvite, contains no chlorine, and is a desirable fertilizer for soils that cannot tolerate additional chlorine. Langbeinite is a rare mineral, found only in the Carlsbad area and in eastern Europe (DEIS, 1979, pp. 9-16, 9-18, 9-19; FEIS, 1980, pp. 9-21, 9-23).

The existence of potash within the WIPP site poses a number of dangers to the WIPP repository: (1) The DOE contends that "active institutional controls" will prevent potash mining within the WIPP site for 100 years after closure, even though the DOE has never committed to exercising such control and expects other government agencies to do so. After institutional controls are lost, potash mining could destroy much of the Salado Formation as a geologic barrier. (2) If water were to flood the potash mines, the water would travel laterally along marker beds in the Salado Formation, and could reach the WIPP shafts. (3) The potash mines themselves could serve as preferential pathways for migration of contaminated water from the WIPP repository. (4) Potash mining could cause fracturing, subsidence, and collapse of overlying strata, thereby increasing the hydraulic conductivity of the Rustler aquifers and damaging the casings of oil wells, as DOE acknowledges (SEIS, 1996, pp. 4-21, H-14).

Thus there is no such thing as an "undisturbed scenario." It is inevitable that the hydrology of the WIPP site and vicinity will be adversely affected by future potash mining. Accordingly, for purposes of performance assessment, groundwater flow in the Rustler Formation should not be modeled under steady-state assumptions. DOE states in the SEIS (p. H-14) that it has taken this into consideration by examining the impact of a 1000-fold increase in the hydraulic conductivity of the Culebra dolomite due to potash mining, but the reference given (DOE 1996f) is not listed in Appendix H. CARD expects to be granted ample time to analyze said reference after its identity is revealed to us.

One of the most plausible breach scenarios for WIPP involves exploratory drilling for oil and gas beneath the repository. After institutional controls are lost, which DOE expects to be 100 years after closure, someone could drill directly through the waste emplacement panels and penetrate a pressurized brine reservoir in the Castile Formation, creating an instant breach of the WIPP repository, and carrying contaminated brine to the Rustler aquifers or to the land surface. To DOE, pressurized brine reservoirs are only "hypothetical" (SEIS, 1996, Figures H-9, H-10, H-12, H-14), and an open borehole such as this would
only be a "potential" pathway between the brine reservoir and the WIPP repository (SEIS, 1996, p. H-48). According to DOE, this pathway could flood the repository and flush "water," but not radionuclides, to the overlying Rustler aquifers (SEIS, 1996, p. H-48). Even though the WIPP-12 brine reservoir is under artesian pressure and flowed from a depth of 3016 feet to the land surface at a rate of 45 gallons per minute (DOE, 1982, TME 3148, p. 3), DOE assumes that, under this drilling intrusion scenario, it would take 10,000 years for radionuclides to migrate as much as 200 feet above the WIPP repository in concentrations equal to or greater than one picocurie per liter (SEIS, 1996, Figure H-12). Accordingly, the dose to a member of the drilling crew is always within acceptable limits, never more than 520 millirem (SEIS, 1996, Table H-31). This dose is from ingestion of drill cuttings (SEIS, 1996, p. H-63) if a panel of contact-handled transuranic waste (CH-TRU) is penetrated. The dose from remotely-handled transuranic waste (RH-TRU) is only 220 millirem (SEIS, 1996, Table H-31). This defies common sense, because the maximum allowable surface dose for a canister of RH-TRU (1000 rem/hour), is 5000 times higher than for a canister of CH-TRU (200 millirem/hour). That is why RH-TRU is remotely handled.

Under the drilling intrusion scenario, DOE assumes that the borehole would be "plugged at abandonment using standard regulatory requirements and practices" (SEIS, 1996, p. H-49) "and thereafter maintains a relatively low permeability. ... For these assumed conditions, no releases to the Culebra were simulated." (SEIS, 1996, p. H-87) This enables DOE to consider radiation exposure only to the drilling crew, and nobody else. It defies common sense to assume that with 45 gallons per minute of brine contaminated with plutonium and associated with hydrogen sulfide gas flowing out of an exploratory oil well, the drilling crew is going to plug the hole. Moreover, DOE assumes that even if the hole is not cased during drilling, and contaminated brine were to reach the Rustler Formation, it would be transported only to a well used to supply water for cattle, which could then become a source of meat consumed by a cattle rancher (SEIS, 1996, p. H-14). DOE does not consider that contaminated brine could be carried all the way to Nash Draw, Laguna Grande de la Sal, and the Pecos River, thus exposing large numbers of people, because this could violate EPA standards for radiation exposure.

The latest breach scenario, and perhaps the most serious, is known as the Hartman Scenario. This involves brine injection, which the DOE refuses even to consider. This scenario is not hypothetical. It cannot be prevented by institutional control of the WIPP site. It is happening today. These are the facts:

Brine injection is utilized by oil companies for one of two reasons: (1) salt water disposal, which involves the injection of unwanted brine through a disposal well and into permeable rock strata bounded above and below by impermeable rock strata; or
(2) waterflooding, which involves the injection of pressurized brine into an oil-bearing zone in order to force additional oil to flow toward a producing oil well (EEG-62, 1996, p. 2).

In 1991, Doyle Hartman, an independent oil operator, attempted to drill an oil well on the Bates lease, 40 miles east-southeast of the WIPP site. Known as the Bates #2 well, it was located about two miles from a brine injection well operated by Texaco for waterflooding purposes. In 1953 the Bates #1 well, located 100 feet away, had been drilled successfully; the well had been plugged and abandoned in 1988. The Bates #2 well encountered pressurized brine at a depth of 2240 feet, and drilling had to be terminated at 2280 feet. Brine flowed from the Bates #2 well at a rate of 840 gallons per minute, or 1200 barrels per hour, for 5.5 days. Fluid pressures were so high that the well could not be shut in for fear of an underground blowout. A total of 298 truckloads were required to haul the salt water away, and a pipeline had to be constructed to help alleviate the problem.

When the Bates #2 well was finally brought under control by using rapid-setting cement to shut off the flow, a shut-in pressure of 1000 psig was observed at the land surface. This equates to a pressure gradient of 0.966 psi per foot of depth, compared to the normal gradient of 0.525 psi per foot of depth for a column of saturated salt water. The only source in the vicinity with documented pressure gradients equal to or greater than those observed at the Bates #2 blowout was Texaco’s fluid injection well, two miles to the south (Van Kirk, 9/16/94; Bredehoeft to Lovejoy, 1/8/97). Hartman sued Texaco, won the case, and was awarded $5.6 million in damages (EEG-62, 1996, p. 8).

It turned out that pressurized brine injected by Texaco at 3000 feet below the surface (EEG-62, 1996, p. 131) had risen 700 feet vertically and migrated two miles horizontally through an anhydrite marker bed in the lower Salado, the same formation in which the WIPP repository is located. A failed well casing, due to long exposure to corrosive brine, was the most logical pathway into the Salado. The brine was being injected at pressures greater than lithostatic, high enough to induce massive hydraulic fracturing of the anhydrite marker bed over a large area that included the Bates #2 well (Bredehoeft to Lovejoy, 1/8/97). There are at least ten anhydrite marker beds in the lower Salado; they extend across the entire Delaware Basin, which is why they are called “marker beds.” According to Dennis Powers of Sandia National Laboratories, the Hartman blowout probably occurred in Marker Bed 140 or 142 (EEG-62, 1996, p. 66), which are 67 feet and 104 feet, respectively, below the WIPP repository horizon.

Despite the 40-mile distance between the Bates #2 well and WIPP, the characteristics of the Salado marker beds remain the same. If pressurized brine is injected and is able to leak through the casing of an oil well into an anhydrite marker bed, it can be
expected to induce fracturing and to travel two miles or more (Chaturvedi, in EEG-62, 1996, pp. 104-105). There are already 130 oil or gas wells within two miles of the WIPP site; four of them have been converted to brine injection wells (EEG-62, 1996, Figure 2.2-2), at least one of which is operating at a pressure that exceeds the lithostatic pressure at the repository horizon (EEG-62, 1996, p. xvii). The consequences of waterflooding of the WIPP repository due to pressurized brine injection would be catastrophic (Van Kirk, 9/16/94, p. 12). If pressurized brine were injected into Marker Bed 139, which is four feet below the repository, the WIPP could be flooded with massive amounts of water, and dissolved radionuclides could be carried out of the repository, away from the WIPP site, and into the accessible environment (EEG-61, 1996, p. 6-3; EEG-62, 1996, p. 16).

It has been argued that waterflooding of the WIPP repository is unlikely because brine injection near WIPP takes place in the Bell Canyon Formation, at a much deeper horizon than at the Texaco well. Indeed, there are at least 15 brine injection wells within eight miles of the WIPP site (EEG-62, 1996, Figure 2.6-2), and all of them inject into the Bell Canyon Formation (EEG-62, 1996, p. 15). However, recent water level rises in the Culebra dolomite at WIPP test well H-9b, located 6.45 miles south of the WIPP site, are strongly correlated with brine injection into the Bell Canyon Formation, more than 4400 feet below the land surface, at a well (Devon Energy’s Todd 26 Federal #3) located three miles away. There is more than 3700 feet of vertical separation between the Bell Canyon and the Culebra; between them lie the relatively impermeable salt beds of the Castile and the Salado; and yet injected brine was able to rise all the way to the Culebra. It is apparent that, in the vicinity of brine injection wells, the Castile and the Salado are not reliable geologic barriers (EEG-62, 1996, pp. 127-128, 132).

As Bredehoeft concludes: "The Hartman Scenario is not easily dismissed." (Bredehoeft to Lovejoy, 1/8/97). And yet the DOE does exactly that. DOE contends that, according to the criteria for compliance with EPA standards, "the most severe human intrusion scenario" that requires analysis is "inadvertent and intermittent drilling for resources" (40 CFR 194.33b1, cited in EEG-61, pp. 6-1, 6-2). DOE contends that "consequences greater than that of exploratory drilling" need not be considered (EEG-62, 1996, pp. xv, 16). Because the Hartman Scenario has more severe consequences than the drilling intrusion scenario, it need not be considered. CARD agrees with EEG; this "defies common sense." (EEG-61, p. SCR-6) The EPA criteria, at 40 CFR 194.32c, plainly require that DOE analyze the effects of "boreholes and leases that may be required for fluid injection activities." (EEG-62, 1996, p. 159) EPA, in its Supplementary Information, Subpart D, requires that DOE analyze the effects of "water-flood injection for secondary recovery of oil, solution mining and the disposal by injection of brine accumulated during recovery of
oil." Not to consider the Hartman Scenario is flagrantly illustrative of a callous disregard for human life.

Ultimately, waste containment at WIPP depends upon DOE’s ability to seal the shafts and plug the boreholes perfectly, forever, because the overlying Rustler aquifers cannot be relied upon even to retard the migration of radionuclides in groundwater. DOE’s Compliance Certification Application (CCA) describes in some detail the "presently envisaged shaft seal system" (DOE/CAO 1996-2184, pp. 3-15 to 3-21). DOE admits to three potential flow paths within the shaft seal system: (1) through the seal materials themselves; (2) along the interface with surrounding rock; and (3) through the "disturbed rock zone" (DRZ) adjacent to the shaft wall. Even if the engineered seal materials are of low permeability, and even if construction methods ensure a tight interface with the surrounding rock, the disturbed rock zone will be a groundwater flow path (DOE/CAO 1996-2184, p. 3-25). In DOE’s words: "It is well known that a DRZ develops in the rock adjacent to the shaft immediately after excavation. After closure of the shaft this fractured zone is initially a major flow path regardless of the material placed within the shaft" because whatever seal components are used will be more permeable than intact Salado salt (DOE/CAO 1996-2184, pp. 3-23, 3-24). In the WIPP ventilation shaft, the disturbed rock zone includes five "washed out zones" which had to be cased with liner plates to prevent further caving of the shaft wall (TME 3179, Figure 1). With this in mind, it will be useful to examine the components of DOE’s "presently envisaged shaft seal system."

(1) Compacted earthen fill will extend from the land surface to the top of the Dewey Lake Redbeds. Obviously, this will be more permeable than surrounding Gatuna and Santa Rosa sandstone.

(2) A concrete plug will extend 40 feet downward from the top of the Dewey Lake Redbeds. At this interval, DOE admits that the shaft will have to be "grouted before removal of the shaft lining to assure structural stability of the shaft wall."

(3) Compacted earthen fill will extend from the concrete plug through the Dewey Lake Redbeds to the Rustler Formation. This will be more permeable than surrounding sandstone and siltstone.

(4) Bentonite clay will extend through most of the Rustler Formation, including the Magenta and Culebra dolomite, both of which produce water in the WIPP shafts. The clay would be relatively impermeable, allowing Rustler groundwater to travel along the interface and through the disturbed rock zone.

(5) A concrete plug will be emplaced through 20 feet of the lower unnamed member of the Rustler Formation. Open fractures were observed at this horizon; groundwater will be able to travel along the interface and through the disturbed rock zone.
(6) An asphalt column will bridge the Rustler-Salado contact. Unsaturated Rustler groundwater will travel along the interface, dissolve the Salado salt, and enlarge the disturbed rock zone.

(7) A concrete plug will be emplaced through 23 feet of the Upper Salado. This is intended to fill "irregularities in the shaft wall," but will be ineffective because the disturbed rock zone will be continually enlarged by dissolution.

(8) Bentonite clay will extend through most of the Upper Salado. This will not prevent dissolution in the disturbed rock zone.

(9) Another 23-foot concrete plug will be emplaced near the top of the McNutt Potash Unit. Again, this will be unable to fill irregularities in a shaft wall undergoing active dissolution.

(10) A 560-foot column of crushed and compacted salt will extend from the concrete plug almost to the repository horizon. The crushed salt will be more permeable than the rock salt. DOE admits that salt column will offer "limited resistance to brine migration" for about 100 years after emplacement.

(11) Another 23-foot concrete plug, at the bottom of the salt column, will be unable to fill irregularities in the shaft wall.

(12) About 100 feet of bentonite clay will be emplaced at the bottom of the shafts. "to promote early healing of fractures in the surrounding salt." Again, the interface and the disturbed rock zone will be more permeable than the bentonite clay.

(13) A salt-saturated concrete monolith will be installed to fill the underground excavations at the repository horizon.

It is apparent that the "presently envisaged shaft seal system" will not be able to prevent the downward migration of unsaturated Rustler groundwater. It surely will not be able to withstand pressurized brine, whether from the Castile brine reservoir, from salt water disposal, or from waterflooding operations.

In addition to the four WIPP shafts, there are six deep boreholes within the WIPP site that penetrate deeper than the repository horizon. DOE seems aware of only four of them (WIPP-13, WIPP-12, ERDA-9 and DOE-1). There are also two deep drill holes (Badger Federal and Cotton Baby, identified in EEG-61, 1996, p. 3-7) which were abandoned by private operators (EEG-55, 1994, Figures 11, 12, 13; also shown in FEIS, 1980, Figure 8-6); these do not appear on the map of unplugged boreholes in DOE's Compliance Certification Application (DOE/CAO 1996-2184, Figure 3-9).

"The DOE had planned to develop special borehole plugging procedures for boreholes at the WIPP site. It now appears that conventional plugging procedures for commercial wells will be
followed." (EEG-61, 1996, p. 3-6) Thus it is with good reason that EPA requires DOE to assume, for purposes of performance assessment, "that the permeability of sealed boreholes will be affected by natural processes, and ... that the fraction of boreholes that will be sealed by man equals the fraction of boreholes which are currently sealed in the Delaware Basin." (40 CFR 194, Subpart C) DOE, in its Compliance Certification Application, speaks of shaft seals and borehole plugs in the present tense (DOE/CAO 1996-2184, pp. 3-19 to 3-21); DOE has no right to do so, as the technology for sealing shafts and plugging boreholes in salt formations has not been demonstrated. In fact, DOE attempted in 1977 to plug the ERDA-10 borehole at the Gnome Site in Nash Draw. Four separate plugs were emplaced for a total length of 4430 feet (SAND 81-2034), but no report appears to be available describing the success or failure of the attempt.

Ever since WIPP tunnels were excavated, saturated brine from Salado marker beds has been seeping into the WIPP repository. This brine would be capable of flooding the WIPP tunnels, corroding the steel drums, and dissolving the waste, creating a radioactive slurry at the repository horizon. Because the brine is saturated it would not be capable of dissolving any more salt; and once the WIPP tunnels are filled, the contaminated brine would have no other place to go but up the WIPP shafts, in what is known as the "undisturbed scenario." It is CARD's position that the sealing of shafts and the plugging of boreholes are too important to be left to chance. The credibility of the WIPP site depends upon it. Until the technology is demonstrated, in the field, it is premature even to consider allowing WIPP to open.

**ALTERNATIVES TO RADIOACTIVE DUMPING**

There are alternatives to radioactive dumping. DOE dismisses them too easily. In the Final Environmental Impact Statement (FEIS, 1980), DOE devoted more than a thousand pages to geologic disposal, and only three pages to alternative technologies (pp. 3-2 to 3-5). In the Supplemental Environmental Impact Statement (SEIS, 1996), DOE devotes over seven hundred pages to geologic disposal, and only two pages to alternative technologies (pp. 3-43 to 3-45), often stating that these alternatives were considered and rejected in the FEIS. From beginning to end, DOE has skewed the NEPA process so as to make the decision to proceed with WIPP appear reasonable and inevitable. This is in direct violation of NEPA case law, which states that the Environmental Impact Statement should treat the decision "as an impending choice to be pondered, (not) as a foregone conclusion to be rationalized." [372 F. Supp. 223, 253 (1974)] (For a discourse on NEPA case law as it applies to WIPP, see "Radioactive Dumping: The State of the Art," reprinted in WIPP-DOE-173). These are some of the alternatives to radioactive dumping:
Transmutation of isotopes with long half-lives into isotopes with short half-lives could greatly reduce the necessary period of waste isolation. DOE rejected transmutation because: (1) the process would be carried out in a nuclear reactor; (2) the process has not yet been proven for large-scale facilities; (3) waste products would be created in the process, so that geologic disposal might still be necessary; and (4) transmutation could not be performed upon contact-handled transuranic waste (CH-TRU), which consists largely of contaminated laboratory materials. But transmutation might be feasible for remotely-handled transuranic waste (RH-TRU) and high level waste (HLW), in which radioisotopes are more highly concentrated. Transmutation has been demonstrated on an experimental basis at Los Alamos National Laboratories (LA-UR-94-3022; LA-UR-94-4351; LA-UR-95-1792).

Vitrification would combine RH-TRU and HLW with molten glass. The advantage to vitrification is that it would make the waste less mobile, and therefore easier to contain. The waste would be less able to be entrained in the air, and less able to be transported by groundwater. DOE rejected vitrification because of the large volume of CH-TRU, again failing to address the feasibility of the process for RH-TRU and HLW. DOE argued that a vitrification program would delay TRU waste disposal, skewing the decision-making process in favor of geologic disposal.

Engineered barriers in the form of improved waste containers could lengthen the period of time before waste in a geologic repository would come in contact with the host rock. In the FEIS (1980, pp. 9-159, 9-160), DOE hoped to develop a canister that could remain intact for 300 to 500 years, a span of time embracing ten half-lives of cesium-137 and strontium-90, which are the major heat-producers in HLW. Again, DOE does not consider improved waste containers for disposal of TRU at WIPP.

Taken together, these alternatives could make isolation of RH-TRU and HLW possible. Short-lived isotopes, in vitrified form, in containers designed to resist corrosion, emplaced in a geologic repository, might remain isolated from the environment for ten half-lives or more, during which time the radioactivity will have decreased by a factor of 1000. Instead, DOE plans to bury long-lived isotopes, untreated in any way, in steel drums, in direct contact with wet salt, the most corrosive host rock imaginable.

It is CARD's position that no waste should be brought to WIPP. The waste should be stored above ground, in a monitorable and retrievable manner, until a solution is found. DOE admits (DEIS, 1979, p. 9-165) that the environmental effects of leaving the waste where it is, in the short term, would be less than the effects of retrieving it, identifying it, packaging it, trucking it, unpackaging it, lowering it down the WIPP shafts, and burying it at WIPP. The $17 billion that DOE plans to spend on WIPP could fund a genuine scientific effort to solve the problem.
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DOE Response

R.H. Phillips and D.K. Mitchell present a series of points relating to the future evolution of the WIPP site. Their comment refers extensively to the Supplementary Environmental Impact Statement (SEIS). The SEIS was prepared in accordance with the requirements of the National Environmental Policy Act (NEPA), which has different requirements to those in 40 CFR Part 191 and 40 CFR Part 194. The Compliance Certification Application (CCA) was prepared to respond to the requirements of 40 CFR Part 191 and 40 CFR Part 194. However, the SEIS and the CCA have much material in common, and most of the events and processes Phillips and Mitchell discuss are considered in the CCA. The DOE provides a response here to all comments, except where they are specific to the SEIS.

Change of site selection criteria

1 Section 1.3 of the CCA provides a summary of the site selection process that led to selection of the WIPP site. The site selection criteria used by the DOE and its predecessor organizations were used as guidance to choose a site for additional, more detailed investigation. Fulfillment of these criteria, however, is neither a necessary nor a sufficient condition for demonstrating compliance with the criteria in 40 CFR Part 191 and 40 CFR Part 194. Once the WIPP site had been identified as a potential site, it was subject to an extensive site characterization program. Data from this characterization program, and the results of modeling studies based on these data, have been used along with other information to demonstrate compliance with the EPA’s criteria.

Pressurized brine

2 The CARD comment describes the pressurized brine reservoir encountered during drilling of WIPP-12, but does not present specific comments concerning the extent of brine reservoirs or their treatment in the performance assessment (PA). The DOE is aware of the WIPP-12 brine reservoir (see CCA Section 2.1.3.3), and has devoted considerable resources to determining the extent of this and other brine reservoirs. Sections 6.3.2 and 6.4.8 of the CCA describe how the DOE has treated the possible intersection of a pressurized brine reservoir by a future borehole in CCA calculations.

Borehole ERDA-9 was drilled near the repository footprint. Appendix SCR of the CCA (Section SCR.2.3.8.2) considers WIPP investigation boreholes as potential
pathways for radionuclide transport. The screening discussion concludes that, in comparison to other pathways, WIPP investigation boreholes are of low consequence to the performance of the disposal system.

ERDA-9 is not "an existing pathway to the WIPP repository". A number of conditions would need to be satisfied for ERDA-9 to act as a pathway for radionuclide transport as hypothesized by CARD: a brine reservoir must be present; a mechanism is required to establish a pathway from a brine reservoir to the base of ERDA-9; a plug must be in place above the repository horizon to prevent brine flow to the surface; fracturing of anhydrites must take place between ERDA-9 and the nearest waste panel. Even if all these conditions were satisfied and brine entered the repository, cumulative releases to the accessible environment would be negligible, until such time as the repository were to be inadvertently penetrated by a future borehole. It is important to remember also that the DOE has committed that ERDA-9 will be plugged with a continuous plug (see CCA Chapter 3, Section 3.3.4)

Boreholes are routinely sealed in the Delaware Basin and elsewhere, and continuous concrete plugs of the type that will be used to seal ERDA-9 are an established technique. This type of plug is mandatory for deep boreholes in the potash enclave. Their use is required by the Bureau of Land Management (BLM) and the New Mexico Oil Conservation Division (NMOCID) because of their effectiveness.

Appendix DEL of the CCA describes corrosion of casing and degradation of cement in short plugs, but contrasts this with the stability of continuous plugs. The different physical and chemical conditions within continuous plugs ensures that they will remain effective for periods in excess of 10,000 years. In the context of the CARD comment, if ERDA-9 were to be left unsealed, and in the unlikely event of brine from the Castile reaching the borehole, then any brine would flow towards the surface and not enter the repository via the interbeds.

Resource disincentive

With regards to resource disincentive requirements in 40 CFR § 191.14(e) the DOE is fully aware and has accounted for all resource exploitation in the CCA PA. The DOE does not claim the site is "grandfathered"; the WIPP meets the requirements of 40 CFR § 191.14(e) because the 40 CFR § 194.45 criteria is met regarding resource disincentive. 40 CFR § 194.45 states that:

If performance assessments predict that the disposal system meets the containment requirements of § 191.13 of this chapter, then the Agency will assume that the requirements of this section and § 191.14(e) of this chapter have been fulfilled.

The DOE has shown that the WIPP meets the containment requirements (see Section 6.5 of the CCA), and concurs with the EPA that this demonstrates that the favorable
characteristics of the site compensate for any increased likelihood of intrusion due to
the presence of resources.

Consideration of natural resources has been a part of the WIPP program since 1974.
Early resource evaluations included caliche, salt, brine, sulphur, uranium, gypsum,
potash and hydrocarbons. The results of these evaluations are summarized in
Appendix GCR of the CCA.

The report contained in Appendix GCR was the principal source of natural resource
information considered in the development of the Final Environmental Impact
Statement (FEIS), which was issued in 1980 (DOE, 1980). The FEIS Record of
Decision (DOE, 1981) concluded that “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”. The FEIS evaluations were performed with the requisite
level of independence so as to meet the NEPA requirements.

The statement by CARD that the DOE has not committed to exercising 100 years of
active control of the site after closure is inaccurate. The DOE will maintain active
controls for at least 100 years (reference Chapter 7 and Appendix AIC of the CCA).

Potash mining

CARD appear to have misunderstood several aspects of the DOE’s treatment of
potash mining in determining compliance with the EPA’s criteria. In particular,
CARD are incorrect in asserting that the DOE has not committed to establishing
active institutional controls that would prevent potash mining within the controlled
area.

40 CFR § 194.41 states that:

(a) Any compliance application shall include detailed descriptions of proposed active institutional
    controls, the controls’ location, and the period of time the controls are proposed to remain
    active. Assumptions pertaining to active institutional controls and their effectiveness in terms
    of preventing or reducing radionuclide releases shall be supported by such descriptions.

(b) Performance assessments shall not consider any contributions from active institutional controls
    for more than 100 years after disposal.

Section 7.1 and Appendix AIC of the CCA comply with 40 CFR § 194.41(a) by
providing a detailed description of the active institutional controls (AICs) that will be
employed at the WIPP site and their location. These descriptions have been
supplemented by a detailed schedule for implementation of the AICs, submitted by the
DOE in response to a request for additional information [Response to Comment 43 in
EPA Letter of December 19, 1996; Enclosure 1].
As for the period of time that AICs are proposed to remain active, the DOE is committed to implementing the control programs for as long as such controls are useful and practical. However, in compliance with 40 CFR § 194.41(b), credit for active institutional controls is not considered in the performance assessment beyond 100 years from closure of the repository.

The DOE can foresee no credible scenario whereby active control of the WIPP site will be lost within 100 years following closure. Governments have successfully controlled and protected facilities of national importance for hundreds of years. The US Government in particular has existed and effectively maintained many facilities under its control for over 200 years. The DOE and its predecessor agencies have successfully maintained (preventing intrusion) several major facilities, including nuclear facilities, for over 50 years. Therefore, the DOE believes that AICs will be effective for at least 100 years, and are likely to be effective for substantially longer periods.

In the period following the assumed failure of AICs, the potential for potash mining to take place in the controlled area and to affect the hydrogeological properties of the Rustler is considered in CCA calculations (see Sections 6.4.6.2.3 and 6.4.12.8 of the CCA). The DOE does not argue that the disposal system will be unaffected by potash mining; calculations of “undisturbed performance” are required by the regulations applicable to the WIPP. Undisturbed performance is defined in 40 CFR § 191.12 to mean:

“the predicted behavior of a disposal system, including consideration of the uncertainties in predicted behavior, if the disposal system is not disrupted by human intrusion or the occurrence of unlikely natural events.”

Consideration of only undisturbed performance is required for compliance assessments with respect to the Individual and Groundwater Protection Requirements (40 CFR § 191.15 and 40 CFR § 191.24).

The dose calculations referred to by CARD in their comment do not form part of the DOE’s documentation of compliance with 40 CFR Part 191 and 40 CFR Part 194 in the CCA, and so a detailed response is not presented here. As a general point, the DOE would point out that RH-TRU waste is similar to CH-TRU waste except that the former is contaminated with short-lived beta-gamma emitters as well as the long-lived actinides present in CH-TRU waste. These beta-gamma emitters will rapidly decay during the 100-year post-closure period of active institutional control. After several hundred years, the radiological effects of drilling through an RH-TRU container will be similar to those from drilling through a CH-TRU drum. Furthermore, because an intrusion borehole would intercept a stack of three CH-TRU drums rather than a single RH-TRU container, after a certain period of time, doses arising from CH waste could be greater than doses arising from RH waste.

DOE's Response to CARD's March 1997 Letter on the WIPP Compliance Certification Application
With respect to the CARD comment on the 1,000-fold increase in Culebra hydraulic conductivity, the EPA guidance on 40 CFR 194 (EPA 402-R-95-014) suggests assess mining impacts by randomly sampling the hydraulic conductivity of the Culebra using a probability distribution of 1 to 1,000.

Mining within the controlled area after 100 years is included in calculations of disturbed performance using the conceptual model outlined in 40 CFR § 194.32(b). The regulations state that the PA should consider "... that mineral deposits of those resources, similar in quality and type to those resources currently extracted from the Delaware Basin, will be completely removed from the controlled area during the century in which such mining is randomly calculated to occur." The DOE has therefore based its analysis of the effects of future potash mining inside the controlled area on the quantity and type of potash currently extracted from the Delaware Basin, as summarized below.

Figure 6-20 in the CCA shows potential mining targets within the controlled area. The DOE estimated the mining targets based on areal extent and thickness of ore-bearing zones, ore grades, and current mining practices with respect to economic viability. The DOE's approach is the same as that used by Griswold in NMBMMR, 1995, p. VII-6. In this context it is important to remember that terms like "minable reserves", "reserves", and "resources" are different and have different definitions. The DOE used the term "resources" to describe the areal extent of potash mineralization. The volume of potash resources considered to be Lease Grade Reserves was determined by identifying those resources that either met or exceeded the BLM criteria of "four feet of 10 percent K₂O as sylvite or four feet of 4 percent K₂O as Langbeinite, or equivalent combinations of the two minerals." Griswold further screened the Lease Grade Reserves by applying current economic factors to identify those zones where extraction would occur if the areas located within the controlled area were available for lease.

In this text at p. VII-10, Griswold points out that for the 4th ore zone, the "16" contour line defines the boundary for a resource to meet the criteria for classification as Lease Grade Reserves. The "37.5" contour represents the criteria for economic mining. Likewise on p. VII-11, with regard to the 10th ore zone, the "40" contour line represents the minimum criteria for a reserve, and the boundary line representing the "55" contour line represents the economic mining criteria.

The DOE has estimated future mining impacts as stipulated in 40 CFR 194, within the CCA PA modeling. The mining impact analysis used in the CCA PA is conservative and adequately represents all possible future impacts on the WIPP disposal system.
Plugging of flowing wells

CARD are correct in noting that brine may flow to the surface if future drilling for oil and gas intersects a pressurized brine pocket in the Castile. Brine flows in exploration boreholes are not an unusual feature of exploration drilling, and nor is the presence of hydrogen sulfide. This means that there are well established practices for countering increases in pressure, brine flows, and gas pockets during drilling. Typical procedures used in the Delaware Basin are described in Appendix DEL of the CCA.

The brine flow of 45 gallons per minute that is mentioned by CARD was encountered during the drilling of WIPP-12, which was an investigation borehole for the WIPP project. The well was allowed to flow in order to discover information about the Castile brine reservoirs. Drillers exploring for oil and gas would not be concerned with acquiring this type of information and would take steps to reduce the flow.

Brine flow up a borehole from a Castile brine pocket would entrain little, if any, waste from the repository because brine moving straight up a borehole will not mix significantly with the waste (see Section 6.4; Appendix MASS, Section MASS 16.2; Appendix MASS, Attachment 16-2; and Section 9.3 of the CCA). Releases from the repository during drilling are associated with cuttings and cavings from the waste as the drill bit first encounters the waste, and from spallings and brine releases if the pressure in the repository is high enough. These releases are all accounted for in the PA calculations. The DOE conservatively assumes that drillers do not take preventative measures at this point, allowing for drilling to continue in the normal way into the Castile. If drillers were monitoring for radioactivity, they would detect the intrusion and take appropriate measures prior to drilling into the Castile.

In summary, there is no basis for CARD to suggest that drillers would abandon a flowing well or that such an action would release additional radionuclides into the accessible environment.

Releases to the accessible environment

If PA calculations showed that radionuclides would reach the accessible environment in sufficient quantities to violate the EPA standards, the DOE would not have submitted the CCA. Because there are no significant releases beyond the controlled area, the DOE conjectured that people may live near the boundary of the controlled area at some time in the future, and made a highly conservative calculation of hypothetical doses. The boundary of the controlled area is closer to the repository than is Nash Draw, and groundwater flow from Nash Draw to the Pecos River is not relevant to determinations of dose.
CARD have provided other, more detailed comments on groundwater flow in the Rustler, and the DOE has provided responses to these comments elsewhere. In the context of defining release scenarios, the DOE's reason for assuming that a cattle rancher may consume beef from cattle that have drunk water from the Rustler is to ensure that the dose calculations are conservative.

The Hartman Scenario

As elsewhere in this comment, Phillips and Mitchell do not appear to have located all relevant information in the CCA. These comments are very similar to those that were made by the EEG on the Draft Compliance Certification Application (DCCA). The DOE has thoroughly evaluated the so-called Hartman scenario and has also provided additional material to the EPA in response to their comments of 19 March 1997 (Response to Comment 21 in EPA Letter of 19 March, 1997). This information validates the original FEP screening decision in the CCA (see Appendix SCR.3.3.1.3.1.).

Shaft seals

The comment discusses the shaft seal design presented in the CCA. As the comment notes, this is the currently envisaged design that the DOE has used to demonstrate that the WIPP satisfies the containment requirements of 40 CFR Part 191. As stated in the CCA, the DOE does not intend to limit the design of the system to current technology. Future advancements in materials and sealing designs can and will be used, as appropriate, to ensure maximum performance of the shaft sealing system. However, the current design, used in PA, is reliable, appropriate, and known. All proposed changes to system design will be documented and approved by the EPA prior to implementation, as required by 40 CFR 194.4.

The CARD comment lists the proposed components of the shaft seal system and makes a series of unsupported assertions concerning their performance. Each of these components is described in detail in Appendix SEAL of the CCA. CARD appear to be under the misconception that the shaft seals will be required to attain their long-term performance characteristics upon emplacement. The shaft seal system has been designed explicitly to allow for the DRZ in the halite above the repository horizon to heal through salt creep, and analyses indicate that the salt column becomes an effective long-term barrier in less than 100 years (Appendix SEAL, Section 7.4.2). During this period the repository pressure will be too low, and there will be insufficient brine in the repository, for flow to take place up the shafts. Active institutional controls will prevent intrusions during this period and the shaft seals will not be subject to pressurized brine from the Castile. Even in the absence of institutional controls, the concrete and asphalt water stops will provide sufficient sealing to prevent brine flow up the shafts. Concrete fills irregularities in the shafts.
Wall, while use of the Salado Mass Concrete assures good bonding with salt. Salt creep against the rigid concrete components establishes a compressive stress state and promotes early healing of the shaft DRZ surrounding the concrete plugs (see Chapter 5 of Appendix D to Appendix Seal).

22 The CARD comment asserts that Rustler groundwater will flow down the shaft seals, but does not cite any evidence from head measurements to show why such a flow would occur. The DOE's discussion of the potential for borehole-induced solution and subsidence in Appendix SCR.3.3.1.4 of the CCA is relevant in this regard. Even if the permeability of the shaft DRZ were great enough to allow flow to take place, the absence of a sink for any downward percolating water would prevent significant dissolution of the Salado. At the most extreme, freshwater reaching the top of the Salado would dissolve sufficient halite to become saturated, and dissolution would then cease.

Migration of brine

24 The CARD comment notes that brine seeps into the repository from the marker beds in the Salado, and that this brine will become contaminated through waste dissolution. These processes are well recognized by the DOE and have been the subject of much research and analysis. Brine flows into the repository at present because the pressure within the repository during the pre-closure period is less than that in the Salado. Once the repository is sealed, however, the repository pressure will be controlled by gas generated through corrosion and other processes. The complex interaction of brine inflow and gas generation is modeled by the computer code BRAGFLO (see Section 6.4 and Appendix MASS of the CCA for further details). The scenario presented by CARD of uninhibited brine flow into the repository and then up the shafts does not have a physical basis.

Alternatives to Radioactive Dumping

25 In addition to comments concerning the future evolution of the WIPP site, Phillips and Mitchell also discuss possible alternatives to deep disposal of radioactive waste. Their comments in this section concern the Environmental Impact Statement that has been prepared by the DOE in accordance with the requirements of NEPA (DOE 1980, 1996). The comment also refers to alternative strategies for high-level radioactive waste (HLW), despite the fact that the WIPP site will not receive HLW.

The CCA was prepared to respond to the requirements of 40 CFR Part 191 and 40 CFR Part 194. One of the assurance requirements in 40 CFR Part 191 [40 CFR §191.14(d)] requires that:

Disposal systems shall use different types of barriers to isolate the wastes from the accessible environment. Both engineered and natural barriers shall be included.
Compliance with this requirement is discussed in CCA Section 7.4, and an analysis of different engineered barriers is presented in Appendix EBS of the CCA. Amongst the engineering alternatives considered in this analysis were different canister designs and vitrification of appropriate waste components (Appendix B of Appendix EBS). Transmutation was included in the candidate list of engineering alternatives, but was not included in later analyses as it has only been demonstrated for pure isotopic fractions and is therefore inappropriate for wastes comprising mixtures of materials (Appendix C of Appendix EBS).

References


CLOSING ARGUMENTS ON EPA'S PROPOSED DECISION TO OPEN WIPP
Presented by Richard Hayes Phillips, Ph.D.

January 9, 1998

My name is Richard Hayes Phillips. As you know, I am a doctor of karst geomorphology. I have studied the WIPP site for 19 years, and I conducted eight months of field work at the WIPP site. I have already presented to you a cogent description of the regional hydrology of the WIPP site and the Nash Draw watershed, based upon measured data and field observations. My concerns are not imaginary; they are real. I address you today as if I were an attorney, making closing arguments to the jury, on appeal. I will specifically address the Technical Support Document for the EPA's proposed decision, which is what these hearings are supposed to be about. I will point out some of the false statements made by the DOE to the EPA, and relied upon by the EPA, in arriving at its proposed decision.

Searching for a presumed barrier to rainwater recharge and karst hydrology at the WIPP site, DOE indicated that the Mescalero caliche is typically present beneath the sand. DOE told EPA that the Mescalero caliche covers the WIPP area as a hard, caliche crust up to ten feet thick, which led EPA to conclude that karst development is not a threat to waste containment at WIPP. DOE also said that the Mescalero caliche is expected to be continuous over large areas, and that WIPP data are limited mainly to boreholes. EPA is referred once again to my doctoral dissertation. EPA has three copies, including one with color photographs submitted at public hearings in Albuquerque in 1990. My dissertation contains site-specific maps and photographs of the Mescalero caliche surface, based on 1000 augur holes.
and ten backhoe trenches which I dug at the WIPP site and vicinity. Four of these trenches were located in the eastern end of a karst valley, within the WIPP site, within the rainwater recharge area, where Mescalero caliche is in direct contact with the Dewey Lake Redbeds. The karst valley, one mile long, is plainly visible in the WIPP site air photos. Trench exposures in the karst valley revealed 15 solution pipes, 1 to 14 feet in diameter, most of them passing entirely through the caliche, the largest of them displaying surface collapse in the Dewey Lake Redbeds. Altogether, 15.3% of the caliche surface was absent, with surficial sand in direct contact with Dewey Lake Redbeds. A smooth, continuous caliche surface cannot be expected; the effect is more like Swiss cheese. After heavy rainstorms, water runs along the caliche surface until it disappears into the solution pipes and infiltrates into the Dewey Lake Redbeds. DOE knows this. DOE videotaped the trenches. Larry Barrows, Al Lappin, Steve Lambert and George Bachman all viewed the trenches, as did a number of other scientists affiliated with New Mexico Tech, Texas Tech, EEG and EPA.

DOE stated that the Dewey Lake Redbeds have not produced water within the WIPP shafts, or in boreholes in the immediate vicinity of the waste panels, and that the Dewey Lake exhibits no flow at the WIPP site. These statements are false, and here is why: The Dewey Lake Redbeds have produced water in the WIPP exhaust shaft at approximately 100 feet below the surface, which EEG says can be traced to recharge. The Dewey Lake produced water in the air intake shaft as well. The Dewey Lake Redbeds have produced water in four test wells in the immediate vicinity of the waste panels (H-1, H-2, H-3 and WQSP-6). One of these wells, H-1, is located directly above the waste panels. The Dewey Lake
Redbeds do exhibit flow at the WIPP site. According to the neutron log for H3-b4, a down-hole camera recorded water streaming from a fracture only 35 feet above the Rustler Formation, which leads to the inescapable conclusion that, in the immediate vicinity of the waste panels, the Dewey Lake Redbeds contain feeder channels which readily transmit water to the Rustler Formation.

DOE's fallback position is that the Rustler anhydrites, siltstones and claystones are confining layers, barriers to rainwater infiltration. In performance assessment, the Forty-Niner, Tamarisk, and lower unnamed members of the Rustler Formation are assigned a permeability of zero, despite occasional reports of Rustler claystones producing water at rates equivalent to the Culebra or Magenta dolomites. CARD has correlated and presented borehole data showing washouts and consistent loss of core in two distinct horizons of Rustler mudstone: in the Forty-Niner member about 20 feet above the Magenta, and in the lower unnamed member immediately beneath the Culebra. These are not occasional occurrences. CARD succinctly summarizes 12 such encounters above the Magenta and 14 beneath the Culebra, all of them at or near the WIPP site. CARD describes a similar horizon in the Tamarisk member, with washouts or loss of core in 5 locations and reports of dissolution residue in 7 others. Evaporite rocks are not typically fractured, and a consistent lack of core recovery in horizons identified by the actual drillers as being dissolution residues is a clear indication of unconsolidated or cavernous zones capable of transmitting water with little resistance. When these occurrences are correlated and mapped, as CARD has done, it is shown that these zones snake across the WIPP site, penetrating its heart at the ventilation shaft.
DOE claimed that the Magenta dolomite is unfractured at WIPP. This claim was later modified to read that the Magenta has no hydraulically significant fractures at WIPP. The Peer Review Panel was unconvinced. DOE, in response, stated that the only location on the WIPP site at which open fractures have been observed in the Magenta is WIPP-13. At WIPP-13, according to the lithologic log, the Magenta dolomite is broken and shattered by numerous fractures dipping 60° to 80° and displacing bedding planes. At WIPP-19, open fractures were found in Magenta core; and in the WIPP ventilation shaft, eleven fractures in the Magenta, all of them vertical to subvertical, all of them open, were observed and mapped.

DOE told EPA that it does not appear that the Culebra dolomite is extensively fractured in the vicinity of the WIPP shafts. The truth is that in the WIPP air intake shaft, much of the Culebra dolomite exhibits extensive subvertical to vertical fracturing. About half of the fractures are filled with gypsum, and the rest are open. The lower six inches consists of brecciated dolomite. At H3-b2 the Culebra is totally fragmented. Only three core samples totaling 4 feet were recovered; 18 feet of Culebra core was lost, and another 5 feet of core was lost in black clay (not claystone -- clay) immediately beneath the Culebra. At H3-b3 the whole Culebra interval was broken into pieces less than one foot in length; where pieces were preserved, the core was very porous; some fractures were open, some were filled with gypsum; 14.5 feet of Culebra core was lost, and another 4 feet of core was lost in the black clay beneath the Culebra. This is entirely consistent with a cavernous groundwater flow path through the Culebra dolomite and the claystone of the lower unnamed member of the Rustler.
DOE says that Culebra groundwater is saturated with respect to gypsum. DOE made this statement in response to EPA's concerns about the potential for dissolution of gypsum fillings in fractures in the Culebra dolomite. DOE convinced EPA that dissolution processes are not presently occurring in the Rustler Formation, and that conditions are not expected to change during the regulatory period, that is, in the next 10,000 years. DOE's argument is that infiltrating waters that would cause the dissolution would become saturated with respect to gypsum and therefore would be unable to dissolve anhydrite or gypsum. The truth is that infiltrating groundwater will not be saturated with gypsum until it has dissolved enough gypsum to become saturated. Presently, some Rustler groundwater is saturated with respect to gypsum, and some is not; concentrations of dissolved calcium and sulfate vary not only from well to well, but also from time to time -- for example, along the entire southeastern flow path from the WIPP site to Nash Draw, at test wells H-3, DOE-1, H-11 and P-17. Dissolution of gypsum fillings in Culebra fractures is presently occurring.

DOE states that there is no evidence from hydraulic conductivities that the karst development found at WIPP-33 extends into the WIPP site. The truth is that WIPP-33 was never converted to a hydrologic test well, and so there are no multiwell pump tests designed to determine whether or not the five water-filled caverns found at WIPP-33 -- two in Magenta dolomite, two in Forty-Niner gypsum, and one in Dewey Lake siltstone -- are hydraulically connected to the WIPP site. If there is no evidence, this is because DOE has not done the necessary testing. Absence of evidence is not evidence of absence. However, a multiwell pump test centered in the Culebra at WIPP-13, located within the WIPP site, did show a hydraulic connection to WIPP-25, located 4 miles away
in Nash Draw, which DOE admits is a karst valley. The response was extraordinarily rapid; the delay in maximum drawdown at WIPP-25 was only 26 hours. The transmissivity between WIPP-13 and WIPP-25 was calculated at 650 square feet per day, which works out to a hydraulic conductivity of 27 feet per day. WIPP-33 is located almost exactly midway between WIPP-13 and WIPP-25. WIPP-33 is the westernmost of a chain of four sinkholes; they are almost perfectly aligned with WIPP-13. There was also a measurable response at the WIPP exhaust shaft, 1.5 miles southeast of WIPP-13, which suggests an existent northwesterly flow path from the WIPP repository all the way to Nash Draw, by way of WIPP-33.

Ladies and gentlemen of the EPA, you have been deceived, through no fault of your own. You have a duty to overturn the proposed decision to open WIPP, because it was based upon false testimony. To change your mind now would not be an embarrassment. It would be an act of courage.