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HYDROLOGIC STUDIES FOR THE WASTE ISOLATION PILOT PLANT

Peter B. Davies
Geohydrology Department
Sandia National Laboratories

Introduction

The objective of this paper is to provide a general overview of hydrologic conditions at the Waste Isolation Pilot Plant (WIPP) by describing several key hydrologic studies that have been carried out as part of the site characterization program over the last 20 years. The paper is composed of three parts: background information about general objectives of the WIPP project; information about the geologic and hydrologic setting of the facility; and information about three aspects of the hydrologic system that are important to understanding the long-term performance of the WIPP facility. For additional detailed information, the reader is referred to the references cited in the text.

Background Information

The WIPP is located in southeastern New Mexico approximately 25 miles east of Carlsbad (Figure 1). The facility is designed for the receipt, handling and storage, and ultimately the disposal of approximately 180,000 m^3 of defense-related transuranic (TRU) waste (U.S. Department of Energy, 1990). Figure 1 shows the main components of the facility. Beneath the waste handling facilities on the land surface are four shafts to the underground workings. At the north end of the workings, an experimental area has been developed where various in-situ experiments are being conducted. In the waste storage area, the repository is designed to have eight waste storage panels, with each panel consisting of seven individual disposal rooms. At this point in time, only the first waste storage panel has been excavated.

Waste transported to WIPP will consist of waste materials such as metal, glassware, cellulosic materials (paper and cloth), and processed sludge. These wastes have been produced as a by-product of defense-related nuclear activities and contain small quantities of plutonium or other transuranic elements and their fission products. Most of this waste is contained in 55-gallon drums, which will be placed into the disposal rooms and then backfilled with crushed salt (Lappin et al., 1989). A smaller quantity of waste, in canisters having a higher surface dose rate, will be transported in shielding casks and the canisters will be placed into large-diameter, horizontal boreholes in the walls of the disposal rooms. As a panel is filled, it will be backfilled with salt mined from the next panel. Each panel is closed off with an engineered seal once it is full.

Geologic and Hydrologic Setting

The repository is located in the Delaware Basin, a large geologic structure with laterally continuous layers of different types of sedimentary rock (Lappin et al., 1989). Figure 2 shows the sequence of rocks in the uppermost 1200 meters of the basin. Most of these rocks were deposited over 230 million years ago. The shallowest rock unit is primarily fine-grain sandstone and siltstone. These rocks have relatively low to moderate permeability. Below this shallow unit is the Rustler Formation, which contains two thin dolomite layers. The deeper of these two layers, the Culebra Dolomite, is the most permeable, laterally continuous layer overlying the repository.

The WIPP repository is located approximately 650 m below land surface in the lower part of the Salado Formation (Figure 2). The layered halite (salt) of the Salado Formation was selected as the host rock for the repository because of its extremely low permeability, which provides hydrologic isolation, and because the relatively plastic halite will eventually deform and flow, thereby encapsulating the waste. The Salado Formation also contains a number of thin layers of anhydrite, a somewhat wore brittle rock. Below the Salado Formation is the Castile Formation, which is made up of thick alternating layers of halite and anhydrite.

Important Aspects of the Hydrologic System

Over the past 20 years, extensive field and laboratory testing and analysis have been carried out to characterize the hydrologic conditions at the WIPP site. The following sections describe three aspects of the hydrologic system that play an important role in the assessment of long-term repository performance.

Pressurized Brine in the Castile Formation

Localized reservoirs of pressurized brine (water that is saturated with dissolved salt) have been encountered in the Castile Formation, occurring in the uppermost anhydrite layer of this formation. Figure 3 shows the locations where these pockets of pressurized brine have been encountered in the Castile Formation while drilling deep holes (Borns et al, 1983). Most encounters with pressurized brine have occurred in an area that has experienced moderate salt flow and associated deformation of the anhydrite within the Castile. Pressurized brine was also found in an exploration hole, WIPP-12, inside the WIPP site boundary. WIPP-12 is located about one mile north of the waste storage panels.

Figure 4 illustrates a north-south cross section (i.e. "vertical slice") through the rock units at the WIPP site. At the WIPP-12 drillhole, where the pressurized brine was encountered at the bottom of the uppermost Castile anhydrite unit, relatively mild salt flow and deformation has occurred in the Castile Formation. There are over 200 meters of halite between this anhydrite unit and the stratigraphic horizon of the WIPP repository. Although more pronounced deformation is present at drillhole WIPP-11, no pressurized brine was encountered at that location. Given the presence of pressurized brine in the Castile, an important question is how might the occurrence of pressurized brine affect long-term repository performance. Two different scenarios are pertinent in addressing this question.

The first scenario considers repository performance under undisturbed conditions. Because there are over 200 meters of extremely low permeability halite between the uppermost Castile anhydrite and the repository horizon, no brine is expected to flow from the Castile into the repository. Therefore, the presence of brine (if it were to occur beneath the waste storage area) has no significant impact on undisturbed performance of the repository.

The second scenario is driven by the regulatory criteria set forth by the Environmental Protection Agency (EPA) for radioactive waste disposal (U.S. Environmental Protection Agency, 1985). These criteria require that in addition to undisturbed performance, the repository must be evaluated for human intrusion in which some future society inadvertently drills through the repository (Lappin et al., 1989; Reeves et al., 1991; WIPP Performance Assessment Department, 1992). In this human-intrusion scenario, a drill hole penetrates both the repository and a hypothetical pocket of brine in the Castile Formation (Figure 5). While current drilling regulations require that such drillholes be plugged, the human-intrusion scenario assumes that over time the plugs will degrade, thereby allowing pressurized brine to flow upward through the repository. It is assumed that brine flowing through the repository will pick up dissolved radionuclides and that this contaminated brine will enter the Culebra Dolomite, where it will be carried laterally to the site boundary. In order to assess the regulatory impact of this scenario, it is important to understand the flow and radionuclide transport characteristics of the Culebra Dolomite.

Flow and Transport in the Culebra Dolomite

The Culebra Dolomite is the most permeable, laterally continuous unit overlying the WIPP repository and, therefore, represents the most likely pathway for off site radionuclide transport for the human intrusion scenario (Lappin et al, 1989). This dolomite unit is approximately seven meters thick and has both horizontal and vertical fractures. Extensive hydraulic testing of the Culebra has been carried out at 41 different locations, including large-scale pumping tests centered in drill holes WIPP-13, H-3, and H-11 (Figure 6). These tests reveal the location of the more permeable portions of that Culebra Dolomite and provide important data for the analysis of water movement through this unit (LaVenue et al., 1990).

In addition to extensive hydraulic testing to characterize ground-water flow, tracer tests have been completed at five locations to determine the transport characteristics of the Culebra (Jones et al., 1992). In these tests, nonreactive tracers are injected at as many as three wells while water is pumped from a nearby pumping well (Figure 7). Tracer concentrations in the pumped water are then measured and plotted versus time. These tracer concentration curves are then analyzed to provide important information about how contaminants such as dissolved radionuclides would move through this fractured rock unit. An important question that is being addressed by these tracer tests is to what degree, when relatively concentrated solutes flow through a fracture, do significant quantities of solute diffuse into the rock matrix adjacent to the fracture. This matrix diffusion process would significantly retard lateral transport of contaminants.

Hydraulic- and tracer-test data are used to construct computer models of ground-water flow across the site and to examine the transport for the hypothetical human intrusion scenarios (Lappin et al., 1989; Reeves et al., 1991; WIPP Performance Assessment Department, 1992). These models are used to quantify the uncertainty in transport calculations due to limited knowledge of parameter values. These models are also a powerful tool to examine a variety of "what if" scenarios that provide important information about the behavior of the hydrologic system in the vicinity of the WIPP repository.

Brine and Gas Flow at the Repository Horizon

The halite of the Salado Formation that surrounds the WIPP repository is an extremely low permeability rock. In fact, there is some question as to whether brine would flow through this rock at all. In-situ testing at the repository horizon has revealed that there is indeed a small quantity of brine that may flow through some of the impure halite and thin anhydrite layers at the very high pore-pressure gradients that exist adjacent to excavations in the salt.

Quantifying flow parameters in these very low permeability rocks is extremely difficult because the volume of flow is so small. Hydraulic tests to measure permeability have been carried out in a series of small-scale tests in different Salado layers (Beauheim et al., 1991, 1993). In addition, a 3-m-diameter, 110-m-long cylindrical room was excavated at the repository horizon to monitor the rate and volume of brine inflow under controlled conditions (Nowak, 1990). Over the past four years, approximately 150 liters of brine have been collected from this experimental room. Although some brine may have been lost to evaporation or trapped in a localized fractured zone around the room, this experiment confirms that quantity of brine that can flow though the halite is extremely small compared to most other common rock types.

Another important hydrologic issue for assessing long-term repository performance is the potential for generating gas by corrosion of the metal barrels that contain waste, metal in the waste, or by microbial degradation of cellulosic materials in the waste. Laboratory studies have shown that gas-generation rates are much higher if the waste is submerged in brine than when waste is exposed only to humid conditions (Brush et al., 1992). An important scenario being evaluated is that when the salt deforms and a disposal room starts to creep shut and encapsulate the waste, a small amount of brine flows into the room (Figure 8A). Contact of this brine with metal leads to gas generation and causes fluid pressure in the room to rise. At some point, pressure in the room may get high enough to drive brine and/or gas outward from the room (Figure 8B). The most likely pathway for brine and gas flow is the thin anhydrite layers, which have slightly higher permeability than the surrounding halite. To assess the impact of gas generation on long-term repository performance, one must understand how the presence of gas influences release of radionuclides under the human intrusion scenario. The potential for lateral transport of volatile organic compounds from the waste within these thin, anhydrite layers also must be evaluated.

An important tool for evaluating these scenarios is numerical flow and transport models (Davies, et al., 1992; WIPP Performance Assessment, 1992). Data for these computer models are provided by both laboratory and in-situ hydraulic testing of the halite and anhydrite layers. Ongoing experimental and model-development work is focusing on reducing uncertainty and on developing a better understanding of the coupling between the hydrologic processes of brine and gas flow to and from disposal rooms, the mechanical process of room closure and consolidation, and the chemical processes that control gas generation.

Closing Comments

A high level of confidence in flow and transport models at the WIPP is important because these models are a critical component of the analysis of long-term repository performance under a wide variety of conditions. One approach taken to develop confidence has been for the WIPP project to participate in the International Project to Study Validation of Geosphere Transport Models (INTRAVAL). The objective of INTRAVAL is to increase understanding of how various geophysical, geohydrologic, and geomechanical phenomena influence radionuclide transport and how these phenomena are described by the mathematical models that provide the basis for numerical models of system behavior. Multiple working groups from the international scientific community use information from specific laboratory and field experiments, as well as analog studies, to test both conceptual and mathematical models. Two WIPP test cases have been submitted to INTRAVAL, one on brine flow in the Salado Formation and one on flow and transport in the Culebra Dolomite. For each test case, WIPP data were submitted for evaluation and analysis (INTRAVAL, 1993). Feedback from INTRAVAL participants has been extremely useful for evaluating the strengths and weaknesses of field tests and mathematical models of the hydrologic system at the WIPP.

Over the next few years, experimental work will continue to address key data needs and resolve remaining hydrologic issues. This information will then be incorporated into assessments of the long-term performance of the entire WIPP disposal system. This performance assessment with provide the technical basis for a formal Department of Energy compliance submittal to the Environmental Protection Agency.

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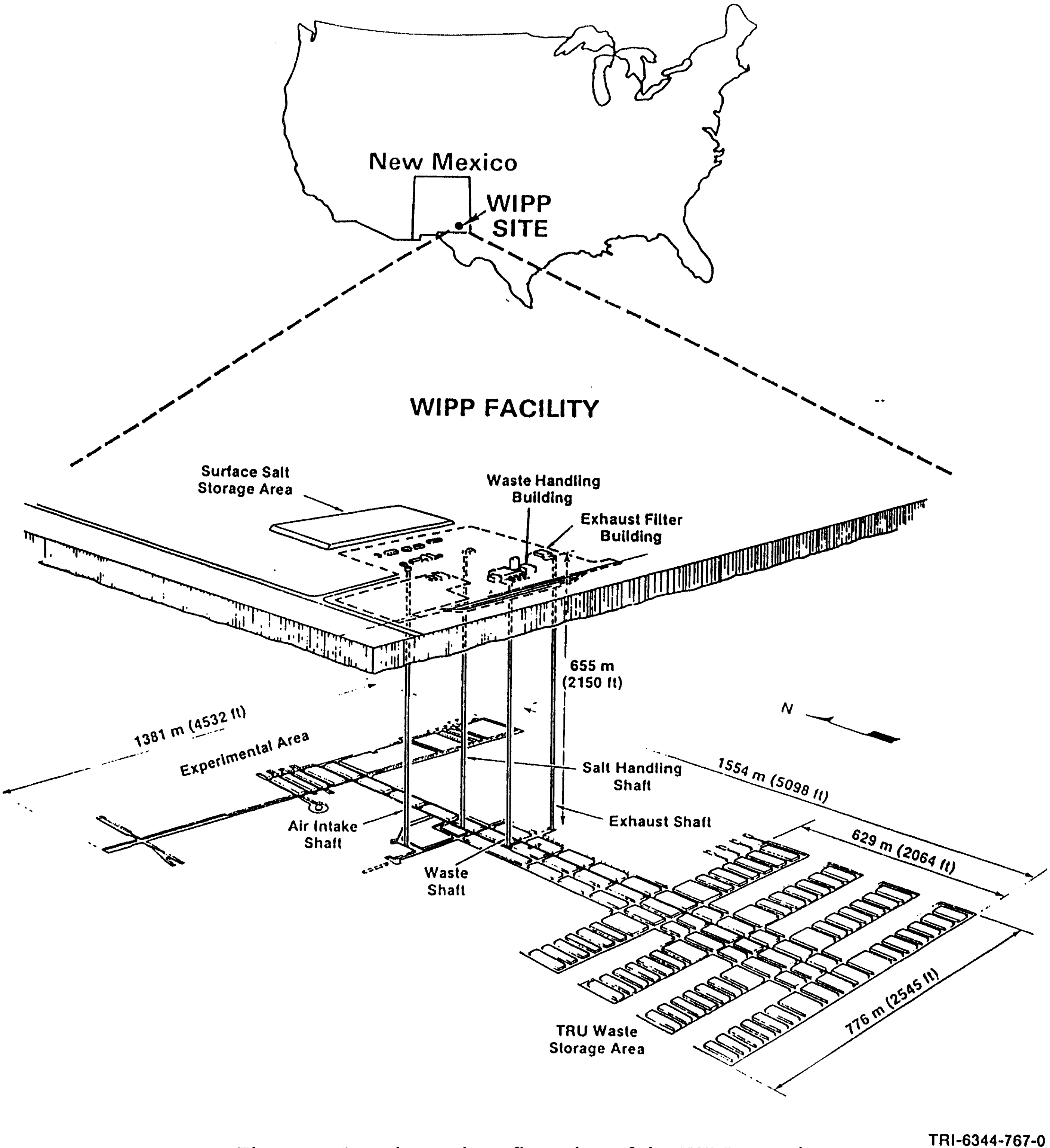

Figure 1. Location and configuration of the WIPP repository.

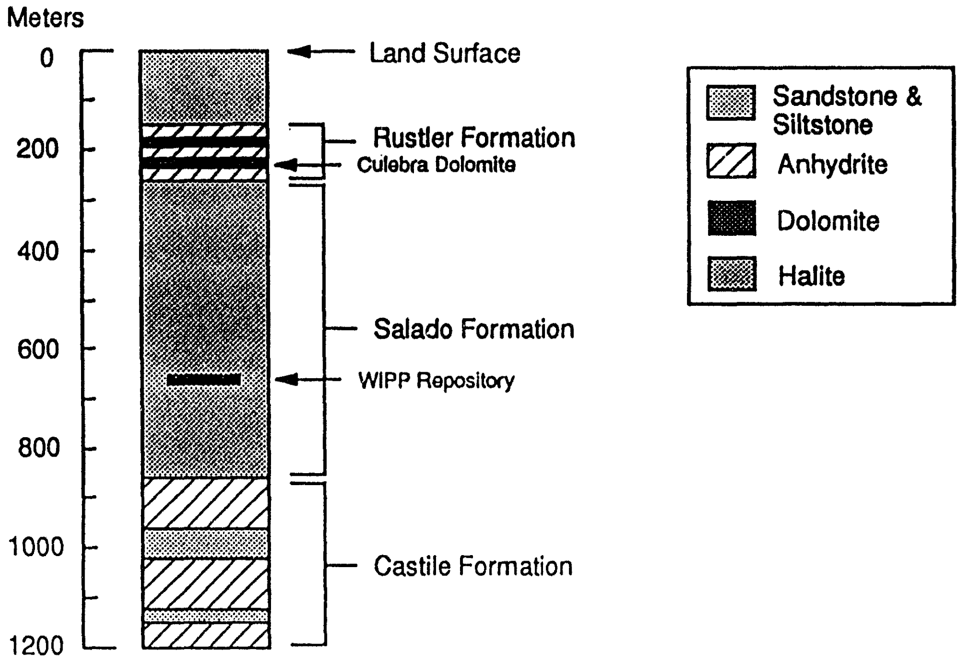

Figure 2. Stratigraphic section at the WIPP site.

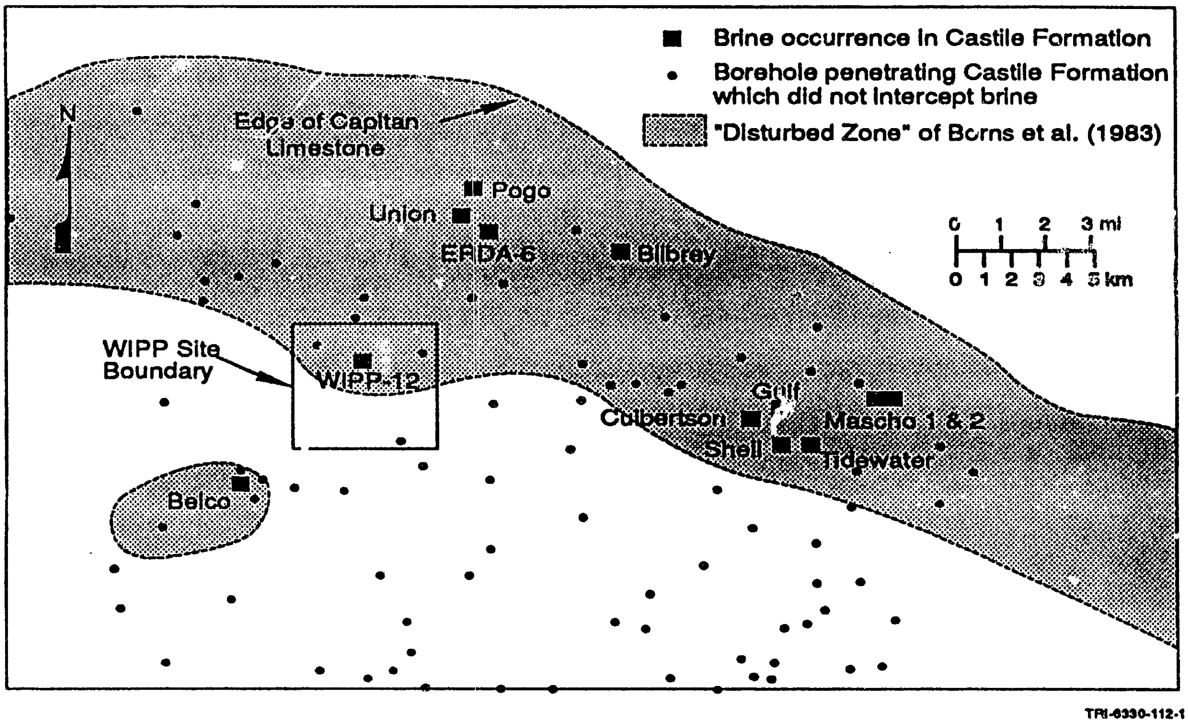

Figure 3. Map showing locations of brine occurrences in the Castile Formation.

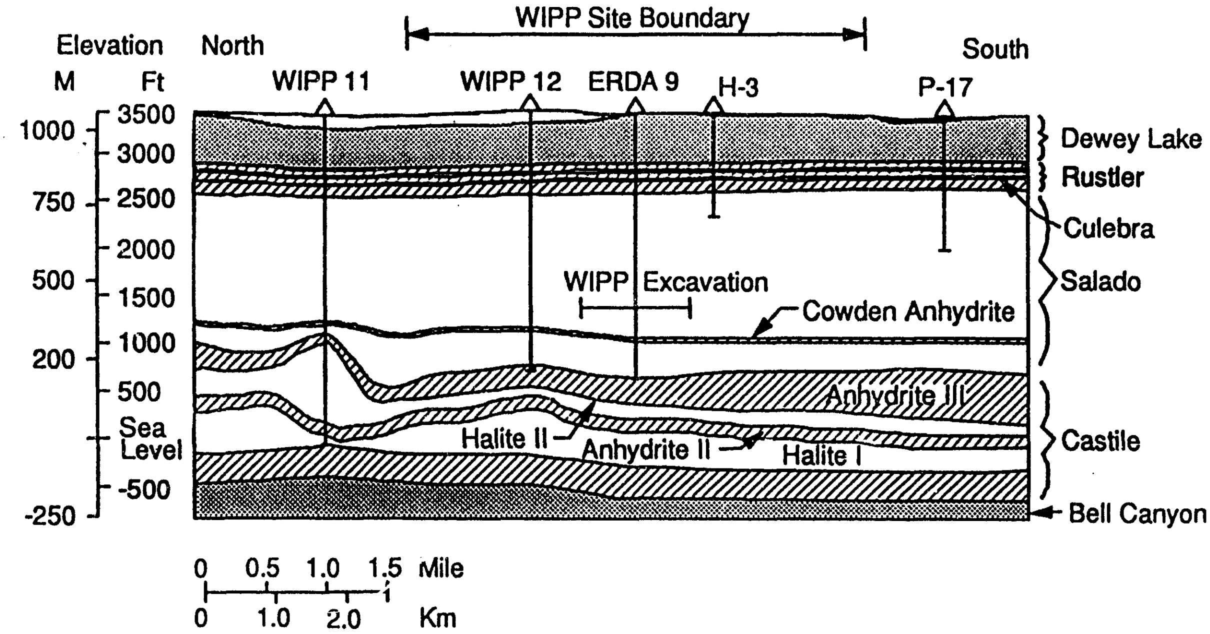

Figure 4. North-south cross section (i.e. "vertical slice") in the WIPP region.

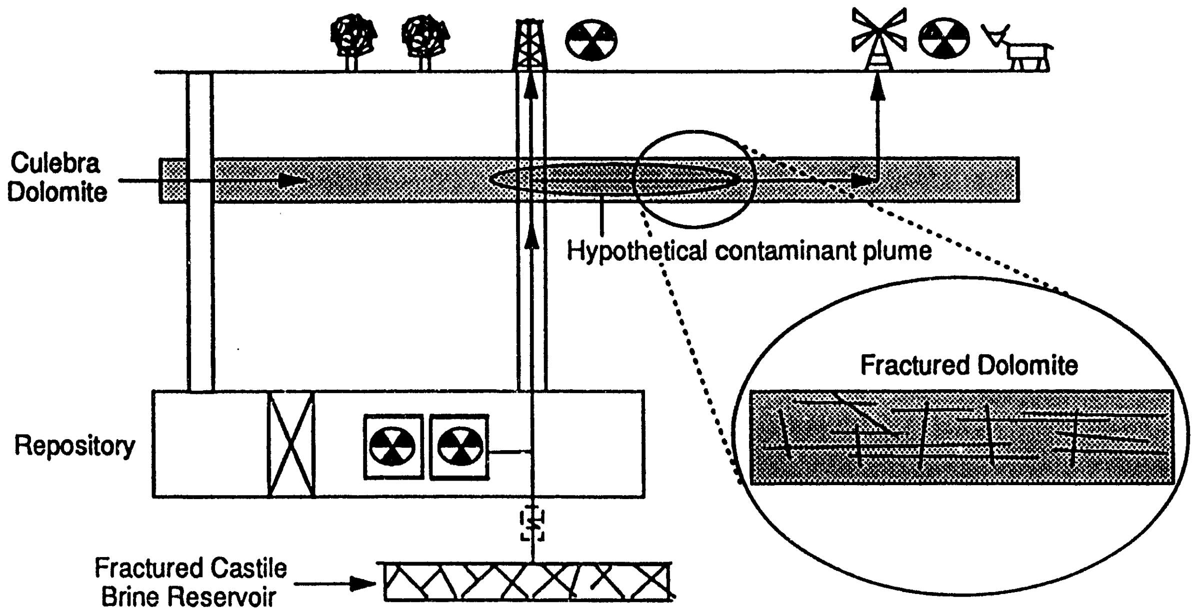

Figure 5. Schematic illustration of the human intrusion scenario. [not to scale]

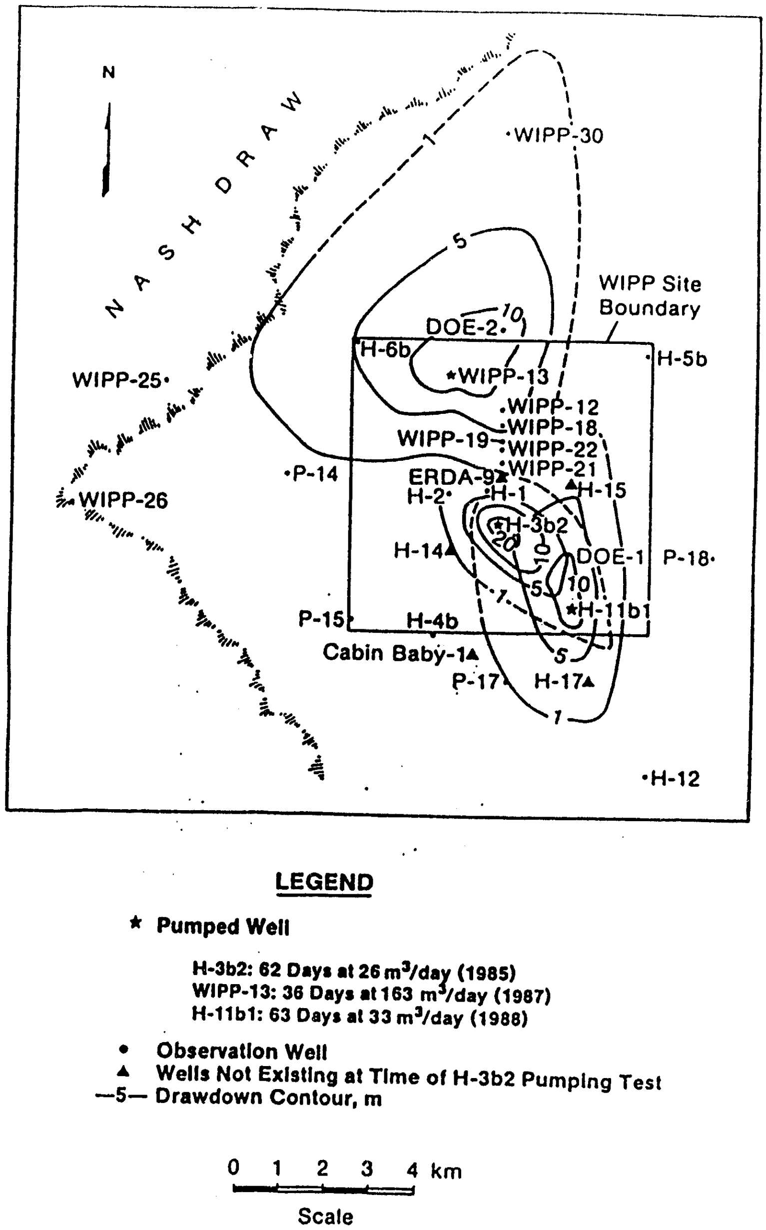

Figure 6. Water level draw downs from three large-scale pumping tests in the Culebra Dolomite.

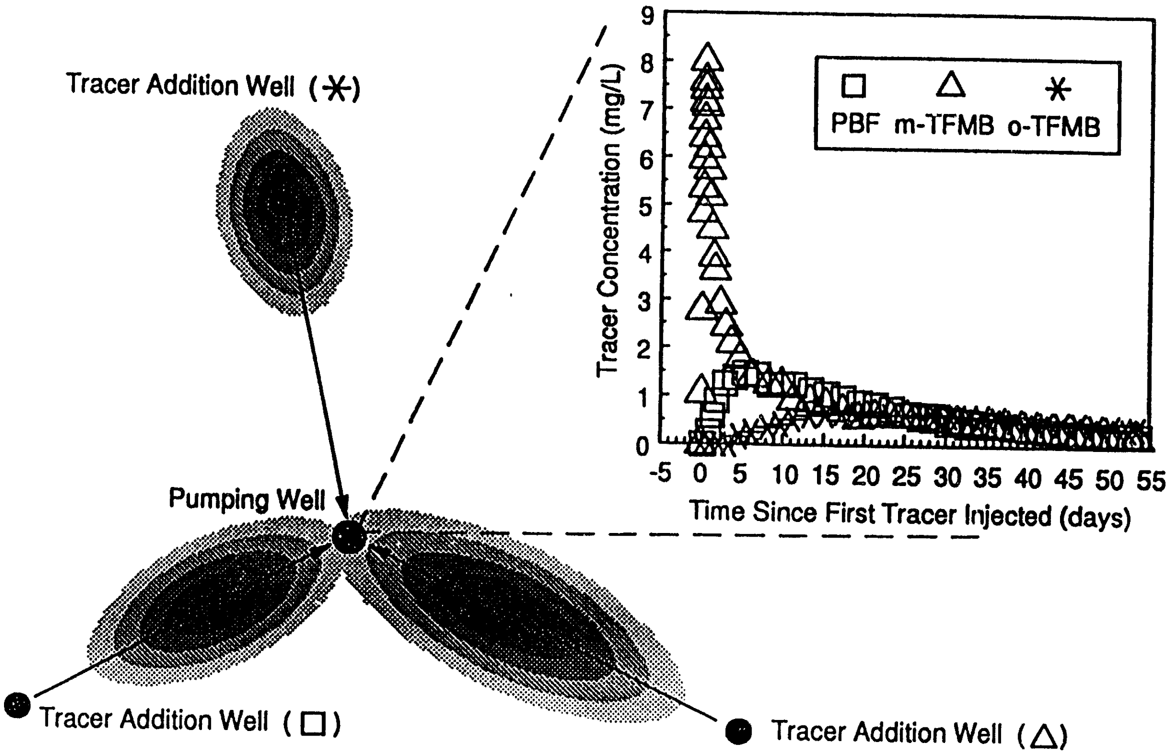

Figure 7. Schematic illustration of a converging flow tracer test.

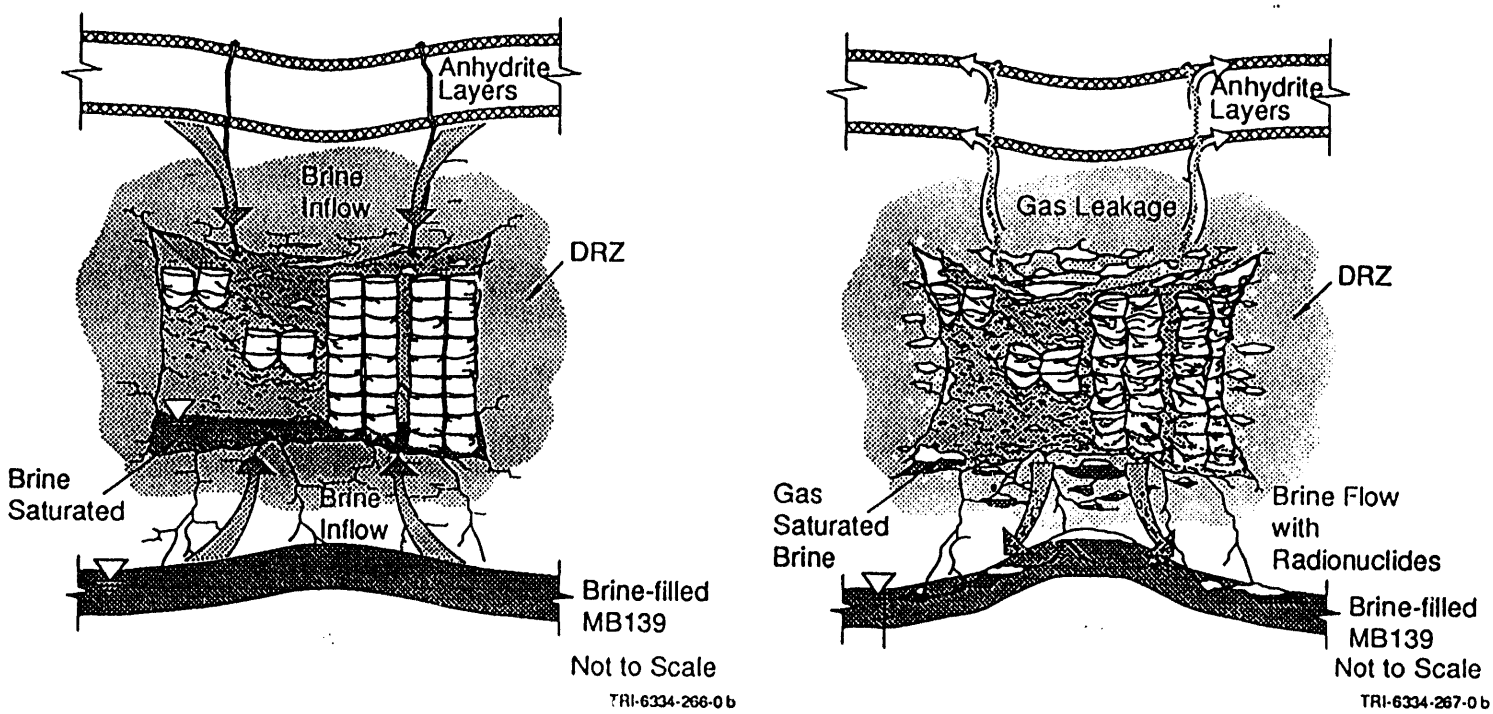

Figure 8. Schematic illustrations of room closure and brine inflow early in the post-closure time period (A) and brine and gas outflow at a later time in response to gas generation by corrosion and/or microbial processes.

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