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# Summary Evaluation of the Waste Isolation Pilot Plant (WIPP) Site Suitability

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# **Summary Evaluation of the Waste Isolation Pilot Plant (WIPP) Site Suitability**

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## **Abstract**

Geotechnical studies oriented toward selecting a radioactive waste disposal site began in southeast New Mexico in 1972. These geological studies have focused on the present WIPP site since November 1975 and have been accompanied by investigations of the ecologic and socioeconomic environment. Surface-based geotechnical investigations have relied heavily on geologic mapping, on geophysical exploration techniques, and on drillholes for confirmation of interpretation, core examination, and acquisition of hydrologic parameters. These studies have now been supplemented by direct examination and measurement of the subsurface geology in two shafts and in several thousand feet of mined drift at the depth selected for the WIPP. Additional studies are not likely to change significantly the level of confidence that now exists with regard to the suitability of the WIPP site. Consequently, Sandia has now evaluated the information available on the WIPP site and, in this report, summarizes the information and judgments reached for each of the 21 site qualification criteria. The site satisfies the intent of all the site criteria. Sandia recommends, without reservation, the use of the Los Medanos site for the WIPP.

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# Summary Evaluation of the Waste Isolation Pilot Plant (WIPP) Site Suitability

## Introduction

Sandia National Laboratories (SNL) has had responsibility since 1975 for site evaluation studies for the US Department of Energy (DOE) on the Waste Isolation Pilot Plant (WIPP). These studies now allow sound professional judgments regarding how well the WIPP site meets the site qualification criteria and associated siting factors. Additional study is not likely to result in major changes in the confidence levels associated with these judgments; consequently, SNL is providing a final recommendation to the DOE regarding the suitability of the WIPP site.

Two previous interim recommendations were made to the DOE. The first<sup>1</sup> was in December 1978 at completion of the Geological Characterization Report.<sup>2</sup> This recommendation concluded that the geotechnical knowledge of the site after 3 years of study provided adequate confidence to justify proceeding with planning for the WIPP in the Los Medanos area. It also recognized a need for additional study to further quantify certain parameters and to understand the geological processes responsible for certain of the observed phenomena. The second recommendation<sup>3</sup> was provided to DOE in October 1980 after an additional 2 years of geotechnical study that focused on issues identified in the first recommendation as needing more evaluation. This recommendation stated that "The studies conducted since August 1978 have provided additional confidence that the existing hydrology, geology and the on-going geologic processes will not endanger the repository operation or its long-term ability to isolate radioactive wastes from the biosphere." The 1980 report recommended continued consideration of the Los Medanos site for the WIPP, reiterated the conflict with natural resources

noted in the first recommendation, and urged completion of surface-based studies and initiation of subsurface horizontal investigations of the proposed WIPP horizon.

This document, SNL's final evaluation of the suitability of the WIPP site, addresses all the siting factors listed in the Geological Characterization Report<sup>2</sup> and in the Final Environmental Impact Statement.<sup>4</sup> These factors were reformulated in the Site Validation Program<sup>5</sup> in a format more consistent with that of the National Waste Terminal Storage (NWTS) commercial waste management program; this document follows that outline. This document briefly summarizes the relevant facts pertaining to the siting factors, indicates whether in Sandia's judgment the factors are satisfied, and, for those more contentious factors provides a technical discussion and judgment on whether a significant threat exists to site integrity or public safety. The reader is referred to appropriate reports for detailed presentations and discussions of supporting data.

## Background

The history of site selection for WIPP began in 1955 when the US Atomic Energy Commission (AEC) (now the US DOE) asked a committee of the National Academy of Sciences to examine the issue of permanent disposal of radioactive waste. This committee concluded<sup>6</sup> that "the most promising method of disposal of high level wastes (HLW) at the present time seems to be in salt deposits." This recommendation led the AEC to sponsor several years of research at the

Oak Ridge National Laboratory (ORNL) on phenomena associated with the disposal of radioactive wastes in salt. In 1962 the US Geological Survey (USGS)<sup>7</sup> reported on the distribution of salt deposits in the United States that might be suitable for such disposal. The Permian Basin, which includes the Delaware Basin in southeastern New Mexico and large areas in Kansas, west Texas, and Oklahoma, was one of the areas discussed. In 1963, ORNL research expanded to include a large-scale field program in which irradiated nuclear fuel elements, supplemented by electric heaters, were placed in Permian salt beds in an existing salt mine at Lyons, Kansas. These studies, called Project Salt Vault,<sup>8</sup> supported the use of salt beds for radioactive waste disposal, and in June 1970 the Lyons site was selected by the AEC as a potential location for a repository. The selection, however, was conditional on satisfactory resolution of site-specific issues then under study. In 1972 the Lyons site was judged unacceptable for the following technical reasons:

- There were previously undiscovered drillholes nearby that, it was feared, could lead to extensive dissolution of salt
- Water injected as part of a nearby solution-mining operation could not be fully accounted for

The Lyons site was then abandoned, and a nationwide search for a suitable salt site began,<sup>9-15</sup> ending with the selection by the USGS and ORNL of a portion of the Permian Basin in New Mexico as best meeting their site selection guidelines. Four locations within this area were examined in more detail<sup>16-20</sup> and, from these four potential locations, a location 30 miles east of Carlsbad, New Mexico, was chosen for exploratory work. Field investigations began in March 1974 with the drilling of core holes AEC 7<sup>21</sup> and AEC 8.<sup>22</sup> Field work was suspended after a shift in program emphasis by the AEC in May 1974. SNL received program funding to continue field investigations in March 1975, and field work recommenced with the drilling of ERDA 6<sup>23</sup> in May 1975. ERDA 6 encountered unexpected subsurface geologic conditions. Formation contacts were much higher than anticipated, and the Castile salt and anhydrite beds exhibited severe distortion. Fractured anhydrite at a depth of 2710 feet contained pressurized brine. The complexity and unpredictability of the geologic structure at this site ruled out its use, and site selection began anew. Siting guidelines were reexamined at this time, and two

major changes were adopted.<sup>2</sup> An additional site selection guideline required the site area to be at least 6 miles from the Capitan Reef front to avoid the zone of most intense Castile deformation. The other change relaxed the exclusion radius for deep boreholes, penetrating through the evaporites, from 2 miles to 1 mile. This latter change was made possible by the knowledge gained about the hydrology of the northern Delaware Basin aquifers and by studies of possible salt dissolution around boreholes.<sup>24-26</sup>

The New Mexico portion of the Delaware Basin was reexamined for more suitable site areas by both the USGS and SNL. On November 14, 1975, the USGS recommended for further examination an area about 7 miles southwest of the original site identified by ORNL. SNL had independently selected the same area as the most promising for a repository site. Abundant geologic data were available for this region from oil and gas wells and from shallow drillholes used to explore for potash. In a regional study, the USGS found that dissolution of the top of Salado salt (the formation of interest for facility development) was distant enough from the proposed site to pose little, if any, threat to the WIPP. A 3-square-mile underground facility could be located to avoid the known potash area (KPA) and to be at least 1 mile from all boreholes penetrating through the salt. No private land and less than three sections of state land were present in the potential withdrawal area. A stratigraphic core hole, ERDA 9, was started in parallel with geophysical studies of the area. ERDA 9, drilled in the center of the area under study, revealed normal stratigraphy and the desired flat bedding (dips are about 75 feet/mile).<sup>27</sup> Physical properties of the salt beds were satisfactory;<sup>28</sup> beds at depths of about 2100 and 2600 feet were selected as appropriate for TRU and heat-generating wastes, respectively.

NOTE:—While the principal mission of WIPP has always been to dispose of defense TRU waste, during the early stages of site selection the AEC/ERDA wished to maintain an option for HLW disposal at the selected site. Consequently, the site selection program did consider this option. A deeper, thicker, and purer salt unit was selected for HLW emplacement to minimize the unknowns of the interaction of heat-producing waste with salt beds having more impurities and more closely spaced interbeds. The more recent site studies have not examined the needs or consequences of HLW disposal at WIPP because HLW disposal was removed from the WIPP mission by Congressional authorization. The WIPP in situ test program will, however, consider the effects of heat-producing waste in the less pure salt beds selected for TRU emplacement.

An extensive program of site evaluation and laboratory investigation was begun to fully characterize site properties and to understand the geologic processes relevant to site suitability.

A final element of background information on the site evaluation studies is a brief discussion of major exploratory techniques. Extensive geologic mapping<sup>29,30</sup> and correlation of borehole data provide a solid geological base for interpreting geophysical surveys. More than 350 petroleum industry boreholes penetrate the evaporites in a 900-square-mile area centered on the WIPP site, and many potash exploration holes penetrate into the middle unit of the Salado Formation. About 280 of the most pertinent of these holes were cataloged by computer, and divers structure and isopach maps were prepared to aid in understanding salt-dissolution and salt-deformation issues. These industry borehole data, together with about 1500 line miles of petroleum-industry seismic reflection data and regional gravity and aeromagnetic surveys, were readily available before starting detailed site characterization. The DOE drilled 78 boreholes (including the two shafts), totaling 113 646 feet of hole and 29 397 feet of core, specifically for evaluating the WIPP site. More than 40 of these holes were used to acquire hydrologic data for establishing conceptual models of the site and regional hydrology.<sup>31</sup> Hydrologic data for aquifers in the Delaware Mountain Group were obtained principally from industry holes,<sup>32</sup> but were confirmed by a few deep WIPP holes (AEC 7, 8; ERDA 10) drilled near the site. Special techniques, including tracer tests, were used to refine our knowledge of the Rustler aquifers and to establish more definitive parameters for the hydrologic modeling.<sup>33</sup>

A wide variety of geophysical exploration techniques was used to examine the WIPP site,<sup>34</sup> with seismic reflection profiling the most useful. Industry data, useful in defining geologic structure deeper than 4000 feet, were of limited use for shallower depths. About 195 line miles of reflection were run for WIPP to evaluate structure within the evaporites. In addition, a special high-resolution reflection survey of 2.3 miles was conducted to see whether it would improve discrimination in the Salado Formation. It did not, primarily because of surface noise interference. Five miles of refraction data were acquired, principally to provide information on the near-surface velocity variations for use in reducing the reflection data. Electrical resistivity was also used extensively, with a closely spaced set of gradient array measurements (more than

9000 data points) made over the entire site area. Schlumberger soundings were also made in selected regions to investigate changes in resistivity with depth. Resistivity was particularly useful in screening the site region for solution features, such as breccia pipes, that might not have topographic expression. A developmental technique, controlled-source audio-frequency magnetotelluric (CSAMT), was applied in a limited fashion to describing the geometry of a brine reservoir.<sup>35,36</sup> While the method holds promise, it cannot be relied upon at this stage of its development for definition of brine reservoir geometry. Available gravity and aeromagnetic surveys were purchased for the WIPP site and environs. A high-precision ( $\pm 0.02$  milligal) gravity survey covering about 9 square miles was conducted to evaluate its usefulness in mapping structure in the deformed Castile north of the WIPP site.<sup>37</sup> Lateral density variations in the overlying, shallower rocks mask any gravity anomalies produced by deformation in the Castile, but some small-scale anomalies of shallow origin were observed. Available aeromagnetic data are adequate to search for and rule out any igneous dikes in the WIPP area similar to the one mapped magnetically and by direct observation some 11 miles west and north of the WIPP.<sup>28</sup> Limited ground-base magnetic surveys were run to search for faulting/subsidence of the Dewey Lake Red Beds. The National Geodetic Survey (NGS) has established several level-line benchmarks in the WIPP region. These will be periodically reoccupied to monitor long-term vertical motions at and near WIPP.

In addition to the extensive field program, laboratory geochemistry,<sup>38-42</sup> physical property determinations,<sup>43,44</sup> and petrologic studies<sup>45</sup> have played an essential role in understanding the nature and origin of dissolution and deformation features in the WIPP region.

## Qualification Criteria and Factors for Evaluating the WIPP Site

The WIPP site investigations have been guided by an established set of site selection criteria.<sup>2</sup> These criteria, and the factors that address the criteria, are listed in this section. The criteria are broad statements of desired conditions and must be addressed in

practice by identifying and quantifying pertinent site factors. When this has been done, a judgment can be made on how well the criteria are satisfied. The basic criteria listed below are from the WIPP GCR;<sup>2</sup> more specific site evaluation factors are from the Site Validation Program document.<sup>5</sup> The site evaluation fac-

tors have been restructured (and renamed Site Qualification Criteria) in this document to conform more closely with the format used in the commercial waste-management program<sup>46</sup> for easier comparisons. Regardless of source or format, all the same site qualification factors and issues are addressed.

## **Listing of Site Criteria and Qualification Factors**

### **Site Criteria**

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

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

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

**Physical-Chemical Compatibility**—The repository medium must not interact with the waste in ways which create unacceptable operational or long-term hazards.

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

The specific site qualification factors which must be examined in order to assess how well these criteria are fulfilled are listed as follows.

### **Site Qualification Factors (Criteria)<sup>5</sup>**

#### **1.0 Topography**

The site must:

- 1.1 Permit access for transportation.
- 1.2 Possess relief low enough to avoid significant differences in lithostatic stress at waste disposal level.
- 1.3 Preclude inundation from surface floods.

#### **2.0 Depth**

The waste disposal horizon must be:

- 2.1 Deep enough to remain below the influence of surficial phenomena (infiltration of surface waters, erosion/denudation).
- 2.2 Within the depth where lithostatic stresses will not produce excessive rock deformation rates.

#### **3.0 Thickness of Host Rock**

The thickness of waste disposal host rock must be sufficient to:

- 3.1 Provide a thermal and mechanical buffer zone above and below the facility.



#### **4.0 Lateral Extent**

The lateral extent of the waste disposal host rock must be sufficient to:

- 4.1 Provide the required lateral continuity and distance from the disposal facility to structural or erosional breaches or dissolution boundaries.

#### **5.0 Lithology**

The lithology of the waste disposal host rock must:

- 5.1 Be relatively low in brine content with respect to any horizon selected for heat-producing waste experiments.
- 5.2 Be relatively pure mineralogically to reduce the chemical interaction which must be considered.

#### **6.0 Stratigraphy**

- 6.1 The individual beds of rock in the disposal zone must be continuous enough to permit location of the facility at essentially one stratigraphic horizon.
- 6.2 The location and characteristics of interbedded materials, such as clay, must not preclude construction of stable excavations nor provide transport pathways which would significantly reduce the containment capacity of the waste disposal rock.

#### **7.0 Structure**

- 7.1 The site shall be free of active or capable faults.
- 7.2 The dips of strata at the disposal level shall not exceed the acceptable grade for excavations unless the stratigraphy/lithology allow construction of the disposal facility in beds either side of the selected horizon.

#### **8.0 Dissolution**

- 8.1 The disposal horizon must be free and remain free from dissolution for at least 10,000 years, based upon rates of dissolution determined from an assessment of previous rate of dissolution.

#### **9.0 Subsidence**

- 9.1 Subsidence caused by dissolution or mining should be avoided if it adversely affects the waste facility.

#### **10.0 Surface Water**

- 10.1 The site must be free of flooding hazard which could affect unplugged penetrations to the waste facility.

#### **11.0 Groundwater**

- 11.1 Facility and related shafts must not adversely affect existing aquifers which are, or could be, sources of water supply for humans or animals.
- 11.2 The underground facility must be able to be isolated from waterbearing strata and must not, itself, be located in a water-bearing stratum (stratum which will yield water to a drillhole under the influence of gravity alone).
- 11.3 The hydraulic conductivity of the facility stratum must be sufficiently low ( $10^{-6}$  cm/sec or less) to prevent flow of water through that stratum from any source which could develop after facility construction.
- 11.4 Calculated hydrologic transport of radionuclides through the waste disposal facility and overlying strata must be slow enough that a significant hazard to humans would not exist even if the disposal stratum were breached.

## **12.0 Tectonic Stability**

- 12.1 The magnitude of maximum historical seismic events must demonstrate a low seismic risk to the site.
- 12.2 Major faults and pronounced linear structural trends should be avoided.
- 12.3 Major flow structures (anticline) should be avoided or evaluated for presence of brine.
- 12.4 Diapirism will be avoided for WIPP siting.
- 12.5 Areas of active regional uplift or subsidence should be avoided.
- 12.6 Areas of active or recent volcanism or igneous intrusion should be avoided.
- 12.7 Areas of high geothermal gradient should be avoided.

## **13.0 Physical-Chemical Compatibility**

- 13.1 The disposal stratum should not contain more than 3% water content.
- 13.2 Beds of unusual composition and/or containing minerals with bound water should not occur within 20 feet of the waste horizon.
- 13.3 The mineralogy of the disposal horizon rock must not be chemically reactive with the waste or waste packages in a way that will reduce the effectiveness of the rock as a barrier to nuclide transport.
- 13.4 Radiation effects must not compromise the effectiveness of the disposal horizon rock as an enclosing medium.

## **14.0 Natural Resources**

- 14.1 The site should be located so that losses of natural resources are reduced to acceptable levels, which shall be determined by the value of the resources and alternative sources of those commodities.

## **15.0 Man-Made Penetrations**

- 15.1 Boreholes or shafts which penetrate through the disposal level to underlying aquifers should be at least 1 mile from the facility.

## **16.0 Transportation**

- 16.1 Transportation routes should be capable of satisfying transport needs to the site with ready development. Transportation routes should avoid population centers as much as possible.

## **17.0 Accessibility**

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

## **18.0 Land Acquisition**

- 18.1 The site should be located on federal land to the greatest extent possible.

## **19.0 Population Density**

- 19.1 The site should be located in a low population area.

## **20.0 Ecological Effects**

- 20.1 The site should not contain ecological conditions, the disruption of which is irreversible or uncontrollable due to construction or operation of the facilities.
- 20.2 Archaeological and historical features of significance should be preserved.

## **21.0 Sociological Impacts**

- 21.1 Construction and operation of the facility at the selected site should not create unmanageable impacts on local governmental, educational, or social institutions.

Before discussing the WIPP site in relation to these criteria, a few comments are in order.

- First, very few of the qualification factors, by and of themselves, disqualify a site. The reason is that assurance of waste isolation relies on the synergy of many factors; one (or a few) unsatisfied factor can often be adequately compensated for by other favorable factors. Only an unsatisfied factor that clearly leads to failure of isolation or that is in opposition to DOE policy would result in *a priori* site rejection. For the same reason it is usually inappropriate to establish quantitative limits for the site factors. These factors may be considered as favorable or unfavorable, or as sufficient but perhaps not necessary for site acceptability.
- Second, these factors were prepared at a time when the WIPP mission considered the possibility of HLW disposal and therefore had to include the aspects important to long-term irradiation and to high-temperature effects. These factors, while they will be addressed (and identified), do not apply to TRU waste isolation.
- Finally, these factors were developed and are worded to apply to sites in the bedded salt of the Delaware Basin. Without omitting any of the generic guideline aspects, they are specific to the WIPP geologic and geographic environment. WIPP siting factors should not be applied to other locations and to other geologic settings. The recently published DOE Draft Siting Guidelines,<sup>47</sup> which apply only to siting of commercial HLW repositories, have been examined; the WIPP siting factors are consistent with these guidelines in scope and intent.

## Examination of the WIPP Site Qualification Factors

### 1.0 Topography

The elevation at the WIPP site (Zones I, II, and III) ranges from about 3310 feet at the southwest corner to 3550 feet at the eastern edge. This variation is generally smooth (about 50 feet/mile) over the site, with surface sandhills contributing local relief of up to 20 feet. Nash Draw is the major surface relief feature in the surrounding area. It is a shallow valley 5 miles

wide and some 200 to 300 feet lower than the surrounding terrain. Its eastern boundary, Livingston Ridge, forms a west-facing escarpment that may reach a height of 75 feet in places. The site is about 500 feet above the Pecos River at its closest point, about 14 miles southwest of the site.<sup>2,4,48</sup>

This relief presents no problems for access by road or rail, and variations at depth in overburden stress resulting from the local relief are too little to initiate deformation of the salt at depth. No floods or impoundments, now or in the future, will adversely affect the site. Drainage channels that might develop in future pluvial periods would probably follow existing topographic lows without affecting the WIPP site.

The WIPP site is well qualified with respect to the criterion on topography.

### 2.0 Depth

The WIPP facility will be excavated at a nominal depth of 2160 feet below the surface. This depth will vary several tens of feet over the extent of the underground facility. These depths assure that casual surface activity will not influence the facility containment. Even possible future potash extraction or exploration would not adversely affect the WIPP site integrity since it would take place about 400 feet above the facility level.<sup>2,48,49</sup> The depths, both of the facility and to the Salado Formation, assure that erosion will not adversely affect the WIPP. Experience and modeling both assure that safe mining can take place at this depth and that room closure rates will be well within acceptable bounds.<sup>50,51</sup>

The WIPP site is qualified with respect to the criterion on depth.

### 3.0 Thickness of Host Rock

The interval of halite selected for excavation of the facility is about 75 feet thick. It is bounded on the top by a bed of argillaceous halite and on the bottom by an anhydrite marker bed (MB 139) that has an undulatory upper surface varying up to 20 inches in elevation. Within this interval are several clay seams. In the first 27 feet above MB 139 there are no major clay seams or partings.<sup>52</sup> Consequently, to facilitate mining operations and minimize support requirements, the excavated interval will be placed with its floor about 5 feet above MB 139.

The thickness of the host rock is sufficient to contain the excavated rooms and drifts for TRU emplacement and to provide a stable rock-mechanics

environment for operational safety. Since there is no significant heat from the TRU waste, thermal considerations are not a factor. To conduct the simulated defense high-level waste (DHLW) experiments, the test room will be excavated above the 27-foot-thick interval of salt, thus allowing the waste to be emplaced in the center of this salt unit. The 27-foot thickness eliminates undesired effects of interbeds during the experiment. Clay seams at the upper room level will allow investigations of the rock mechanics effects of these preferred assumed planes of weakness on stability of the rock mass.

The factor of host-rock thickness was originally included to assure availability of a horizon where it was not necessary even to consider the effects and behavior of nonhalite interbeds subjected to higher temperatures. One benefit from the WIPP in situ experiments will be a determination of whether stratigraphic uniformity must be considered in siting a DHLW repository in salt.

The WIPP site is qualified with respect to the criterion on thickness of host rock.

#### 4.0 Lateral Extent

The Salado Formation and the stratigraphic interval within the Salado where wastes will be emplaced both extend for many miles in all directions from the WIPP site.<sup>2</sup> The regional dip brings the Salado nearer the surface west of the site. Much of the Salado salt west of the WIPP site, where it rises near the surface, has been removed by groundwater dissolution. In the vicinity of US Highway 285, the Salado halite is completely absent.<sup>29</sup> More proximate to the WIPP site are other features used as lateral extent site selection factors:<sup>2</sup> (1) deep boreholes extending through the evaporite sequence, (2) the edge of the Capitan Reef, and (3) the position of the dissolution front at the top of the Salado. Conservative separation distances from each of these features of 1, 6, and 1 mile, respectively, were selected to minimize concern for dissolution and deformation at the facility level. The WIPP site was selected specifically with these criteria in mind.<sup>2,28</sup>

The WIPP site is qualified with respect to the criterion on lateral extent.

#### 5.0 Lithology

The lithology of the host rock is a significant siting factor principally for disposal of heat-producing

HLW. The brine content of the host salt has posed a concern since brine migration in the thermal field became an issue in the early 1970s. These concerns focused on corrosion and/or mobilization of waste canisters due to accumulations of brine at or near the canister. As a result of several studies,<sup>53,54</sup> this issue is no longer considered a significant threat to an HLW repository. Even before this conclusion, an average brine content of 3% was considered acceptable. The WIPP horizon has a measured brine content varying between 0.05% and 1.8%.<sup>52</sup>

It has also been considered desirable to have a relatively pure salt host rock immediately surrounding HLW. This was simply to avoid addressing the multitude of radiological and chemical interactions present in a complex mineralogy, and to enhance our ability to understand and model physical and chemical behavior of the system. This is still a valid position. A "dirty" salt containing argillaceous material, however, may actually be a preferable disposal medium because of increased sorption of isotopes by the clay fraction.<sup>55</sup> The DHLW experiments in WIPP will allow examination of this issue to some degree, since the salt at this level is not quite as pure as the deeper horizon once chosen for HLW disposal. Nevertheless, the host rock for WIPP is relatively clean halite. An average of samples taken from the SPDV exploratory drift shows less than 1.5% water-insoluble impurities. Petrologic examination indicates that the soluble fraction is preponderantly halite with less than 5% non-halite soluble minerals.<sup>52</sup> These low levels of non-halite mineralogy are acceptable for disposal of TRU waste and for experiments with DHLW and would be acceptable even for HLW emplacement.

The WIPP site is qualified with respect to the criterion on lithology.

#### 6.0 Stratigraphy

It is desirable, in a bedded-salt disposal facility, to construct the entire underground facility in the same rock unit that was selected for its favorable lithology. Continuity of the salt beds allows this at the WIPP site.<sup>2,52</sup> Mining of the Site and Preliminary Design Validation (SPDV) drifts has shown that the same salt unit can be followed reliably over a 5100-foot north-to-south distance. Thousands of miles of drift in potash mines in the northern Delaware Basin also provide confidence in the continuity and predictability of the stratigraphy.

The presence of clay seams or interbedded materials, such as anhydrite or polyhalite, may pose an operational concern if they act as failure planes in or near the excavations. Such interbeds are routinely encountered and accommodated by mining operations in bedded salt. The SPDV has demonstrated that the WIPP excavations can be constructed without undue operational problems and with minimal support. The WIPP rooms will have a nominal 10-foot back without any major interbeds. Interbeds must also be evaluated with regard to their potential role in providing preferred pathways for fluids into or out of the TRU waste rooms. There are no such major interbeds within the horizon to be excavated for the TRU waste rooms. The nearest interbeds of significance are 10 feet above and 5 feet below the room. The permeability of the salt<sup>52</sup> is low enough to prevent any connection between these interbeds and the waste rooms. The permeability of the interbeds is also quite small.<sup>52</sup> Gases, predominantly nitrogen, do occur in some clay seams. The potash mines routinely drill relief holes at drift intersections to relieve gas pressures. The presence of pressurized gas is itself an indication of permeabilities low enough to provide long-time confinement. Consequently, the WIPP horizon is not expected to present a concern relative to interbed pathways of low permeability.

The WIPP site is qualified with respect to the criterion on stratigraphy.

## 7.0 Structure

This factor specifically refers to the existing structural conditions at or near the site. (Ongoing processes and salt deformation are considered under 12.0, Tectonics.) If there are recently active faults near the site, this would have implications for seismicity and its effects on operations. Active or inactive faults also might represent permeable zones through which water could reach the waste and perhaps transport it to the biosphere. There are no known Quaternary (less than 2 million years old) tectonic faults nearer than the west side of the Guadalupe Mountains, about 65 miles away.<sup>2,56,57</sup> The region near the WIPP site is typically aseismic (see 12.0, Tectonics). Possible faults in the older rocks, inferred from seismic reflection and from some deep drillholes,<sup>58</sup> have been demonstrated not to cut the upper Salado and Rustler and thus have not been active in the last 200 million years. Even if fault

offsets were to occur all the way through the evaporites, salt has a major advantage over other potential host rocks since its physical properties effect sealing of potential pathways by creep and/or recrystallization. The WIPP site is not threatened by any known active or inactive faults.

Another structural aspect to consider is the attitude of the beds in which the facility will be excavated. This is primarily an operational factor that assumes a desire to stay entirely within a chosen unit of rock. There is no firm value for allowable dips, but 3° is clearly acceptable for mining. The WIPP facility will be in beds with an average dip of less than 2°.<sup>2,52</sup>

The WIPP site is qualified with respect to the criterion on structure.

## 8.0 Dissolution

Salt, as compared to most other rocks, is relatively soluble in water. Consequently, dissolution of salt by circulating groundwater is an obvious concern in assuring adequate longevity of the salt beds encapsulating the waste. Dissolution in the Delaware Basin has often been thought of as occurring in one or more of three possible modes: (1) regional (or blanket) dissolution at the top of the evaporites (often called "shallow" dissolution), (2) regional dissolution at depth, within or at the bottom of the evaporites (often called "deep" dissolution), and (3) local dissolution features, such as breccia pipes that originate at or beneath the base of the evaporites or sinks, which originate at the top of the evaporites. This distinction does not necessarily imply a difference in the process causing the dissolution, but rather comes about because the investigations to examine each of the modes have been separate and distinct programs.

It is relatively easy to establish whether any of these dissolution phenomena exist at a particular site; both drilling and geophysics were used to address this issue. And there is general agreement on the degree to which such phenomena currently exist at the WIPP site. This issue is contentious, however, because dissolution may be an active, ongoing process requiring prediction into the future. This means that the rates and processes must be understood, or at least bounded, to provide adequate assurance of site integrity. Each of the three dissolution processes is addressed here separately.

## Shallow Dissolution

Shallow dissolution of Rustler and Salado evaporites has long been recognized in the Delaware Basin. In 1974 the USGS estimated the extent and rate of shallow dissolution.<sup>59</sup> These estimates are derived from observations in Nash Draw, the nearest area of active dissolution. Studies of salt loading in the Pecos River also provide a method of estimating the current rate of shallow dissolution.

Bachman<sup>29</sup> considers Nash Draw to have formed as a result of dissolution and erosion that began before or during Gatuña time, about 600 000 years ago, and that are continuing today. Bachman ascribes the origin of Nash Draw to the following process:

- Initial dissolution occurs along surficial joints and fractures in gypsum, forming tunnels and caves in dendritic patterns
- Sediments are then carried into these dissolution cavities by erosion
- Continued dissolution within the central drainage system increases the stream gradient and results in headward cutting by erosion
- Nash Draw widens further as a result of the dissolution of halite and gypsum

These processes combined to produce a topographic feature with a greater width-to-length ratio than found in normal erosional valleys. The processes that form Nash Draw are active mostly in the Rustler Formation and at the top of the Salado, with the dissolution front progressing west to east in these horizons.

The rates of dissolution were estimated to evaluate the potential hazard to the site of continued dissolution in places such as Nash Draw. Since Mescalero time, about 600 000 years ago, Nash Draw appears to have subsided between the flanking Livingston and Quahada Ridges as much as 180 feet. At one place its surface is 180 feet below the projected elevation of the Mescalero caliche. However, the interval between the top of the Salado Formation and the top of Marker Bed 124 in the middle of the Salado at the same location is 420 feet, or 330 feet less than at Livingston Ridge, where relatively little of the Salado salt has been removed. It is concluded that about 150 feet of the Salado salt was removed before Mescalero time and about 180 feet since. With this in mind, Bachman<sup>59</sup> analyzed the dissolution in Nash Draw as having occurred since the development of the Mescalero

caliche, 600 000 years ago, and found that the average vertical-dissolution rate was about 330 feet per million years.

This rate is neither constant through geologic time nor the same throughout the region. At least two other factors must be considered:

- Dissolution and subsidence rates have probably not been constant in Nash Draw during the past 600 000 years. Much of the subsidence may have occurred during periods of higher rainfall in the late Pleistocene (Wisconsin time). Bachman estimates the annual rainfall at no more than 25 to 30 inches or less during this time, the conditions necessary for the formation of the Mescalero caliche.
- Rate of subsidence in Nash Draw, whenever it occurred in the Pleistocene, does not apply to the whole region. From the western part of the WIPP site to the area of Quahada Ridge east of WIPP, the Mescalero caliche is relatively undisturbed, suggesting no extensive regional or local differential dissolution since Mescalero time.

An alternative approach to the estimation of dissolution rates<sup>12</sup> estimated that the maximum amount of salt dissolved and discharged by springs and streams along the east flank of the Pecos River basin is 955 tons per square mile each year. This gives a present vertical-dissolution rate of about 500 feet of salt in 1 million years.

The estimated horizontal rate of the shallow dissolution front in the western part of the Delaware Basin is about 6 to 8 miles per million years toward the east, based on the assumption that at the end of Ogallala time (late Miocene to Pliocene) the soluble evaporites within the Salado Formation extended to the Capitan Reef escarpment on the western edge of the basin. Bachman,<sup>29</sup> recognizing that salt dissolution also occurred earlier than Ogallala time, concludes that this estimated average rate of salt removal by shallow dissolution is an overestimate.

Bachman has determined that semiarid climates must have prevailed in southeastern New Mexico for the last 600 000 years. This conclusion is based on the climatic conditions under which the Mescalero caliche, which began to be deposited about 600 000 years ago, could be formed and preserved as it is over the WIPP site. This indicates a relatively stable environment over that period. Thus, although there were

significant climate-caused geologic changes elsewhere in the United States during that time, there were no significant geologic effects at the WIPP site. The normal pluvial cycle has a 10 000- to 20 000-year period; thus several of these would be included in any determination of past dissolution rates and would therefore be factored into future expectations as well.

These estimates of horizontal and vertical dissolution rates suggest that the waste in the WIPP could be expected to remain isolated from dissolution effects for at least 2 to 3 million years.

## Deep Dissolution

Deep dissolution has been proposed by some investigators as a threat to the salt beds at the WIPP site.<sup>60-62</sup> Isolated, local features such as breccia pipes are considered by these authors as forerunners of the more general advance of the deep dissolution front, with the lower Salado the most susceptible formation to dissolution based on their log correlations. They initially postulated that dissolving fluids would enter from and depart by the Delaware Mountain Group (DMG) aquifer. "Gradient density flow" is the assumed mechanism for this flow, which gains access to the halite through faults or fractures in the Castile and DMG. Further, the removal of salt is postulated as relatively rapid. Local and basin-marginal thinning of salt units in the Castile/Salado is interpreted as a result of halite removal by dissolution. This is coupled with an interpretation that over 70% of the original lower Salado salt has been removed from the basin, mostly in the late Cenozoic.

Several studies were made to examine these hypotheses.<sup>29,63,64</sup> Salient points that represent our judgment and evaluation on deep dissolution aspects are summarized as follows:

- Deep dissolution, to the extent that it may have occurred in the Delaware Basin, has taken place over a much longer period of time than late Cenozoic.<sup>29</sup>
- Apparent absence of salt from the lower Salado in much of the northern Delaware Basin is not caused by dissolution, but by depositional variations.<sup>63</sup>
- Core from ERDA 10, drilled in an area of postulated extensive deep dissolution of Castile halite, shows no such phenomenon.<sup>65</sup>

- Significant salt removal by means of the Delaware Mountain Group aquifers is ruled out by observations of hydrologic and geochemical parameters.<sup>63,64</sup> The volume of water available and the rates of transport are too small for the process to be effective. Solute content is inconsistent with major contributions from Castile halite.
- Breccia pipes are restricted to the Capitan Reef area and are not forerunners of regional deep dissolution.<sup>29,66</sup>
- Deep dissolution, if it occurs, proceeds because of groundwater flow along interbeds. Its lateral progression, though not necessarily uniform, is relatively predictable in the sense of progression.
- Recent correlations of geophysical borehole logs and the isopach maps derived from this study do not support the concept of salt removal by dissolution.<sup>64</sup>
- Core from deep drillholes near WIPP does not show evidence of extensive dissolution of salt.<sup>64,65</sup>

From these observations we may conclude that (1) regional deep dissolution is not present at or near the WIPP site, (2) its existence as an active mechanism in the northern Delaware Basin has not been demonstrated, and (3) if deep dissolution should occur, its most probable mode and rate of development would not imperil the integrity of the WIPP site over the time span required for isolation.

## Localized Dissolution

Localized dissolution features generally may form either by removal of salt from the top of the evaporite section or from its base. Some features may be initiated by collapse into cavities developed in formations beneath the evaporites as is the case for the breccia pipe explored by borehole WIPP 16. Breccia pipes, which result when overlying rock collapses into a cavity formed at or below the base of the evaporites, are of greater potential concern than shallow sinks because they may create a permeable "short circuit" of the salt barrier, allowing water to enter and leave a repository. Many domal topographic features in the Delaware Basin resemble the domes associated with known breccia pipes.<sup>67</sup> Therefore, it has often been

assumed that breccia pipes were common throughout the basin. Geologic mapping<sup>29,30</sup> and drilling<sup>68,69</sup> (WIPP 32, 33) have now shown these domal features in the basin are not deep-seated breccia pipes. The known breccia pipes are all over the Capitan Reef. One drilled to depth<sup>66</sup> was in fact shown to originate in the Capitan limestone reef and not in the evaporites. The hypothesis that best explains this correlation is that major aquifers (or cavernous rock), such as the reef, are necessary either to provide the cavity or perhaps to remove salt by dissolution, thereby creating the cavity into which the overlying rock collapses.<sup>29</sup> Conceivably the same process could occur wherever the underlying aquifer carries enough water and is somehow connected to the salt. Calculation of the maximum salt dissolution rates for the DMG aquifer indicates a very slow cavity growth rate, about 1 meter height in 10 000 years.<sup>63</sup> This could result in gradual subsidence rather than collapse and thus would not likely pose a threat through formation of a brecciated, highly permeable channel. Finally, there are several aspects worthy of note observed in two of the existing breccia pipes over the reef. The most significant is that they did not enlarge beyond their original diameter and had very little effect on dissolution of salt outside the chimney margin. The two pipes are not now permeable at depth, and even though they intersect aquifers, they do not produce water in drillholes (or, in one case, in an excavated drift.<sup>66</sup> While they may (or may not) be permeable when initially formed, they are not permeable now. They have sealed themselves off. This is a quality often attributed to salt, and it is demonstrated here on a grand scale.

Based on all the preceding arguments, it is our judgment that none of the three types of dissolution pose a threat to the integrity of the WIPP salt beds, certainly not over the next 10 000 years and, in all likelihood, not over very much longer periods of time.

The WIPP site is qualified with respect to dissolution.

## 9.0 Subsidence

Surface subsidence might conceivably affect the long-term integrity of the WIPP site if such subsidence were to alter the hydrologic system so as to accelerate dissolution effects, thereby breaching the salt beds isolating the WIPP.

There is currently no potash mining-induced subsidence at the WIPP site. In the long term, some

subsidence will occur because all the open space in WIPP cannot be completely backfilled. This surface subsidence is not expected to exceed about 1 foot.<sup>4</sup> This is not significant in altering surface drainage or in altering the flow in the overlying aquifers.

Natural subsidence has already occurred over part of the WIPP site due to dissolution of halite from within the Rustler.<sup>29,68</sup> This has resulted in an overall east-to-west permeability increase in the Magenta and Culebra aquifers, but has produced no other aquifer characteristics significant to WIPP. Nash Draw has experienced major collapse largely due to dissolution of a few hundred feet of salt. This subsidence has markedly altered the hydrologic parameters in this region. Even with this extreme subsidence, the resultant fracturing of aquifers, and the development of a brine aquifer zone on top of the Salado salt, the resultant rate of vertical dissolution is less than 500 feet per million years. It is therefore considered unrealistic to have subsidence over the WIPP site that could unacceptably affect its isolation performance.

The WIPP site is qualified with respect to the criterion on subsidence.

## 10.0 Surface Water

The concern with respect to surface water is that runoff, floods, or future impoundments must not enter the facility through unplugged openings. After decommissioning and plugging of the holes and shafts, this factor will not be significant for WIPP.

There are no perennial streams or surface-water impoundments at WIPP. The nearest permanent stream is the Pecos, 14 miles west of the site; it is more than 400 feet lower than the WIPP site. WIPP is sited and constructed such that surface runoff from flash floods will not adversely affect its operation or long-term performance.<sup>4,48</sup>

The WIPP site is qualified with respect to surface waters.

## 11.0 Groundwater

Several aspects of the groundwater criterion must be examined. The aspects listed earlier in this report may be restated as follows:

- The existence of the facility and its penetrations through overlying aquifers should not adversely affect those aquifers and their use.



- One must be able to assure isolation of the underground facility from surrounding aquifers, and the underground facility must not itself be in a water-producing stratum.
- The permeability of the host rock must be low enough to prevent significant flow of water through it if water comes into contact with the host rock in the future.
- The hydrologic regime at the site should limit the transport of radioisotopes to the biosphere, in the event of a facility breach, to prevent any significant consequences.

The only aquifers of any significance at the WIPP site are in two dolomite beds in the Rustler Formation. The more important of these is the Culebra; the other is the Magenta. The Santa Rosa, an important source of water farther east, has been thinned by erosion at the WIPP site and, with the exception of borehole H-5c, does not produce water in borehole tests. The Culebra and Magenta do produce water at the WIPP site, but it is not suitable for use by humans. Not only is the salinity too high (more than 10 000 milligrams per liter of dissolved solids), but it is produced in quantities too small to be of interest.<sup>70,71</sup> The open, 6-foot-diameter, WIPP shaft produced only 0.4 gallons per minute<sup>72</sup> and no hole within 2 miles of WIPP, down-gradient to the southeast, has had a flow yield of more than 0.2 gallons per minute over an extended pumping period.<sup>33</sup> Near the site there is localized production of small quantities of water for livestock from discontinuous pockets of water in shallower sediments, probably in the Dewey Lake or Gatuña Formations. No production of water from the Dewey Lake (or any other overlying formations) was obtained in the WIPP hydrology testing. Based on these facts, there will be no adverse impact on use of these aquifers because of WIPP drilling and construction.

Another concern is whether these aquifers can be isolated adequately from the underground facility. Recent shaft construction has shown that this will be no problem in the short term.<sup>52</sup> A 12-foot-diameter hole, lined and cemented down to the salt, was readily constructed and easily lined, sealing off the Rustler aquifers. Even an unlined 6-foot-diameter shaft produces scarcely any water from the Rustler, about 0.4 gallons per minute.<sup>52,72</sup> Sufficient confidence in permanent, long-term isolation is provided by the Plugging and Sealing Program<sup>73-75</sup> and by consequence

assessments that indicate even open holes do not result in unacceptable effects. A test already conducted in borehole AEC 7 illustrates the capability of installing adequate plugs in boreholes.<sup>76</sup> The vertical distance of 1400 feet between the underground facility and the Rustler Culebra aquifer provides a long interval for eventual plug installation, thus providing even further assurance of permanent isolation.

The facility host rock itself has a very low permeability,<sup>52,77</sup> thus assuring that water from possible external sources at depth (boreholes, flooded potash mines, etc) will not gain access to the waste through the salt. The salt itself has in situ permeabilities <0.01 microdarcy.<sup>52</sup> The 100-foot interval containing the excavated zone is expected to have in situ permeabilities of only a few microdarcies (about 10-20 microdarcies) based on tests in AEC 7.<sup>77</sup>

The last issue is, for the WIPP, the most significant of the hydrologic aspects. Basically, it is how well the hydrologic regime at the WIPP site will limit transport of radioisotopes to the biosphere (or accessible environment, if one uses the Environmental Protection Agency (EPA) terminology) if the facility is breached by some mechanism—with drillholes the most likely mechanism. The answer to this question requires a hydrologic model for the site area that allows one to make reliable transport calculations. Early calculations for WIPP breach scenarios<sup>4</sup> used a very conservative conceptual hydrologic model to assure bounding of the release consequences. The hydrologic model that better represents the site and may now be used for safety assessment, would be considerably different.<sup>31,78,79</sup>

Perhaps the most significant change involves the flow path for fluids if a deep drillhole were to penetrate through the disposal horizon connecting the Rustler and Delaware Mountain Group aquifers. The data now show that for this breach scenario (by far the most probable scenario) the flow would be downward into the DMG aquifer.<sup>31</sup> Pluvial cycles would not alter this tendency. The result of this change is to de-emphasize the significance of transport associated with the Rustler aquifers. The water flow in the DMG is very slow<sup>63</sup> and may be virtually nonexistent.<sup>64</sup> Water passing under the WIPP site will require about 500 000 years to reach the Capitan Reef, some 10 to 15 kilometers down-gradient. This compares to the previously estimated travel times of about 5000 to 40 000 years to the Pecos River by means of the Rustler

aquifers.<sup>48</sup> The second aspect of the hydrologic model to be changed involves the flow through the Rustler. This path must still be considered since some of the less likely breach scenarios still would transport waste to the Rustler aquifers. We now know from tracer tests that the actual flow in the Culebra is primarily through a system of joints and/or fractures filled with porous secondary material.<sup>78,79</sup> A model based on this system and that uses the present potential surface and hydraulic conductivity data,<sup>79</sup> indicates that water will move less than 2 miles in 1000 years in the region near the site. As in the earlier Rustler transport calculations, flow is more rapid in the regions where much salt has been dissolved and collapse has occurred. Since the transit time near the site is so long, more rapid movement of groundwater near the Pecos River is relatively less important. The absence of detailed models, as provided by tracer tests, is of minor consequence for these more distant portions of the flow path.

In addition to the favorable hydrologic conditions provided by the low flow rates and by saline waters, the rocks of the DMG and Rustler aquifers would significantly retard the major radioisotopes in WIPP. Distribution coefficients have been determined in laboratory batch and column tests for Rustler aquifer rock. These vary with both isotope and environmental conditions, but for "transuranic" isotopes range from about 10 milliliters per gram for uranium to 2100 milliliters per gram for plutonium.<sup>48,55,80,81</sup>

A final aspect of hydrology to be considered in this section is whether karst geohydrology could play a significant role in the transport of fluids at and from the WIPP site. Near-surface morphology typical of karst development is known to exist over portions of west Texas and southeast New Mexico.<sup>82</sup> Karst in the regional area of the WIPP site has been described and noted in previous WIPP studies.<sup>2,29</sup> The regional karst is best developed in the Rustler Formation in Nash Draw, where caves and "swallow holes" are observed. Interest in the potential for karst nearer the WIPP site was stimulated by the discovery of sinuous, short-wave-length gravity anomalies north of the WIPP site. These anomalies, originating from shallow density variations, have been attributed by Barrows et al<sup>37</sup> to alteration along karst channels.

The appropriate questions to be addressed with respect to WIPP are:

1. Does karst exist at the WIPP site, and more especially in view of the relevant breach scenarios, does it exist over WIPP itself?
2. If it does exist (or cannot be disproven), is it a significant path for transport of radioactive isotopes in the hypothetical breach scenarios for WIPP?

There are several reasons to doubt the existence of karst conditions over the WIPP site. These are briefly enumerated and discussed.

- The studies of Lambert<sup>63</sup> have demonstrated that dissolution and alteration of anhydrite in Nash Draw and nearby areas to the east are proceeding laterally by encroachment of water along beds of fractured (permeable) anhydrite. Thus, the alteration that does exist in the Rustler is not ascribed to vertically downward-moving waters.
- The monotonically decreasing hydraulic conductivities away from Nash Draw (as measured from west to east) support the concept of the stratabound dissolution of salt and alteration of anhydrite progressing laterally eastward from Nash Draw. Features such as the sink examined by borehole WIPP 33 are interpreted by Bachman<sup>29</sup> as a manifestation of this eastward growth of dissolution along fingers extending from Nash Draw. The rate of extension of these dissolution features will thus be comparable with the rate of lateral development of Nash Draw, about 6 miles per million years.
- There are no well-developed topographic expressions at the WIPP typical of well-developed karst. Shallow, circular features in the region of the site (dolines), sometimes ascribed to subsurface dissolution, are of such low relief (less than 10 feet) that they may result from other causes such as deflation.
- The numerous hydrologic test holes and the tests run in them show no direct or indirect evidence of karst channels. These tests indirectly probe the aquifer considerably beyond the well bore (during the drilling of the WIPP

shafts, the hydrologic pressure effects were noticed several thousand feet away)<sup>83</sup> — and no indications of karst were seen in the data.

- The Rustler aquifers at the WIPP site are artesian and have discrete potentiometric heads indicating that the aquifers are not connected to each other by karst development or to a free-water table by vertically developed karst. There is no free-water table at WIPP, a condition usually required for active karst development.
- No water is observed in WIPP hydrology test holes from rocks above the Rustler aquifers. Even after heavy rains, the water balance regime in the area is not believed to require or to support vertical karst development. The only spring observed in Nash Draw (Surprise Spring) appears to fluctuate in discharge with the amount of water discharged from potash operations rather than with rainfall. Stable isotopes in the Rustler waters over the WIPP indicate that these meteoric waters are not of recent origin.
- The negative gravity anomalies north of the site are of a scale that alteration of anhydrite to gypsum might explain them. The anomalies also might be caused by low-density channel filling in the Dewey Lake Red Beds. Alteration is observed in boreholes, i.e., gypsum and selenite, but adequately detailed petrologic studies have not been done to determine if either of the above two concepts is in fact geologically supported and also quantitatively sufficient to explain the gravity observations. WIPP 13 and WIPP 14, drilled in negative gravity anomaly areas, exhibited anhydrite alteration but no direct evidence of karst channels.<sup>84</sup> In any case, the precision gravity survey (although of limited extent) shows these sharp, shallow origin anomalies only in the area of the disturbed zone north of the WIPP site. No such gravity features exist at the WIPP.

For the above reasons, it is believed unlikely that developed karst exists at the WIPP site. Since it is difficult, if not impossible, to offer concrete, absolute proof of a negative or absent condition regarding karst geohydrology, it can be asked what the implications would be if it did exist and the WIPP were breached by drilling. Most significantly, there is no realistic scenario that could introduce water from below into the Rustler aquifers or into karst channels above the

Rustler aquifers. The DMG heads are not sufficient to overcome the Rustler heads and to force water to that elevation in an uncased borehole. Realistic scenarios that entail a brine reservoir encounter would have holes cased through this interval. In any case, direct discharge to the surface, as presumed in these scenarios, would bound the consequences. It may therefore be concluded that not only are karst channels unlikely at WIPP, they would be of no consequence to site acceptability even if they existed.

All the above discussion indicates that the WIPP hydrologic conditions are highly favorable for considerations related to disposal of radioactive wastes. The conceptual model developed for the WIPP site indicates that the flows are small in volume and slow in velocity and satisfactorily inhibit isotope transport from hypothetical breaches.

The WIPP site is qualified with respect to the criterion on hydrology.

## 12.0 Tectonic Stability

There are many ways to form an opinion about the presence or absence of significant tectonic activity and its future likelihood. Many of these indicators have been listed as subcriteria for site selection. Most have obvious answers for the WIPP site and little discussion is required; these are briefly addressed. The main subject of Castile deformation, as exemplified by the “disturbed zone” (DZ), is more fully considered.

The WIPP site is in a relatively aseismic region. Local monitoring since 1974 has detected no microseismic activity at or near the site.<sup>2,48,85-88</sup> The nearest prominent seismicity is in west Texas (Kermit) over the Central Basin Platform. Studies have led to the conclusion that this activity is not natural, but is caused by water flooding for secondary recovery of oil. Rare, small, isolated tremors occur north of the site; these may also originate near an oil field and may be caused by adjustments in the rock as oil is withdrawn. Solution-generated collapse might also cause such signals. No known geologic features in the area suggest active tectonism. To date it has not been possible to determine the origin depth of these tremors. In any event, they do not pose a significant issue to WIPP site acceptability.

There are no major faults or structural features near the WIPP. The nearest major structure to the east is the Central Basin Platform, a structure that

has not been active since late Paleozoic. To the west are the Guadalupe Mountains, probably formed by mid-to-late-Tertiary movements associated with the Basin and Range development. An apparent fault, mapped along the east side of the Guadalupe Mountains by Kelley<sup>89</sup> has been remapped by Hayes and Bachman<sup>90</sup> without finding evidence of any faulting. A series of recent faults along the west side of the Guadalupe outline the graben under the west Texas salt basin.<sup>91,56</sup> The faulting is 65 or more miles from WIPP. No major lineations have been observed in the area of WIPP, though many small lineaments may be observed on aerial photos.

The nearest igneous intrusive to the WIPP is a dike intruded up into the Salado salt about 11 miles north and west of the site. This dike is about 33 million years old.<sup>92</sup> This feature has been examined in potash mines where it intrudes into salt. While alteration does occur in the salt adjacent to the dike, its presence has not led to any significant dissolution of salt by water.<sup>92-94</sup> The geothermal gradients observed in boreholes are normal for the region.<sup>2,95</sup>

Major uplift and tilting of the basin occurred a few million years ago, but some minor broad regional movement may be ongoing. Level-line surveys<sup>57</sup> by the NGS indicate that the major movement is in the Salt Flats graben southwest of the Guadalupe and possibly along the Guadalupe-Delaware mountain trend.

Diapirism, as represented by Gulf Coast salt domes, is not present at the WIPP site, and current conditions do not favor its development. There may be piercement of anhydrite beds in the upper Castile Formation at ERDA 6, a site location previously abandoned.

The remaining topic of tectonic stability deals with the deformation of beds in the Castile Formation in certain portions of the northern Delaware Basin. This deformation is well-exhibited along the front of the Capitan Reef and certain other areas such as at the Belco-Hudson well, southwest of the site. These deformations are of interest to the WIPP for several reasons. First, the disturbed zone (DZ) intrudes onto the northern edge of the WIPP site, and its near proximity raises concern over its origin and nature. Secondly, some of the deformed-zone structures are known to be a focus of brine reservoirs, another topic of concern to the WIPP. The fundamental question, of course, is whether Castile deformation and associated development of brine reservoirs could occur at WIPP within a time frame of concern, and if so, whether or not it would pose a threat to WIPP.

Recently concluded studies<sup>58</sup> shed considerable light upon the nature and mechanisms of these Castile deformations. The most likely mechanisms are gravity sliding and gravity foundering. The first is a basin-wide phenomenon caused by the gradual, and usually gentle, down-dip creep of salt. The second is the tendency of the denser anhydrite to sink into and displace halite when and where the strength of the halite is reduced. Increased concentrations of intergranular fluid near the margins of the basin, areas where the salt has more impurities, may be especially effective in lowering the strength of the salt. Edge effects at the contact between the Castile and the Capitan reef could initiate deformation. Also, structure on top of the Delaware Mountain Group and Anhydrite I could initiate deformation in Halite I as the halite gradually creeps down-dip. This may explain isolated deformation such as at the Belco well. Petrographic studies indicate that several episodes of deformation have contributed to forming the DZ. Some of the deformation may be as early as late Permian; some may have occurred in the late Cenozoic. Indeed, it is not possible to rule out active deformation even at the present time. If deformation is occurring, however, it is at an undetectable rate and will propagate from the present centers so slowly that it will not affect the WIPP site.<sup>58</sup> New and randomly distributed centers of deformation are not likely to develop, since the triggering features described earlier have been in place all along and the driving forces are not getting perceptibly larger. Further, except in rare instances (ERDA 6), the deformation is primarily limited to the Castile and lowermost Salado; it does not involve the overlying Salado Formation where the WIPP is located. If the sort of deformation observed over most of the DZ occurred at WIPP, it would have no detrimental impact on confinement integrity of the WIPP.

The detailed mechanism by which deformation occurs is believed to be pressure solution—recrystallization.<sup>45</sup> This process does not require introduction of fluid into the system, but is facilitated by the presence of intergranular brine. The entire salt body may be gradually “reworked,” and fluid may be gradually moved through the salt. This mechanism might be a possible source of some of the brine reservoir fluid, but such a sole source is inconsistent with solute and stable isotope data.<sup>41</sup> The concentration in the brine of such elements as lithium might be explicable through this mechanism but no experimental data exist to support this hypothesis.

## Brine Reservoirs

Brine reservoirs deserve a discussion of their own although they probably form as a consequence of the deformation just described. The only two brine reservoirs studied to any degree are those encountered in WIPP 12 and ERDA 6. They are discussed in detail in a recent brine reservoir report.<sup>41</sup> The uranium disequilibrium technique for estimating the length of time the brine has been in a relatively stagnant condition is given in References 42 and 96.

This age determination method is subject to assumptions made on how rapidly the brine reservoirs were formed and the source of the brine fluid. The most conclusive statement that can be made at this time is that the system has been active, in the sense of exposing brine to fresh rock surface, within the last 2 million years. Numerical ages can be determined with the existing data only if one assumes brine was injected in a short span of geologic time and has been stagnant since this injection.

The following facts can be stated regarding brine reservoirs encountered in the Delaware Basin evaporites.

- They are present only in Castile structures; 13 separate drillholes have shown this correlation.
- They have been observed only in the upper anhydrites of the Castile, usually in Anhydrite III.
- ERDA 6 and WIPP 12 brines occurred in steeply dipping fractures in the anhydrite.
- All the brine reservoirs are at greater than hydrostatic pressure and exhibited pressures different from that for any adjacent aquifers.
- Adjacent brine reservoirs had different "initial" pressure heads.
- Geochemical analyses of brines indicate that ERDA 6 and WIPP 12 are not connected.
- The brine geochemistry (and potential head) rules out a DMG source for ERDA 6 and WIPP 12.
- The brine source may be original Permian water, or perhaps more recent Capitan water.
- If brines were injected and became static systems in a short period of time, isolation times of a few ten thousand years to several hundred thousand years may be calculated for WIPP 12 and ERDA 6 brines, depending on origin of fluids and assumed initial conditions.
- The brine-reservoirs brines are essentially saturated with respect to halite.

These facts imply the following with respect to the WIPP site.

- Absence of Castile deformation under the WIPP facility makes the presence of a brine reservoir unlikely. It is virtually impossible to prove their absence however.
- If a brine reservoir does exist or if one should form as a result of deformation in the geologic future, it would be confined to the Castile anhydrites, some 800 feet below the WIPP excavations.
- If a brine reservoir does exist or should develop at the WIPP site, it would not interact with WIPP except through human intrusion into both the brine reservoir and the facility.

The last conclusion calls for consequence analysis of possible breach scenarios. These have been done<sup>97,98</sup> and the indicated consequences are not significant. One is led, therefore, to the conclusion that brine reservoirs are not likely to occur under the WIPP facility now or in the near geologic future. If they should occur, they will not interact with the WIPP except through human intrusion. The consequences of this (unlikely) occurrence are not unacceptable.

The WIPP site is qualified with respect to the criterion on tectonic stability (and brine reservoir) considerations.

## 13.0 Physical-Chemical Compatibility

All the subcriteria listed under this topic are of concern principally for HLW, which produces significant quantities of heat and radiation. Even for HLW, they may no longer be necessary due to improved understanding and engineering design. Nevertheless, it is readily established by reviewing the SPDV results<sup>52</sup> that the intent of the criteria is satisfied by the WIPP horizon.

The facility interval contains less than 1% water and less than 5% nonhalite minerals.<sup>52</sup> The interbeds within 20 feet are anhydrite, polyhalitic halites, and clay-bearing seams of quartz and/or magnesite. The anhydrite does not present a thermal barrier or water release concern, and the clay-bearing seams and polyhalite will not release any water as a result of elevated temperatures from WIPP wastes, since temperatures will not occur that are high enough to initiate dehydration. Even for the DHLW experiments, where one

desires to observe the behavior of the clay interbeds, the temperatures will be too low to dehydrate the major hydrated minerals (principally clays and polyhalite) that are present.

The WIPP site is qualified with respect to its physical-chemical properties.

## 14.0 Natural Resources

The WIPP site selection criteria<sup>2</sup> specify that natural resources will be avoided to the maximum extent possible. There are two reasons for wishing to avoid resources. The first is primarily economic; a desire not to remove potentially valuable resources from future exploitation. The second reason is to decrease the probability of breaching the integrity of the facility by exploring for or developing natural resources if administrative control of the site is lost. The WIPP site was carefully selected with a view toward minimizing the potential for natural-resource conflicts while recognizing the requirements of other site selection criteria.<sup>2,4,28</sup>

The two natural resources known to be of economic value in portions of the northern Delaware Basin are potash and fluid hydrocarbons.<sup>4,99</sup> While it was considered possible to avoid potential potash deposits, it has never been considered possible to avoid the *potential* for conflict with fluid hydrocarbons. This would be true for virtually any sedimentary basin, since they have invariably been targets for oil and/or gas exploration. Viewed in a larger and long-range perspective, it is never possible to rule out future human penetration of any site for a geologic repository. There are too many examples of drilling deep holes for purposes other than mineral exploration to believe that any area is sure to be totally free of such activity. While the probability of human intrusion may be reduced by siting considerations, by administrative controls, or by passive marker systems, the surest way to reduce the long-term *risk* associated with human intrusion is to select a site where the site characteristics limit the *consequences* of such intrusion to levels considered acceptable by society.

Let us now examine the resource situation with respect to the WIPP site. The WIPP site was originally divided into four zones.<sup>2,4,48</sup> The two inner zones, I and II, cover the surface and potential underground portions of the facility, respectively. Zone III was to be a mile-wide control zone where underground penetrations would be limited by DOE.<sup>4</sup> Zone IV was still another 1 mile control zone outside Zone III. Zone IV

was established as a precaution against possibly undesirable activities until a determination could be made as to whether, in fact, such avoidance was necessary to protect site integrity. It has now been determined that Zone IV is not required to protect the long-term integrity of the site,<sup>49</sup> and DOE has indicated<sup>100</sup> that drilling and mining will be allowed in Zone IV. Further, exploration for hydrocarbons beneath Zones I, II, and III will be allowed by deviated drilling from outside Zone III if the hole is outside Zone III for the first 6000 feet of depth. As a result of these decisions, only resources within Zones I, II, and III and at depths less than 6000 feet need be considered with respect to resource values in conflict with the WIPP.

Potentially economic potash at the present WIPP site occurs principally in Zone III. A small amount of lease grade potash occurs in Zones I and II, but most of the area is barren or of relatively low grade.<sup>2,4,49,101,102</sup> In all, only 13.3 million tons of langbeinite ore is considered to be economic and to lie within Zone III. While not insignificant, this amount is not a major or long-term source of ore.

More important from the viewpoint of long-term site integrity is the fact that all the known or anticipated potash lies within a limited vertical span of the Salado Formation. This interval is about 400 feet above the WIPP facility horizon. Even if potash exploration or mining occurred directly over WIPP in the future, the 400 feet of vertical separation would preclude any unacceptable interactions between the two levels. The most severe consequence would be to alter the hydrologic regime over WIPP because of subsidence into the mined area and perhaps thereby lead to more rapid dissolution of salt. If so, it is unlikely the dissolution rate would exceed that in Nash Draw where widespread collapse has occurred. The Nash Draw vertical dissolution rate of 300 to 500 feet/million years is quite acceptable if it were to occur at WIPP.

Fluid hydrocarbons have a potential for occurring in economic quantities at the WIPP site even though known oil fields and producing trends were avoided by site selection. Unlike the known existence of potash, the presence of gas or oil is not a certainty. However, based on the statistics of oil and gas occurrence in this part of the Delaware Basin, it can be concluded that the area of interest for exploration of natural gas is at depths of 10 000 to 15 000 feet below the surface.<sup>4,49,103,104</sup> Prospects for oil in this immediate area are not promising.<sup>4,49</sup> Since the interesting prospects are for natural gas at depths of greater than 10 000

feet, existing technology for drilling deviated holes may be used to explore under all Zones I, II, and III for this potential resource.<sup>105</sup>

Thus the important issue relative to hydrocarbons is not one of resource denial, but rather the supposed attractiveness of the geologic setting for future exploration. While one may raise many arguments about how likely this will be in the distant future, it is impossible to assure that drilling into or through WIPP cannot happen. Several such breach scenarios involving drilling into and through the WIPP have been examined.<sup>4,48,97</sup> The conclusion reached as a result of all these studies is that the radiological consequences to future man are not significant.

In summary, some potash resources may be denied by present restrictions, but occurrence of potash and its possible attraction for future generations does not present a breach threat to WIPP. Natural gas resources are not denied by present restrictions, but their possible presence and the overall geologic setting makes drilling through the WIPP a more likely occurrence than in nonsedimentary geologic settings. Possible drilling breaches of WIPP confinement integrity have been analyzed and shown to result in relatively benign consequences.<sup>4,97</sup> It is therefore concluded that the site should not be ruled unacceptable because of potential resource conflicts; this potential is outweighed and compensated by the very favorable hydrologic regime at WIPP.

The WIPP site is qualified with respect to the criterion on natural resources.

## 15.0 Man-Made Penetrations

This factor applies to all shafts and boreholes that penetrate through the evaporites into underlying aquifers. Such penetrations must be at least 1 mile from the underground facility. This criterion was relaxed from a 2-mile exclusion distance when studies of the site hydrology and possible salt solutioning by means of unplugged boreholes showed that even a 1-mile buffer was quite conservative.<sup>2</sup> This requirement is imposed because as yet there is not adequate assurance that such penetrations can be adequately plugged and sealed; thus there is concern that extensive dissolution of salt might occur around the penetration. Future studies could reduce or eliminate this restriction even further.

No such penetrations exist within 1 mile of the proposed underground WIPP facility.<sup>75</sup> Early control of oil and gas drilling by the State of New Mexico provides confidence that all such drillholes are accounted-for. Additional reassurance that no deep drillholes have gone undetected is provided by the long-lasting nature of surface disturbances in this arid climate. Aerial photos easily detect evidence of such activity since drilling began in the area. Aeromagnetic surveys were useful in detecting metal surface conductor pipe or casing usually associated with deep drillholes. Thus it is very unlikely that any unknown deep drillholes exist within the WIPP site.

The WIPP site is qualified with respect to the criterion on man-made penetrations.

## 16.0 Transportation

The WIPP site should be located so that highway and rail transportation can be readily developed and so that population centers can be avoided to the extent possible.

Only a few miles (about 5) of new rail line are required to serve the site. Highway access can be provided from existing roads with only a few miles of new highway. No major problems are anticipated with roads because of the area where the WIPP is located. While control of transportation routes to the WIPP is outside the jurisdiction of this study, this site does not impose any greater hazard on transportation scenarios than would other potential sites. Transportation of radioactive waste to the WIPP has been examined<sup>4,48</sup> and found to entail acceptable risks.

The WIPP site is qualified with respect to transportation.

## 17.0 Accessibility

This factor relates to the ease with which roads, railroads, and utilities may be constructed at and to the site. The WIPP site and its environs present no topographic or engineering obstacles to development of transportation and utility corridors.<sup>48</sup> Access corridors have been surveyed and examined for archaeological sites; the routes do not jeopardize any such sites. Rights-of-way have been obtained for water and utilities that present no construction or environmental problems.

The WIPP site is qualified with respect to the criterion on accessibility.

## 18.0 Land Acquisition

All land designated as part of the WIPP site must be controlled by the DOE. This ownership is presumed to be facilitated by initial federal ownership. Within the present boundary of the WIPP site, all land is either federally owned and administered by the Bureau of Land Management (BLM) (14 sections) or owned by the State of New Mexico (2 sections).<sup>2</sup> The DOE will acquire the two sections of State land through an exchange of lands between the Department of Interior and New Mexico. In addition to land ownership, there are existing leases for potash and oil/gas that must, under current guidelines, eventually be acquired inside Zones I, II, and III. All the area is also now leased for surface grazing rights. Grazing will be allowed to continue except inside the fenced (Zone I) area.

The WIPP site is qualified with respect to the criterion on land acquisition.

## 19.0 Population Density

While surrounding population is not expected to be at risk, it nevertheless is only common sense to select an area of low population density when possible. This lessens still further any consequences to the general population of an accident that might happen at the WIPP site.

The immediate area of the WIPP site is sparsely settled. No one lives at the selected site; and only 16 people live within 10 miles.<sup>4</sup> The nearest community is Loving, 18 miles distant, with a population of 1600. Carlsbad, about 25 miles west of the site, has 28 600 inhabitants and Hobbs, only slightly farther to the east, has a population of about 32 600.

The WIPP site is qualified with respect to the criterion on population density.

## 20.0 Ecological Effects

It is desirable for the ecology of the site to be neither so unique nor so fragile that construction of the WIPP would cause irrevocable harm. Any areas or features of archaeological or historical significance should be preserved.

The WIPP site has been thoroughly examined for its flora, fauna, and ecological relationships.<sup>4</sup> Vegetation at and near the site consists of native scrubland dominated by sagebrush, mesquite, muhly grass, dropseed, three-awn, and yucca. No plants proposed

for the federal list of endangered or threatened species have been observed near the site, and the lack of suitable habitat makes their occurrence at the site unlikely.

About 70 species of animals representing seven mammalian orders may occur in the region of the site. Few are restricted to a specific habitat. Of these, the desert cottontail, black-tailed jackrabbit, northern grasshopper mouse, southern plains woodrat, porcupine, and coyote are observed in all habitats on and near the site; the only big-game species is the mule deer.

Eighty species of birds have been observed on and near the site. The most common are scaled quail, mourning dove, mockingbird, loggerhead shrike, pyrrhuloxia, black-throated sparrow, western meadowlark, lark bunting, vesper sparrow, Cassin's sparrow, and white-throated sparrow.

Amphibians are not an important part of the regional fauna because there are no permanent surface waters at the site. There may, however, be ephemeral surface waters in land depressions during thunderstorm periods. These provide minimal habitat for aquatic biota. Surface waters in the vicinity are limited to water for livestock. Although permanent, shallow saline lakes occur southwest of the site, no species of fish are known to occur closer than in the Pecos River.

Of the endangered terrestrial vertebrates observed in the northern Delaware Basin region, most are associated with habitats not present at or near the site. Only two species on the federal list of endangered species may occasionally be present near the site; they are the bald eagle and the peregrine falcon.

No portion of the ecological system identified in these studies would be significantly or irreparably harmed by the anticipated effects of constructing and operating the WIPP facility.<sup>4</sup>

Archaeological surveys have been made by Eastern New Mexico University over the central 4 square miles of the proposed WIPP site. In addition, drill sites and access roads have been surveyed as a part of the permitting process. In all, 33 archaeological sites and 74 isolated artifact sites were identified. The average density (8 per square mile) of archaeological sites for this area is considerably less than the average indicated by BLM studies (12 to 15 per square mile) for the total potash district. No pit houses, "permanent" structures or other indications of heavy use have been found in the central WIPP area. No significant



archaeological damage to the area need occur as a result of repository, transportation, and utility-corridor construction. Currently there are no sites within the WIPP land withdrawal area that are in either the National Register of Historic Places or the State Register of Cultural Properties. As a result of the WIPP archaeology survey, it has been determined by the Department of the Interior that the 33 aforementioned archaeological sites are eligible for inclusion in the National Register. This does not preclude use of the area for a facility.

The WIPP site is qualified with respect to the criterion on ecological effects.

## 21.0 Sociological Impacts

The site selected should not because of WIPP construction and operation impose severe or unmanageable impacts on the local governmental, educational, or social institutions.

This factor is addressed specifically in the Environmental Impact Statement and has been discussed with State and local officials. The public as well has been asked to comment on this issue as well as others. Based on these studies and comments, the Final Environmental Impact Statement (FEIS) was considered by the federal government as a satisfactory description of the WIPP and its impacts. A Record of Decision was then issued by DOE.<sup>106</sup> A recent cost-reduction proposal was adopted that modified the impacts on local area, primarily by employing fewer people at the site. The changes occasioned by this new concept are evaluated in an Environmental Analysis,<sup>107</sup> which concludes that all impacts caused by the design changes are not significant.

The WIPP site is qualified with respect to the criterion on sociological impacts.

## Conclusions Regarding Site Suitability

The preceding discussion has considered all of the site qualification factors that have been identified for the WIPP. Most of these factors are clearly satisfied by the WIPP site and engender little debate. Some of the factors and their associated aspects are more contentious and have required extensive investigation and study to allow reasoned technical judgments. In the opinion of the Sandia WIPP geotechnical staff,

well-supported judgments can now be made on all the relevant issues.

It is important to realize that an attempt to understand complex geological processes may not result in absolute proof of any one hypothesis. A hypothesis may be ruled out if observed data clearly refute it, but more often a hypothesis is adopted because it best explains the observations and presents fewer conflicts with the evidence. Also, it is often virtually impossible to prove a negative hypothesis with respect to some of these geologic issues. For example, it is not practicably possible to *prove* that a large area in the basin does not contain an incipient breccia pipe or a brine reservoir; the argument is always that they may be just too small for geophysics to detect; or they may have been missed by the latest exploratory hole. The best, most meaningful approach to ruling out negative features is to establish a preferred hypothesis for their origin and then to show that the area in question does not possess the requisite characteristics to satisfy the hypothesis. Likewise, hypotheses may sometimes be ruled out if they require conditions that can be shown not to exist. Occasionally one may be left with two or more hypotheses, and a professional judgment is the only way of arriving at a preferred position. For this reason, opinions may sometimes differ among technically competent scientists. For the same reason, the various state and federal technical review groups have been important in providing an independent, unbiased judgment on the various hypotheses that are offered to explain the observations.

It is the judgment of Sandia National Laboratories that the WIPP site fulfills the intent of all the site qualification factors. Sandia recommends, without reservation, the use of the Los Medanos site for the WIPP.

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