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OFFICE OF THE SECRETARY

October 20, 1994

Mr. Robert Bills
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Dear Bob:

This letter contains a discussion of the initial white paper concerning scenario selection. At the stakeholders' meeting in Carlsbad on September 28 I understood that a further draft is to be generated which will include data supporting the screening of various features, events, and processes ("FEPs") and a description of the base case and other scenarios included in a compliance application under 40 CFR 191 and 268. Such information is clearly essential to review the scenario selection process and conclusions. Please advise when this draft will be available. Needless to say, I request a copy of this draft.

As previously stated, the September 9 draft shows a welcome awareness of the scope and complexity of the process of scenario construction. I have the following comments for reference in generating later versions:

1. The paper states that when EPA issues new compliance criteria, 40 CFR Part 194, the scenario development work will be reconsidered (at 2-2). The paper should make clear that when a public draft is issued by EPA, the scenario development process will be reviewed on the basis of such proposal. DOE stated in Mr. Dials's September 9, 1994 letter to me that "CAO plans to address the content of the 40 CFR 194 standard upon its issue for public comment in the form of a proposed rule." (Enc. II, at 11 ¶20a).

2. The selection of FEP's and scenarios should not be limited by 40 CFR 191 Appendix C, which (a) is nonbinding and (b) is about to be replaced by 40 CFR Part 194.

3. The statement (at 2-3) that human intrusion need not be considered under 40 CFR §268.6 creates an inconsistency with the

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treatment of human intrusion under 40 CFR Part 191 and disregards EPA's draft no-migration guidance, which calls for consideration of "likely human-induced events" (July 1992 draft guidance, at 34).

4. The draft paper calls for "well-defined screening criteria" for screening of FEP's (at 2-4). The criteria must be clearly defined, and this has not been done. To screen a FEP from consideration eliminates the FEP from study in any later stages of PA. Thus, it is a drastic step. Screening cannot be done in anything less than a rigorous process.

5. The paper requires a statement of the system employed to analyze FEP's with regard to possible interactions with other FEP's. This also is critical. It is of some concern that, for example, repository processes such as caving are screened out, even though they are known to be a part of scenarios required to be examined in evaluating compliance.

6. The statement (at 3-7) that under some interpretations of 40 CFR Part 191, Appendix C, the E1E2 scenario need not be considered should either be dropped or justified. The E1E2 scenario has been a subject of intense analysis for some years, and most of those involved have agreed on the necessity of such study. That omission of this scenario should be considered raises serious concern.

7. The initial draft states that work is currently underway to improve understanding of the effect of certain FEP's (at 4-1). Stakeholders cannot appraise and respond to proposals as to the disposition of FEPs where the argument for such disposition has not been developed and stated.

8. It is stated that the work in Chapters 5-7 is in progress and that the work in those chapters should be viewed as a progress report (at 4-1). When will the work be done and a final version submitted?

9. The draft suggests that credibility and defensibility of the work would be enhanced by a formal expert elicitation process, superimposed on the existing work (at 4-3). I concur and inquire whether such a process is planned.

10. As stated above, the screening criteria (at 4-7) must be set forth more clearly. There is a quantification of the probability cutoff. There is no quantification of the consequence cutoff or the level of assurance with which it is to be demonstrated. Will <u>both</u> probability and consequence be estimated, as EPA (Jim Benetti) has suggested? Further, reliance on Appendix

C is erroneous, as stated above.

11. As to low-probability screening, the draft says that there is a bound of 10^{-8} per year on the cumulative probability of all scenarios eliminated on probability grounds (at 4-8). Given that the probability of individual FEPs is difficult or impossible to estimate, it is not clear how this bound is to be applied.

12. Again, as to low-probability screening, the draft says that in most cases, it is "not possible to estimate a probability" (at 4-20). This raises concern, because the qualitative screening arguments advanced generally lack data. It is a drastic step to eliminate a FEP entirely from PA consideration at an early stage, and it should only be done in a very clear case.

13. There is an initial question as to the manner in which FEPs are discussed in Chapter 5. Chapter 5 addresses natural FEPs, but does so only from the perspective that PAs to date have shown no releases from an undisturbed repository. Individual FEPs appear to be considered in Chapter 5 largely without regard to their possible interaction with intrusive events. This is a limiting perspective, particularly when one considers that the environs of the WIPP have already been intruded upon by drilling, extraction, and water injection activities. Further, at the EPA technical exchange on September 22 it was suggested by EPA that current human activities in the area and their effects be incorporated in the base case, and I inquire what will be done along that line.

14. Several natural FEPs are screened out with the observation that work is underway to develop an argument that the FEP can be eliminated on grounds of low probability or low consequence. The complete argument, however, is not presented. This is the case as to the following:

Regional tectonics
Magmatic activity
Fault movement
Fracture development
Seismic activity
Changes in the earth's magnetic field
Erosion/sedimentation
Infiltration/recharge changes
Vegetational change

FEPs within these categories must be retained unless a screening argument is properly made and supported.

15. Fracture development resulting from natural forces cannot be screened out (at 5-7), in light of the acknowledged possibility of such effects resulting from mineralogical and geochemical changes. The viewgraphs presented to EPA on September 22-23 appear to recognize such possibility (at 79).

16. Deep dissolution within the Salado and Castile formations should not be screened out at this stage without clarification of the debated issues of the formation of breccia pipes within the central basin and the origins of brecciated anhydrite in the Castile. There are indications of breccia structures in areas not underlain by the Capitan limestone. See Anderson, R. Y., Deep-Seated Salt Dissolution in the Delaware Basin, Texas and New Mexico, Environmental Geology and Hydrology in New Mexico, at 133-45 (1981); Anderson and Kirkland, Dissolution of salt deposits by brine density flow, Geology 8, 66-69 (1980). The origins of brecciated anhydrites in the Castile are debated, as the text itself states (at 5-9).

17. It is erroneous to screen out naturally-caused changes in mineralogy, if by that term DOE means to include dissolution of fracture fillings in the Rustler. The attached paper by Roger Y. Anderson explains that WIPP is located in a region of developing karst, rendering the site vulnerable to changes in climate. A major climate change could bring active dissolution to the WIPP site. Such a consequential FEP cannot be eliminated at this early stage.

18. The draft acknowledges the "considerable debate" (at 5-12) about the effects of global warming, and yet greenhouse induced changes are listed in Table 5-1 as screened out on grounds of low consequence. With the issue disputed, the FEP cannot be screened out.

19. The discussion of shallow dissolution and soil development (at 5-15) is unclear as to the extent of the FEP being discussed. For reasons explained in the Anderson paper attached, dissolution having effects on the hydrologic characteristics of the Rustler aquifer cannot be screened out. The draft refers to processes of deposition of the Rustler described by Holt and Powers (1988), but these are disputed in Snyder, R.P., Dissolution of Halite and Gypsum, and Hydration of Anhydrite to Gypsum, Rustler Formation, in the vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico, USGS-OFR-85-229 (1985), who supports a dissolution interpretation, and neither theory is wholly satisfactory, as noted in Beauheim, R.L., Interpretations of Single-Well Hydraulic Tests Conducted At and Near the Waste Isolation Pilot Plant (WIPP) Site, 1983-87, SAND 87-0039 (1987),

and Brinster, K. F., Preliminary Geohydrologic Conceptual Model of the Los Medaños Region Near the Waste Isolation Pilot Plant for the Purpose of Performance Assessment, SAND 89-7147 (1991). To exclude halite dissolution on the ground that processes leading to a breach of the repository would go too slowly to have an effect does not account for the process of dissolution altering the flow and transport characteristics of the Rustler, as described by Anderson in the attached paper.

20. The draft paper screens out on grounds of low consequence a FEP involving infiltration and recharge leading to hydrological changes (at 5-16, 5-26). The attached paper by Anderson illustrates that increased recharge due to climate changes may well affect the hydrology of the Rustler. The FEP cannot be excluded. Further, the draft itself says that the three-dimensional groundwater flow model suggests that an increase in recharge can lead to a change in flow direction in the Rustler (at 5-17), a phenomenon that has not been fully assessed. No early decision to exclude such phenomena should be made.

21. The statement (at 5-20) that "there are no naturally occurring events or processes that are expected to have a significant effect on the geometry of the flow system over the period of regulatory concern" is contradicted by the description of increased recharge leading to a change in flow direction (at 5-17) and should also be modified to take account of the dissolution effects following a climate change, as described in the Anderson paper.

22. It is unclear from the draft what treatment is to be applied to departures from the repository design. Possible modifications to backfill and seal systems (at 6-5) and to the waste and canister (at 6-4) are classified as RB. However, it is generally assumed in the draft that, once the design is made final and certified by EPA, the repository will be built as designed (at 7-14), and no intentional or unintentional changes will be made. In our view, FEPs involving departures from on-design construction must be retained. Such FEPs may be modeled in various ways, but it is erroneous to screen them out.

23. Caving should not be screened out as having low consequences (at 6-7). Modeling of disposal room closure includes the characterization of brittle behavior of the Salado. Thus, caving is one of the interrelated processes to be incorporated in the base case.

24. Explosions affecting backfill and flow paths are screened on the ground of low consequence (at 6-10), but no

argument for such screening has been presented.

25. In interpreting the resource area disincentive of 40 CFR §191.14(e) it is not correct that resource potential should be based on current or near-term projections of resource values (at 7-3). The regulations refer to "any material that is not widely available from other sources."

26. The draft relies upon the 40 CFR 191 Appendix C limitations as to human intrusions to be considered (at 7-3). This appendix is nonbinding and will soon be replaced by 40 CFR Part 194. Reliance should not be placed upon it.

27. The assumption that intruders will "soon detect" the incompatibility of their activities with WIPP (at 7-3) comes from the nonbinding Appendix C and should not be used to restrict PA analyses. Further, the assumption is premised in part on a demonstration of effective passive institutional controls, which has not been made. Moreover, the assumption is not supported by current practice. See the Berglund presentation at the February 22-24, 1994 DOE-EPA technical exchange.

28. It is incorrect that any resource extraction would not be an inadvertent process and should be screened out (at 7-3, 7-4). Whether resource extraction may occur without constituting an intentional intrusion must be determined on the basis of a case factually made to support a screening decision -- not on the basis of pure assertion.

29. There is a reference to plugged and abandoned holes in the region (at 7-4). The characteristics of typical plugged and abandoned holes in the area -- if typical cases exist at all -- are still to be demonstrated. Prevailing practice is inconsistent. See U.S. Department of the Interior, OIG, Audit Report No. 90-18, Nov. 1989.

30. The draft notes alternative assumptions concerning oil and gas resource extraction and potash mining within the controlled area (at 7-4). The FEPs described should, in fact, be retained rather than screened out.

31. The exclusion of human intrusion from RCRA no-migration analyses (at 7-5) is erroneous; see point 3 above.

32. The draft excludes exploitation drilling that intersects the repository (at 7-6). As stated, this is erroneous. What should be excluded is intentional intrusion, as characterized on the basis of actual or projected drilling practices.

33. Geothermal exploration and development activities are excluded on the ground that the regulatory interpretation confines consideration to resource activities in the recent past (at 7-7). The focus should be broader and should consider any prospective exploration for or development of scarce or easily accessible resources or any material not widely available from other sources. If that focus would include geothermal sources, the FEP should not be screened out.

34. It is not clear whether drilling to conduct enhanced recovery is included (at 7-7); it should be.

35. If the intent is to exclude disposal of waste in boreholes, that should be corrected (at 7-7). The FEP should be retained.

36. Drilling and other activities in connection with the siting and development of an oil and gas storage facility should be retained as a FEP (at 7-7). At the meeting on September 27, 1994, it was stated that DOE would assemble further information on this subject. Thus, the FEP should be retained.

37. As stated above in point 32, the exclusion on asserted regulatory grounds of resource extraction from a hole which intersects the repository is erroneous.

38. It is not clear why mining which leads to intrusion of the repository should be excluded (at 7-9). Intersection of the repository would not in all cases be intentional intrusion. Perhaps an argument exists on grounds of low probability due to the location of extractable potash, but the argument has not yet been made.

39. Numerous other underground activities are screened out on the basis of low probability (at 7-10). The treatment is so cursory that it is difficult to appraise it. More should be said by way of argument, particularly concerning mining for resources other than potash.

40. Similarly, the exclusion of other surface activities (at 7-11) requires further explanation and support. Human activities affecting recharge may have significant consequences. One example given by EPA is surface excavation of caliche, sand and gravel.

41. The screening of explosives used in resource recovery requires further argument in support (at 7-12). What is the probable location of such efforts and the area affected?

42. Finally, we are concerned that there is no description of the manner in which scenarios are to be constructed from the retained FEPs. The process implicates considerations of aggregation and resolution. Further, there is the issue of expressing the uncertainty of numerous natural and human-induced events and the possible need for multilevel probability analyses (e.g., exploration followed by development activities). These issues should be discussed in the forthcoming draft.

Thank you for giving consideration to these comments.

Very truly yours,

Lindsay

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LAL:mh

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14 July, 1994

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Dear Lindsay Lovejoy,

This document is in response to your 30 June, 1994 request for comments regarding unresolved issues related to the WIPP Compliance Status Report (CSR, DOE/WIPP 94-019). I have examined the items in section 6 which DOE claims as "closed" or resolved. I have not examined or commented upon issues 6.1.1 F, J, K, L, M,N,O. I have prepared comments on two general areas, *Deep Hydrology* and *Surface Hydrology*. Each encompasses several of the issues that DOE has listed as resolved. A minimal number of sources of information have been cited, owing to limitations of time.

Unresolved problems related to deep hydrology are important for Performance Assessment (PA), but how they would effect the performance of the repository would depend on the results of further research and exploration which probably would not be authorized by DOE. On the other hand, what is known about surface hydrology has revealed a site that, under conditions of even moderately changed climate, because of changes in the Rustler aquifer, may not meet present requirements for disposal over a time interval of 10,000 years. Over the next 100,000 years, the certainty of significant climate change means that WIPP cannot accomplish its mission of demonstrating safe, long-term isolation of radioactive waste.

Respectfully Submitted,

Roger Y. Anderson

Roger Y. Anderson

"Deep Hydrology" Issues

6.1.1 A Breccia pipes (closed)
6.1.1 D Brine weeps and seeps (open)
6.1.1 E Dissolution (closed)

The report contains several inaccuracies about the distribution of breccia pipes and their relation to hydrology. Breccia pipes *are* found within the basin and they are *not* restricted to the area above the reef. The occurrence of a breccia pipe within the basin was reported by Anderson and Kirkland (1980) and a photograph of collapse breccia in that pipe was featured on the cover of the national journal which published the reviewed article. The abundant *limestone buttes* (castiles) that are exposed in Culberson County are another example of breccia pipes or chimneys within the basin. All of these vertically penetrating features have a small cross section and the statement that none occur in the vicinity of WIPP would require supporting evidence that the geophysical methods used to explore the WIPP site area were capable of identifying such features. Equally important as their occurrence within the basin, is a lack of understanding about how such collapse features formed and how they are related to the hydrology of the basin.

Other collapse structures found within the basin are Bell Lake Sink and Slick Sink, which occur east of the WIPP site and within an area of the basin where there is no evidence for regional dissolution. No one disputes that these are collapse structures but there is no information about the depth of these structures, about which geologic strata were dissolved to produce the collapse, or about the hydrologic conditions that caused the collapse. It is entirely conceivable, and in fact likely, that the collapse extends downward at least to the Rustler aquifer. The large diameter of Bell Lake Sink, a collapse structure which pre-dates the climate change of the last glacial maximum (LGM), and geochemical evidence for the upward movement of deep formation fluids (Hill, 1993), suggest that Bell Lake Sink is a deep structure. Some information on Bell Lake Sink is in a UNM MS thesis by R. Widdicombe, but the origin of this collapse feature, *within the basin*, has been largely ignored during the characterization of WIPP.

The implications of having a deep, localized collapse structure within the "undissolved" region of the Delaware Basin should not be underestimated. For example, if the structure is rooted in the Rustler aquifer it would mean that fluids moving through the Rustler have produced localized dissolution and collapse well beyond advancing regional fronts of dissolution. Bell Lake Sink contains a high lake stand that probably reflects climate changes during the LGM. The possible renewal of localized collapse before or during the LGM has important implications for the local stability and hydrology of the site under a wetter climate regime and is therefore related to the "closed" issue of climate change. Climate issues are also related to the question of karst and surface hydrology, discussed later.

Still another question related to "deep" hydrology, is the character and origin of the west-to-east, upslope-to-downslope hydrologic communication that is known to exist within the body of Salado evaporites within the Delaware Basin. This hydrologic condition was recognized long ago by Hills (1968), evidence was presented by Anderson (1981, and in several reports to Sandia Laboratories), and EEG has confirmed the validity of the evidence. Possible consequences of having moist salt is the unexpectedly fast rate of salt creep and room closure (see issue 6.1.2 B.2) and increased brine seepage (see issue 6.1.3 F).

The repository is already built and it is too late to use information about this largely unknown hydrologic system for site selection. However, it is not too late to characterize the hydrology and to use this understanding in order to provide more reliable estimates of brine seepage and room closure, issues that are vital to PA. For the reasons cited above, I do not consider dissolution or "deep dissolution", breccia pipes, or brine weeps and seeps to be resolved issues.

"Surface Hydrology" Issues

The remaining issues are closely related to one another and to the larger issue of karst, which DOE claims is resolved.

6.1.1 G Karst
6.1.1 I Paleoclimate and climate change
6.1.3 A Focus on Culebra Dolomite
6.1.4 F Climate change

Karst

History of the Karst Issue

In 1975, after complex structures and a pressurized brine reservoir were encountered at the first WIPP site , the project moved westward to the Los Medaños site along the eastern margin of Nash Draw. Approximately half of the halite in the Rustler Formation was missing at this site (CSR Fig. 2-8). It soon became apparent that dissolution by near-surface ground waters had removed the halite along the eastern margin of Nash Draw (Fig. 1), which borders the WIPP site on the west. Nash Draw is one of the largest karstic dissolution structures with surface expression in North America. Geologic features and surface hydrology around the site clearly are expressions of the kinds of geomorphic features and groundwater flow regimes that geologists, world-wide, refer to as karst.

The issue of surface dissolution and karst was originally investigated to determine if rates of regional dissolution and erosion were sufficient to breach the repository. Although suberosion is too slow for a breach, dissolution does pose a threat to the Rustler aquifer. The CSR separates the issues of karst and dissolution and minimizes its use the term karst in describing the processes of dissolution at the site that effect the Rustler aquifer. The CSR uses the term karst for the deep dissolution troughs that occur in the central and southern part of the Delaware Basin and which contain thick sequences of early Pleistocene Gatuña Formation.

The CSR cites the absence of visible karstic surface features at the WIPP site as DOE's main reason for closing the issues of both karst and surface dissolution. The CSR acknowledges the importance of karst, were it to exist at the WIPP site, but closes the issue by stating that "...karst formation is not a process at the WIPP site which will result in significant compliance-related consequences."

The absence of visible karstic surface features such as sink holes, however, is not evidence that the Rustler aquifer is unaffected by dissolution. The moderate thickness of halite and gypsum strata in the Rustler Formation precludes the development of large, visible collapse structures at the surface until late stages of dissolution. In addition, a cover of dune sand at WIPP obscures any surface expression of smaller karst features such as swallow holes. As will be discussed, there is ample evidence that dissolution is an active process at the WIPP site and the issue of near-surface dissolution(karst) is critical to the effects of climate change on the performance of WIPP.

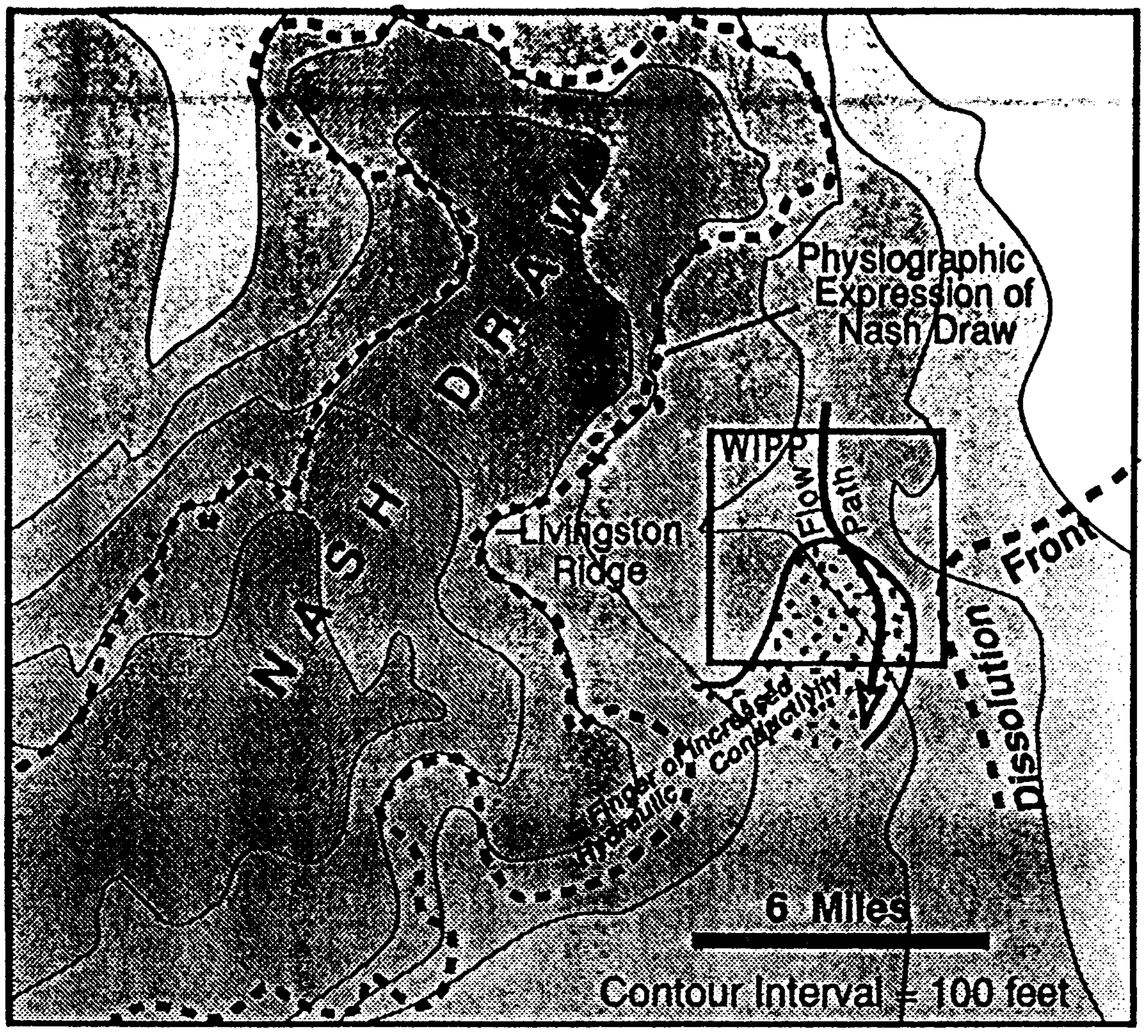

Fig. 1. Location of Nash Draw in relation to WIPP site.

Dissolution, beginning along the axis of Nash Draw, has moved about 10 miles eastward and over the WIPP site to the present position of the dissolution front. Dissolution moved eastward in a series of pulse-like episodes controlled by changes in climate (see Fig. 3).

Notice that the main flow path in the Rustler aquifer and the local area of increased hydraulic conductivity in the southern part of the WIPP site occur as a northward extension of the southeastern lobe of Nash Draw.

Subsiding and expanding topographic depressions, such as Nash Draw, are typical of karst regions and a karstic hydrology.

Age of Dissolution

Although the CSR makes little mention of the age of dissolution in the area of WIPP, other publications by DOE team members (e. g. Beauheim and Holt, 1990) make it clear that most of the dissolution, karst development, and associated fracturing of the Rustler aquifer is believed to have occurred in the Cenozoic. Nash Draw, for example, is considered to be a Cenozoic feature related to the ancestral Pecos drainage and to the deep dissolution troughs in the central area of the Delaware Basin (Beauheim and Holt, 1990). This estimate of the age of Nash Draw clearly is in error because the age of this structure has been adequately dated by tephrochronology as younger than 600,000 years (Bachman, 1974). The young age of Nash Draw is highly relevant because it offers a means for examining the effects of climate change on the progress of dissolution.

The young age of Nash Draw and its growth and development under regional hydrologic conditions that continue to the present day provide a basis for understanding and predicting future dissolution at the WIPP site. For example, Beauheim and Holt (1990) recognize that *"A high transmissivity 'finger' penetrates the southern border of the WIPP site."* This finger is a localized area of high transmissivity in the Culebra aquifer (Fig. 2A). This is the area where test wells that show rapid movement of tracers. It is also the area where groundwater is relatively fresh and unsaturated for gypsum (Fig. 2B), and where gypsum cement in Culebra fractures has been removed by dissolution (Fig. 2C). The "finger" is also the pathway for the most rapid flow in the Culebra and the local site for dissolution of halite above the Culebra (Fig. 2D). Examination of the location and orientation of this finger of high flow, fresher water, and dissolution effects, relative to the configuration of Nash Draw, shows it to be a northeastern extension of conditions that prevail within the southeastern lobe of Nash Draw.

Other geologic features and hydrologic conditions found in the finger and into the central area of the WIPP site are explainable as early stages in the process of karstic dissolution. For example, physical and photographic evidence taken from the main shaft at the center of the WIPP site reveals that fractures in soluble units below the Culebra have been enlarged by dissolution to form flow channels (see Fig. 2 in Chaturvedi and Channel, 1985). The fact that hydraulic conductivity varies by 6 orders of magnitude across the site, as well as the vertical movement of fluids through other stratigraphic units of the Rustler, are conditions that are consistent with karstic dissolution. Some wells in the finger, such as H-11, show high transmissivities and rapid movement of tracers, while other nearby wells

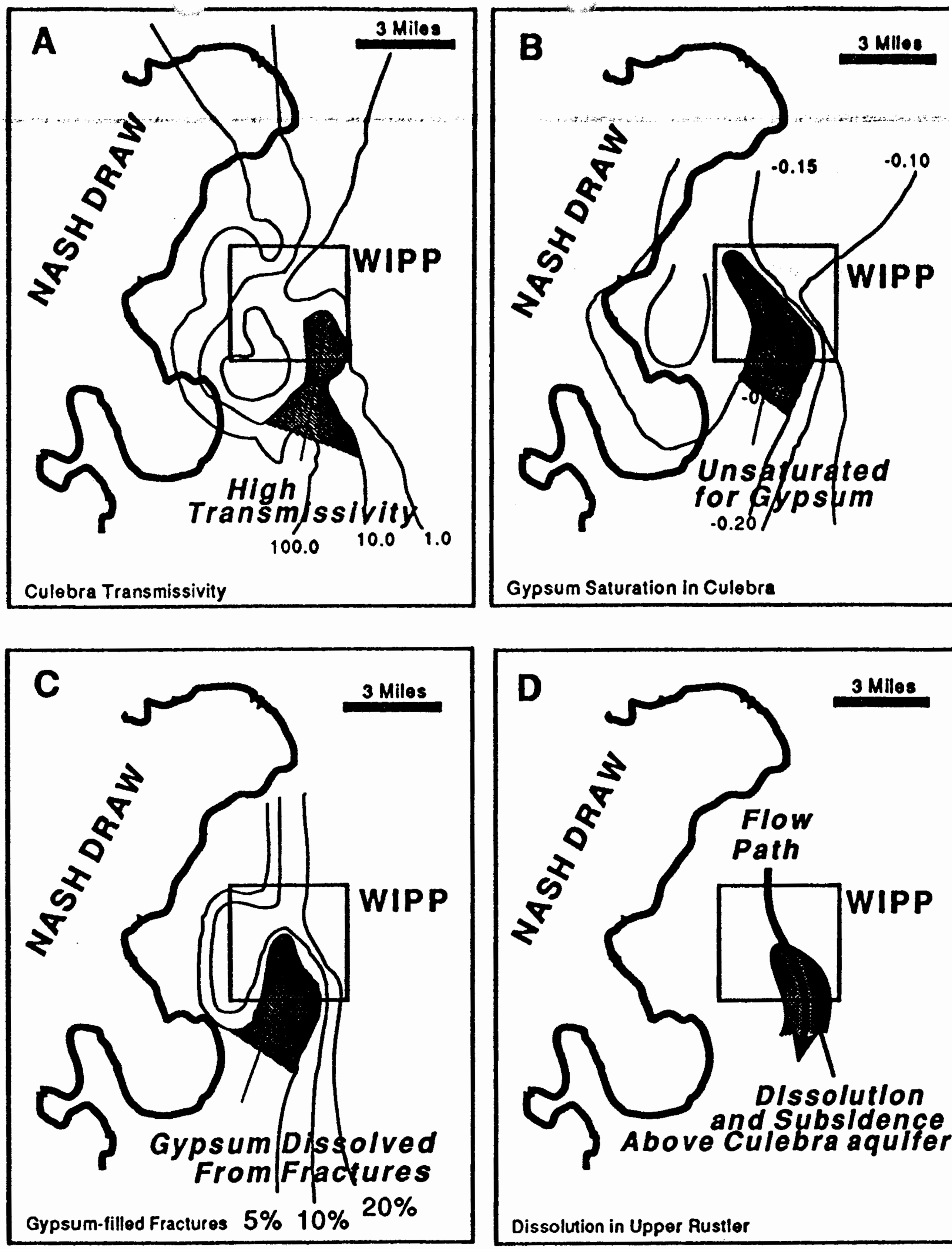

Fig. 2. Expression of active dissolution in the southern area of the WIPP si
Adapted from Beauheim and Holt (1990).

have very low transmissivities. This is precisely what one would expect to find under conditions of developing karstic dissolution.

Present models adopted for the WIPP PA assume only fracture flow in the Culebra, and as will be discussed, a correct understanding of the evidence for dissolution is necessary for the development of valid hydrologic models. In this regard, it is pertinent that a team of international experts, reviewing WIPP hydrologic models, has suggested the use of alternate "fracture channeling models" (see Beauheim and Davies, 1992), thereby acknowledging that the aquifer has developed flow channels and has adjusted to an early stage of karstic development.

Interpreting the "finger" as an advancing extension of the karst hydrology of Nash Draw follows logically from the young age of Nash Draw and from its history of eastward expansion and migration during past episodes of climate change. The response of Nash Draw and adjacent areas to the effects of climate change are critical to predicting the future performance of WIPP.

Climate Change

The CSR contains a meager summary of climate issues and gives conflicting statements, saying in one section that the issue of climate change is open and in another that the issue is closed (12-7 vs 12-24).

I have emphasized the issues of karst and dissolution in because placing the WIPP in a region of developing karst carries with it profound implications for the stability of the site under conditions of variable climate. Problems related to site stability and hydrology are different in character and more acute in a region of soluble strata that continues to be affected by changes in climate.

A brief geologic history of Nash Draw illustrates the problem of long-term site stability. Nash Draw (Fig. 1) formed sometime after a thick surface-layer of soil carbonate (Mescalero "caliche") developed over the region of WIPP. The Mescalero unit is about 500,000 years old. The first stage of dissolution and subsidence was centered in the present axis of Nash Draw and during the last 500,000 years dissolution and subsidence has expanded laterally under a highly variable climate, creating the present topography and reaching the present edge of the regional dissolution front (Fig. 1). Today, the topographic or physiographic expression of Nash Draw resembles a very large dog bone (Fig. 1). In the southeastern corner of Nash Draw, dissolution and subsidence have outflanked Livingston Ridge and the effects of dissolution have encroached upon the WIPP site from the south (Fig. 1).

Dissolution and eastward expansion of Nash Draw occurred mainly during a series of four strong perturbations in climate that occurred in the latter part of the Ice Age and Nash Draw migrated eastward during a series of dissolution episodes, each separated by dry intervals of lesser dissolution, such as the dry episode of the last 12,000 years (Fig. 3). The average amount of precipitation in New Mexico during these major climatic episodes is believed to have increased to more than double its present value. Precipitation during moist episodes also occurred in short pulse-like events of even greater precipitation (Allen and Anderson, 1992). The pulse-like character of these events may have increased the effectiveness of infiltration into karstic systems, thereby facilitating dissolution during moist episodes.

The finger of anomalous hydraulic conductivity in the southern part of the WIPP site, referred to earlier, is also the main flow path through the Culebra aquifer. One can anticipate that during the next major climate cycle of increased precipitation, dissolution will expand along the finger, advance northward, dissolve what remains of the halite in the Rustler Formation, and dissolve some fraction of the upper Salado at the interface between the Rustler and Salado salt (brine aquifer).

A precursor to the path that dissolution is expected to take in the future can be seen, as well, in the distribution of the secondary gypsum in fractures in the Culebra aquifer (CSR Fig. 2-12). To appreciate the significance of this pattern, and the importance of the effects of climate change, it is helpful to describe the process of re-solution of gypsum in stages, as follows, and as depicted in Fig. 3:

1. Creation of a system of open fractures in the Culebra aquifer during episodes of high flow prior to 12,000 years ago.

2. Plugging of the open-fracture network by precipitation of secondary gypsum in fractures during a period of reduced rainfall and infiltration, and low hydraulic head in the WIPP area. This warm dry climate episode occurred in the American Southwest about ~ 8000 to 4000 years ago.

3. Beginning about 4000 years ago, re-solution of secondary gypsum from fractures in the Culebra aquifer occurred after the regional climate changed from dry to the moderately moist conditions of the present day.

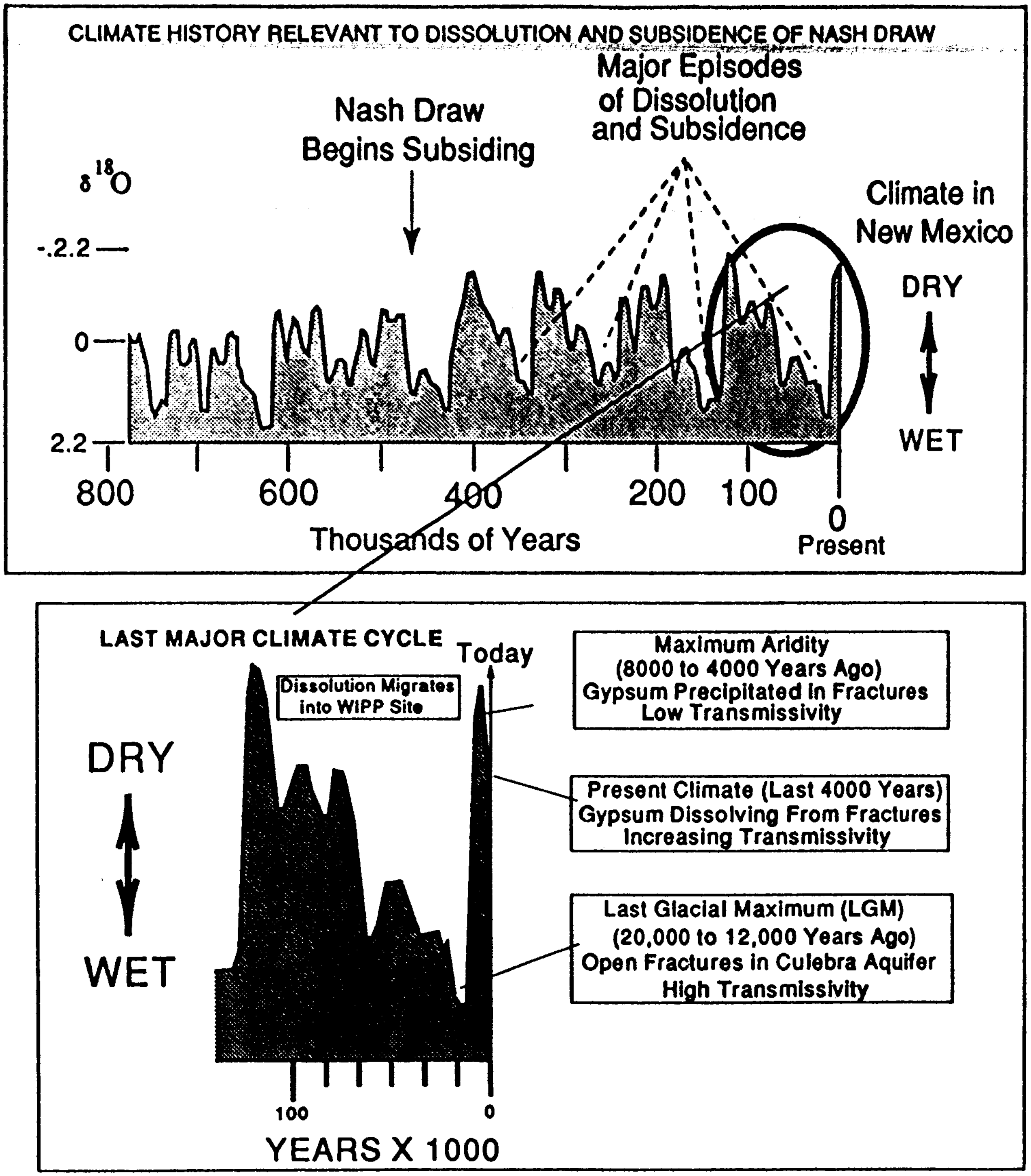

Fig. 3. Wet/dry climate cycles and their effect on the Rustler aquifer in the southern area of the WIPP site. Major climate cycles based on marine isotopic record (see Swift, 1992).

4. Development of a localized pattern of open fractures that corresponds, approximately, with the modern flow path through the Rustler aquifer (Figs. 1, 2, and see Fig. 26 in Beauheim and Holt, 1990).

The effects of the above climate-driven cycle of solution, deposition, and re-solution can be seen in the present-day pattern of open fractures in the Culebra (Fig. 2C, and see CSR Fig. 2-12). This localized pattern corresponds to the area of variable and high hydraulic conductivity, to the area of anomalous tracer tests, and to the main flow path (Fig. 2D).

DOE, as outlined by Swift (1992), has correctly identified a climate history for the WIPP area that is essentially as illustrated in Fig. 3. The CSR, however, does not link this history to dissolution and related changes in the Rustler Formation. The effect on dissolution by the moderate changes in climate that occurred during the last 10,000 years, as shown in stages 1-4 above and in Fig. 3, leads to several observations regarding the effects of larger changes in climate expected in the future.

1. Adjustments of the Rustler aquifer to past changes in climate can be used as a predictor of patterns of dissolution and structural adjustments during future changes in climate.

One can predict that the dissolution front will migrate further eastward and most if not all the remaining soluble beds will be removed from within the Rustler. More important for the performance of WIPP, however, will be the flanking movement of dissolution that extends from the southeastern lobe of Nash Draw. This route will bring active dissolution to the center of the WIPP site shortly after a major change in climate and before the remaining halite in the Rustler Formation is removed along the regional dissolution front.

2. Changes in climate result in rapid adjustment of the aquifer to the altered climate state.

Evidence for this observation is considered in later paragraphs.

3. ***Predictive models based on hydrologic data collected from the existing Rustler aquifer are valid only for the present climate state.***

Rapid adjustment of the aquifer due to dissolution and subsidence following a change in climate means that hydrologic models cannot accurately predict flow rates, retardation, and other measures of WIPP performance on the basis of modern hydrologic data. These adjustments range from dissolution of gypsum in existing fractures to the generation of additional fractures following the removal of soluble strata

Present hydrologic models alter climate input by changing values for hydraulic head in the Culebra aquifer. Such models assume no change in the condition of the aquifer and cannot be used to predict adjustments in the aquifer (e. g. fracturing and channelization) under different climatic conditions. A model that attempted to do so would have to consider so many unknown variables that output from the model would be of little or no value.

Inadequacy of Performance Assessment For Altered Climatic Conditions

The above observations indicate that *there is no adequate means for predicting the performance of WIPP under climatic conditions of increased moisture*. This conclusion is based on the fact that soluble material and strata adjust rapidly, through dissolution and then through subsidence and fracturing, to small increases in the supply of dissolving fluids. For example, a continuation of the increased moisture of the last 4000 years, relative to the dry interval between 8000 and 4000 years ago, will result in further dissolution of secondary gypsum from fractures in the Culebra Dolomite. With only a moderate increase in moisture and head, fractures in the Culebra will continue to widen and accommodate increased flow within a time frame of a few thousand years, thereby reducing the validity of a 10,000-year prediction based on tighter fractures. For even larger increases in moisture, as illustrated in Fig. 3, removal of soluble strata within and below the Rustler Formation will lead to further fracturing and channelized flow, making predictions even less reliable.

DOE, which has closed the issue of karst, probably will challenge the above conclusions on grounds that little or no dissolution, fracturing, or channelization of the aquifer is likely to occur during the next 10,000 years. However, such an argument cannot be based on the assumption that Nash

Draw and the associated fractures in the Rustler are old structures that developed largely during the Cenozoic or early Pleistocene.

Evidence for the on-going nature of dissolution is provided by the distribution of secondary gypsum in Culebra fractures and by the fact that the climate history of the Southwest constrains the time when re-solution and increases in transmissivity occurred (Fig. 3). Another line of evidence that helps date the pace of dissolution is the rate of migration and collapse of Nash Draw. Although Nash Draw grew to its present size during four or five major climate cycles over the last 500,000 years (Fig. 3), eastward migration was undoubtedly marked by episodes of rapid migration during wet intervals separated by cessation of dissolution and fracture filling during periods of dryness. Eastward migration means that most of the soluble materials removed from the Rustler Formation in the vicinity of WIPP were dissolved out during the last major wet climate episode (less than ~100,000 years, see Fig. 3).

Examination of this last major climate cycle at other localities in New Mexico shows that climate changed in a series of strong pulsations lasting no more than a few centuries and that these century-scale wet intervals were grouped into longer cycles of about 2000 years (Allen and Anderson, 1993). Even though the last major wet episode was sustained for more than 50,000 years, actual increases in moisture to double present values during this prolonged interval were much shorter, possibly representing as little as 10,000 years. We are left with the understanding that the time available for active dissolution and the development of karst, in the vicinity of the site, is within the same time frame as the time interval for which prediction is required.

Predictions of future flow in the Rustler under conditions of a doubling of moisture, given the short time frame of dissolution and aquifer adjustment, must deal with the problem of an altered aquifer. For example, assume that a dramatic increase in precipitation occurred 2000 years from now, a real possibility if one examines Fig. 3. Under such conditions a lag between increased precipitation/infiltration and dissolution of nearly 8000 years would be required for a prediction to be valid for 10,000 years. The evidence from the rate of migration of Nash Draw, and from the re-solution of secondary gypsum in fractures, indicates no such lag.

The question of lag effects and how soon dissolution and subsidence will follow a shift in climate depends upon the pathways and rates of infiltration from the ground surface to the Rustler and brine aquifers. Extensive dune cover over the site area has obscured any surface expression of rapid infiltration (e.g. sinkholes and swallow holes). However, a sinkhole and a test well east of Nash Draw and near the western edge of the site (WIPP

33) testify to rapid infiltration. Halite is dissolved from the strata that lie above the finger of high transmissivity, undersaturation, and rapid flow in the Culebra (Fig. 2D). Where did the brine from this dissolved salt go, if not downward and into the Culebra aquifer? Where was the source of dissolving waters? South of the finger is an unexplained decrease in total dissolved solids that provides a strong clue as to how the hydrologic system must work.

The CSR leaves the question of surface recharge of the Rustler aquifer open, stating that "recharge areas and rates remain unidentified" (CSR, p. 6-20). Even after making this unequivocal statement, the CSR concludes, remarkably, that the issues of karst and dissolution are resolved and will not have... "compliance related consequences."

An Important Question

The inability to obtain meaningful predictions of performance over the next 10,000 years raises the question of the proper interval of time for which waste isolation must be assured with acceptable consequences. A 10,000-year period of institutional responsibility was promulgated for radioactive waste disposal on grounds that predictions made beyond that period would be increasingly unreliable. It was argued that if a site could be shown to be stable for 10,000- years, then it was likely that the site would be stable for a much longer interval. Although such an argument might be valid for many geologic sites, it is not valid for the WIPP because of its history of dissolution and the certainty that changes in climate will disrupt the Rustler aquifer.

For a radionuclide such as plutonium (half life of 24,000 years) a realistic period of isolation would be at least 100,000 years. If one examines the regularity of major episodes of past climate change (Fig. 3) and considers WIPP in this context, then the Rustler aquifer would have to survive at least one complete major climate cycle. Given the previous history of Nash Draw, the soluble beds in the Rustler would be completely removed during the next major cycle and the question of retardation of radionuclide transport in the Rustler aquifer would become moot.

A Logical Question

If the existence of karst at WIPP precludes the use of predictive models for performance assessment for the next 10,000 years, how is it that the WIPP project moved forward to its advanced stage of development without recognizing so fatal a flaw?

The answer lies in WIPP history and in an examination of institutional commitments to WIPP as a disposal site. When the first WIPP site had to be abandoned, the one remaining site in New Mexico, Los Medaños, came with several problems. One problem was proximity to potash, petroleum and other resources. For example, producing oil wells nearly encircle the WIPP site. The pattern of well spacing indicates that WIPP sits above a major oil discovery, a fact already known by 1990. The record shows that DOE officials knowingly failed to inform experts about petroleum exploration and production at the site, even though producing oil rigs were in clear view of the WIPP facility (Silva, 1994). This episode illustrates the determination of institutions to complete the WIPP mission in the face of adverse information, but, more importantly, it shows the ineffectiveness of institutional controls and the certainty that the WIPP site is a target for Human intrusion.

The other problem was that about half of the salt in the Rustler aquifer was missing. At that time the reasons for a thin Rustler were not well understood and it was believed that karstic conditions were confined to Nash Draw. Investigators were concerned with travel time for fluids in the Rustler aquifer under existing climatic conditions and profound changes in climate were considered to be mainly a feature of the high latitudes associated with glaciation.

When evidence began to emerge, before WIPP was constructed, that karstic conditions were more widespread than anticipated, this information was ignored, leaving us, today, with consequences made greater by changes in climate. This means that the effects of human intrusion may not only be amplified by the pressurized brine reservoir that is reported to occur beneath the WIPP repository, it will not be possible to predict the consequences of this compounded scenario owing to unknown responses to climate change.

The institutional track record for characterizing WIPP and for considering possible consequences warns us to be certain about having reliable predictions of performance. Therefore, specific recommendations are in order.

Recommendations

1. The discovery of petroleum resources under WIPP, and a greatly increased potential for multiple breaches of the repository, relate directly to climate issues as they effect the performance of the Rustler aquifer. The issue of resources needs to be reexamined, with all the facts on the table.

2. Previous assumptions about the age of Karst are in error, with karst development and dissolution in the site area younger and more extensive than acknowledged. There needs to be a concerted effort to determine the extent of dissolution by means of further exploration.

3. It is acknowledged in the CSR that neither the area nor the rate of recharge of the Rustler aquifer are known. Explanations for Rustler flow, recharge, and geochemistry that draw upon conjectural models of past recharge under changed climatic conditions must be replaced by actual data about the specific areas where recharge is occurring today and about rates of recharge.

4. The Rustler aquifer is progressing through stages of dissolution which may make it impossible to assure predictions of performance within the selected 10,000-year time frame. Further exploration should be directed at determining not only the extent but the history of dissolution within the context of past changes in climate

In the absence of a resolution of key issues related to climate (see recommendations 2, 3, and 4), one must conclude that present hydrologic models are not adequate for performance assessment and that the WIPP project will be unable to demonstrate compliance with EPA requirements for waste isolation.

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