PEER 18 - WIPP conceptual Model Uncertainty Group Review

WIPP PERFORMANCE ASSESSMENT CONCEPTUAL MODEL UNCERTAINTY GROUP

Report on Meeting of 22–25 March, 1993
Albuquerque, New Mexico

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1. INTRODUCTION AND BACKGROUND

The WIPP Conceptual Model Uncertainty Group (CMUG) is an advisory group which was formed to provide guidance to Sandia's WIPP performance assessment (PA) effort. The group includes expertise in hydrology, geology, geochemistry, risk assessment, and environmental modeling. All committee members are consultants drawn from outside the Sandia community (a list of CMUG members is provided in Appendix A). This report summarizes conclusions and recommendations developed by the CMUG during its first meeting, which was held in Albuquerque on 22–25 March, 1993. The first CMUG meeting was held concurrently with meetings of the Geostatistical Expert Group (GXG) and the Fracture Expert Group (FXG), two other WIPP PA advisory groups. The common goal of all three expert groups is to help Sandia produce an accurate and scientifically defensible performance assessment for WIPP.

The motivation for the Conceptual Modeling Uncertainty Group can be traced to concerns expressed by advisory groups, reviewers, and other interested parties about the conceptual basis for WIPP's performance assessment modeling effort. Sandia's approach to PA relies heavily on computer simulations of 'release scenarios' which could conceivably result in the transport of waste from the WIPP repository to the accessible environment. The WIPP PA simulations make many assumptions about the nature of future releases and about the engineered and natural systems that may be affected by such releases. These assumptions have a significant impact on PA predictions and will undoubtedly be focal points for future debates over the validity of the PA.

The WIPP PA procedure relies on a 'conceptual model' of waste transport which assumes that the most likely release scenario is for radionuclides to move through an intrusion borehole upward into the Culebra dolomite portion of the Rustler formation (the E1/E2 scenario). The conceptual model further assumes that wastes entering the Culebra are carried by groundwater moving in response to a regional hydraulic gradient. Exposures at the WIPP compliance boundary depend, in part, on the geohydrologic and geochemical properties assumed for the Culebra. The critical reviews which led to the formation of the CMUG suggested that the PA screening process failed to include a number of plausible alternative conceptual models. Moreover, these reviews argued that the screening process failed to consider a number of physical and chemical processes which could affect waste migration from the repository. Such deficiencies could jeopardize the scientific credibility of the PA process, even if the overall conclusions of the PA are correct.

The charter of the CMUG states:

> "The conceptual model uncertainty ... group is being formed to provide guidance to the WIPP PA program on how to account for uncertainty associated with conceptual models for the groundwater flow and radionuclide transport systems in the Rustler and other non–Salado formations"

The group is also asked to:

> ... help ... on the development of alternative conceptual models and treatment of conceptual model uncertainty ....

It seems neither feasible nor particularly desirable at this point to attempt to quantify conceptual model uncertainty in the way that the GXG is attempting to quantify uncertainty in the travel time predictions obtained from a particular conceptual model. Instead, the conceptual modeling group will try to help Sandia develop a more rigorous scientific justification of the assumptions made in its PA effort. The CMUG may eventually suggest that Sandia carry out new investigations to clarify ambiguities in the existing conceptual model. The CMUG may also suggest that Sandia review and modify assumptions made in the past. Finally, the CMUG may suggest changes in the way that Sandia carries out and documents its PA activities. These items constitute a sort of "working charter" that could change over time.

The next section of this report lists specific topics which the CMUG believes need to examined more carefully in the WIPP PA. The list was compiled from oral and written comments provided by each of the CMUG members after the first group meeting. The final section provides programmatic recommendations which deal with the way the PA effort is organized. It is likely that future meetings of the CMUG will continue to consider programmatic as well as technical questions. CMUG members will be available to help Sandia staff carry out recommendations whenever this is feasible.

2. CONCEPTUAL MODELING TOPICS

During its first meeting the CMUG focused on gaps, ambiguities, questionable assumptions, and simplifications which need to be resolved before a final PA is submitted. The CMUG's initial reaction is that the WIPP PA has concentrated too much on simulation exercises and too little on identifying potential pathways and processes. The PA needs to devote more effort to understanding the origins and evolution of the non–Salado environment, particularly its geology, geochemistry, and hydrology. The PA will rise or fall on its ability to justify the conceptual model used to generate performance statistics.

Specific topics which need more study and/or more careful discussion in the PA report are described in the next four subsections. The first three topics deal primarily with the structure and behavior of the WIPP environment while the fourth topic deals with the selection of transport pathways for PA evaluation.

2.1 Regional Hydrology, Recharge, and the Effects of Climate Change

The WIPP PA effort does not appear to have taken a thorough look at regional hydrology. Basic questions about the sources and magnitude of recharge (if any), the location of the water table, the importance of vertical leakage, and the role of

non-Culebra formations (such as the Dewey Lake Red Beds, the Magenta, and the Tamarisk) remain unanswered. The PA reports prepared to date do not even attempt to give an aggregate water balance for the region. It will be hard to prove that we understand how radionuclides move below the WIPP site if we cannot construct a convincing description of the regional water cycle.

The PA effort should attempt to identify the origin of groundwater flowing beneath the WIPP site. It remains to be seen whether groundwater flow in the Culebra is the result of recharge upgradient of WIPP or is the long term response to a paleoclimatic transient. A paleoclimatic history of the WIPP area should be developed and alternative explanations of regional groundwater flow patterns should be examined in light of this history.

The hydrologic portion of the WIPP PA would probably benefit from a careful analysis of natural geochemical tracers. One of the goals of such an analysis should be to reconcile apparent inconsistencies between available hydrologic and geochemical data. There are large variations in Culebra groundwater chemistry (as evidenced, for example, by TDS measurements) over relatively small distances. These are not discussed in the PA. It seems unlikely that such effects are limited to the Culebra. Future investigations of natural tracers should also include other units above the Salado. An expanded set of geochemical surveys would probably provide useful information about connections between geological units which are now considered to be isolated and independent (see Section 2.3).

It will be very difficult to develop a convincing analysis of the effects of climate change at WIPP until we have a better understanding of groundwater recharge. Recharge depends on vegetation patterns and the hydrogeologic properties of the unsaturated zone as well as rainfall. Moreover, it is likely that recharge in the vicinity of the WIPP site is localized in space and episodic in time. These factors need to be considered as part of a larger study of regional hydrology. It should be noted that recharge at the WIPP site could be comparable to the total flux of groundwater moving through Culebra, depending on the assumptions made. The importance of recharge could increase under the influence of climate change, both as a result of greater total rainfall and as a result of an increase in the intensity and frequency of extreme events which contribute disproportionately to deep infiltration.

Many of the hydrologic questions raised by the CMUG could be addressed with the three-dimensional regional groundwater flow modeling effort currently underway, if this effort were given sufficient support. Unfortunately, the existing 3D modeling effort is not likely to have much impact on the WIPP PA so long as it remains understaffed and underfunded. The 3D modeling work needs to be expanded and a concentrated effort needs to be devoted to the estimation of inputs for the regional hydrologic model. The 3D model should be used to investigate regional flow patterns, including vertical leakage. The model should also be used to assess the significance of transport pathways other than the E1/E2/Culebra pathway which has been the focus of past PA simulations (see Section 2.4).

2.2 Geological History, Evolution, and Structure over a Range of Scales

The CMUG believes that the PA needs to be based on a better picture of the WIPP geological environment. This environment is influenced by a number of interacting factors, including fracturing, dissolution, and regional tectonics. WIPP needs to develop evolutionary (as opposed to purely descriptive) models of Rustler

geology. WIPP should rely on a number of different tools (geological observations, geophysical measurements, geochemical techniques, and hydrologic tests) in its search for scientifically credible models. The WIPP PA does not appear to have used modern geophysical and geochemical techniques to best advantage. This has hindered the development of a credible conceptual model of regional geology.

The WIPP site characterization effort needs to consider the various geological structures or processes that control groundwater flow over the scales of interest for PA. Particular attention needs to be given to the sources and types of fractures present in the Rustler, with an eye to identifying the likelihood that open or highly permeable fractures could be interconnected over significant distances. Horizontal fractures could act as preferred pathways for migrating wastes and vertical fractures could influence recharge and leakage between different units. Although fracture properties provide clues about the processes responsible for fracture formation WIPP does not appear to have made any effort to compile or interpret quantitative data on fracture orientation, density, spacing, or aperture. This makes it difficult to know how fracturing should be accounted for in the PA.

WIPP needs to determine whether connected fracture porosity will induce one, two, or three-dimensional flow and whether this flow contacts a large surface area or is concentrated into preferred pathways. Local variations in fracture structure will have an important effect on transmissivity. Surface area will influence both physical and chemical retardation. There is little or no discussion of such issues in the existing PA. The PA does not justify the use of its "equivalent porous medium" (or continuum) flow and transport models and does not relate the effective properties of these models to the small-scale geological structure of the Culebra. No attempt is made to compare the continuum models to plausible alternatives which may be able to provide just as good a fit to available data.

WIPP geologists appear convinced that dissolution will not be a major issue over the PA time scale. Although this may be true, it would be helpful to see dissolution addressed more seriously (and quantitatively) in the PA. When viewed from a regional perspective the WIPP site is quite close to known dissolution boundaries. It seems conceivable that dissolution could contribute to the enhancement of preferred flow paths in the Culebra, the Salado-Rustler contact zone, and other units lying above the repository horizon. Perhaps dissolution processes could be accelerated by increased recharge rates and/or modifications in brine chemistry resulting from climate change. The presence of Breccia chimneys off-site is an additional cause for concern, even though there is no evidence of such structures in the study area. It seems that the PA should at least consider the possibility that chimneys and other pathways opened by dissolution could serve as transport pathways (see Section 2.4).

2.3 Geochemical Evolution and Composition of Groundwater

The consensus of the CMUG is that the WIPP PA has not given sufficient attention to geochemistry. The project does not presently have either the staff or the data base needed to properly address the complex geochemical processes which have shaped the WIPP environment. The focus in the PA has been primarily on chemical retardation rather than on the geochemical evolution of groundwater at the site. WIPP geochemistry involves much more than "taking credit" for chemical retardation. Improved geochemical understanding could shed light on WIPP geohydrology, providing useful information about regional flow patterns, the effects of recharge, the impact of dissolution, and the importance of preferred

pathways.

Geochemical issues at WIPP can be loosely divided into questions relating to the natural evolution of the site and questions relating to the behavior of radionuclides released into the WIPP environment. The PA should be able to construct, from both geological and hydrochemical data, a coherent description of the composition and history of groundwater in the Rustler and Dewey Lake Red Beds. At present, only the hydrochemical zonation of the Culebra is being addressed and this information has not been convincingly related to flow within the formation (see comments in Section 3.1, above). WIPP should investigate the possibility of combining environmental isotope data (e.g. ^{3}H, D, ^{14}C, ^{36}Cl, oxygen isotopes, etc.) with major and trace element data in order to get a more complete picture of both flow and geochemistry in the units lying above the Salado. Geochemical data from the Magenta, Tamarisk, Dewey Lake Red Beds, and various 'aquitard' units should be included in this investigation.

Considerable uncertainty remains about the composition and properties of radioactive wastes considered in the PA transport studies. WIPP needs to devote more effort to understanding the solubility and speciation of radionuclides in room brines and in the brines naturally present in geological formations lying above the Salado. Organic complexants and chelating agents produced by waste degradation could have a significant influence on the solubility and mobility of radionuclides. The WIPP PA needs to consider the stability of such organics as well as their interactions with the surrounding geologic medium. Engineered barrier corrosion products (such as ferrihydrites) could act as sources of colloidal material which could facilitate transport. The PA needs to consider the production, stability, and sorption properties of colloids in the repository environment and in the Rustler and Dewey Lake formations. Special attention should be given to transport in the vicinity of geochemical discontinuities where radionuclide speciation may change and colloids may be generated or destroyed.

The PA needs to consider the possibility that changes in brine chemistry due to a waste release could have effects on the hydraulic properties of fractures and other pathways in the Rustler and Dewey Lake Red Beds. These changes could result in dissolution in some areas and in fracture "healing" (due to precipitation of supersaturated salts) in other areas. There is also the possibility of anion exclusion or other geochemical processes that could enhance transport by reducing the porosity available for flow. The PA should examine some of the possibilities with exploratory calculations which could demonstrate whether or not a given effect is important enough to be included in the PA simulations.

One of the major questions confronting the WIPP PA is the role of matrix diffusion in radionuclide transport. The critical features are the extent to which the matrix porosity of the rock is available as a diffusion reservoir and the nature of sorbing surfaces within that reservoir. The matrix diffusion model presently used in the WIPP PA does not seem well constrained in these respects since it can produce almost any degree of retardation. The model's parameters need to be related more directly to physical properties such as fracture spacing, matrix porosity, and brine diffusivity (as revealed by paleoprofiles of substances such as chloride, taken across fractures and into the rock). The model should also consider natural decay series radionuclide disposition in rocks and groundwaters as well as the thickness and persistence of clay fracture linings. Pore-filling minerals such as clays will undoubtedly influence the sorption of radionuclides along preferred

transport pathways.

The above discussion indicates that there are many geochemical processes which could be relevant in the complex WIPP environment. It will not be feasible to carry out detailed field or laboratory studies of most of these processes. But the PA should attempt to identify and rank potentially important processes with respect to their possible effect on compliance. Effort can then be concentrated on a few key geochemical issues.

It should be noted that CMUG members differ as to the advisability of 'taking credit' for chemical retardation in the PA. Some members feel that it would be better to avoid debates about geochemistry by making conservative assumptions which ignore sorption. Other members feel that this approach is risky, both because it tends to deemphasize the importance of geochemical effects and because it increases the chance that compliance targets might be violated if new scenarios are included in the PA process. This issue will be discussed further in future CMUG meetings.

2.4 Alternative Transport Pathways

The WIPP PA has, for reasons not completely clear to the CMUG, only identified a single transport pathway for wastes released from the repository — the E1/E2 intrusion borehole Culebra pathway. A preliminary review by the CMUG suggests that a number of other possible pathways deserve further investigation. These alternatives can be summarized as follows:

1. Transport through All or Part of the Rustler Formation — WIPP should consider the possibility that wastes carried upward through an intrusion borehole could travel through a number of different Rustler units, particularly the Magenta dolomite and the Salado–Rustler contact zone. The CMUG recognizes that WIPP's transmissivity estimates suggest that these units are much less conductive than the Culebra. These estimates, which are based on very limited data, should be backed up by geological arguments which identify the reasons why other Rustler units can be ignored, despite the existence of extensive fracturing. Investigations of Rustler transport should consider various intrusion borehole plug options, included no plug (see discussion in Section 3.2 below)

2. Transport through the Dewey Lake Red Beds — Rising water levels caused by climate could saturate significant portions of the Dewey Lake Red Beds, which could then serve as transport pathways for wastes carried upward through intrusion boreholes. It is possible that wastes moving in saturated Dewey Lake units could be accessible to water supply wells drilled in the future. Given ambiguities about the location of the regional water table and existence of perched water it seems that a more careful look at the Dewey Lake pathway is warranted.

3. Multiple Borehole Pathways — It is possible that waste released from the repository could move vertically between various Rustler and Dewey Lake units, following abandoned boreholes (either from hydrologic or oil and gas exploration). Increased vertical communication would enable wastes to travel along least resistance

pathways winding through several different units. Variants on this theme would account for enhanced vertical transport through past and future potash mine shafts.

4. Direct Release of Brine to the Surface — Historical evidence indicates that an unplugged borehole encountering a pressurized reservoir below the repository could carry contaminated brine directly to the surface, at least for a limited time period. Although such surface releases will be transient they could contribute significantly to the cumulative exposures of interest for compliance.

5. Vapor-borne Surface Releases — Radionuclides entrained in a pressurized two-phase gas-brine mixture could conceivably move upward through vertical fractures and abandoned boreholes directly to the surface, bypassing the slower, more tortuous groundwater pathway. It does not appear that the PA has given any serious thought to this escape route.

6. Enhanced Culebra Transport — Preliminary calculations suggest that the flux of brine released by an intrusion borehole penetrating a brine reservoir below the repository could be much larger than the natural groundwater flux through the Culebra, at least for a relatively short time following intrusion. If this hypothesis is correct, it is possible that liquid wastes could be pushed through the Culebra under pressure, irreversibly opening up fractures and shortening travel times to the accessible environment. The brine transient could also be expected to change the density of the natural groundwater, with accompanying effects on groundwater flow, and to induce major changes in Culebra geochemistry.

7. Pathways Created by Intrusion-induced Subsidence — It seems possible that future intrusions, particularly potash mining, could have effects similar to dissolution, in that they could induce localized collapse such as observed at Breccia chimney locations near the WIPP site. Collapse could open new pathways or enhance transport in existing pathways between the Culebra and the accessible environment.

We wish to emphasize that the CMUG does not necessarily believe that any or all of the transport pathways identified above are more important than the E1/E2/Culebra pathway investigated in the PA. But it is reasonable to expect some justification for the omission of such alternatives from a screening analysis which is supposed to be comprehensive. The assumption that the Culebra is confined is not justified in the PA, which also does not mention that the location of the water table is unknown over most of the study area. The PA should clearly explain why the Culebra pathway is the only one worth considering or, alternatively, it should be expanded to include consideration of other pathways.

3. PROGRAMMATIC RECOMMENDATIONS

The following recommendations address programmatic issues which the CMUG believes are relevant to Sandia's ability to produce a scientifically defensible PA. The recommendations are grouped into three broad categories which deal, respectively, with the formation of an in-house conceptual modeling group, the scenario screening process, and the scope of the PA effort.

3.1 In-house Conceptual Modeling Group

WIPP should start an in-house conceptual modeling group which brings together representatives from both the PA and test plan sides of the project. This group should meet periodically in open-ended workshops and brainstorming sessions. Questions raised in the in-house group should be similar to those raised by the CMUG. In fact, if the WIPP group is truly successful it should be able to take over most of the functions of the CMUG. The in-house conceptual modeling group should take maximum advantage of available WIPP literature in documenting responses to conceptual modeling questions raised both inside and outside the group. Representatives of this group should include long-term staff members who can provide corporate (or project) 'memory'. The in-house conceptual modeling group may be able to provide most of the staff resources needed to produce the 'issue papers' mentioned in Section 3.3 below.

3.2 Scenario Selection and Screening

The WIPP PA formalism reserves the word 'scenario' for uncertain events that may happen in the future. These include discrete natural events such as earthquakes, prolonged natural events such as dissolution or climate change, and discrete human intrusion events. The PA has devoted considerable effort to consideration of an extensive list of possible events which have been eliminated, one by one, from consideration. The result of this screening process is essentially two 'scenarios', an undisturbed (or 'base') case and a borehole intrusion scenario which has a few variants (the E1/E2 scenario).

The CMUG believes that the assumptions and methods used in the scenario screening process need to be reviewed. The difficulties of the present approach to screening are illustrated by the way the E1/E2 scenario was developed. The final intrusion scenario was assumed, without any real justification, to include an impermeable borehole plug placed just above the Culebra. This has the effect of forcing released waste through the Culebra and diverting it from the Dewey Lake Red Beds and other potential pathways mentioned in Section 2.4. The borehole plug assumption was made despite the fact that pressurized brine has already escaped from unplugged exploratory boreholes drilled at the site.

It appears that the WIPP PA has relaxed the questionable borehole plug assumption since publication of the last PA report. But the fact remains that a scenario screening process that could come up with such an assumption should be viewed with some skepticism. Scenario screening and conceptual model formulation are not objective processes. They depend on the creativity and judgment of the analyst. For this reason the process of identifying scenarios and conceptual models should provide for input from many sources and should be sufficiently open-ended to include new alternatives as they arise. Particular attention should be given to coupled scenarios, which combine one or more intrusion events with various natural events (such as tectonic activity, enhanced dissolution, and/or increased recharge). Coupled scenarios that have low probability but give high cumulative exposures may have an important impact on compliance and cannot be dismissed out of hand.

The WIPP PA should seriously consider ways to better relate the scenario screening process to site characterization and test plan activities. The process of eliminating plausible events, such as a rising Dewey Lake water table or opening up of fractures due to a low-probability tectonic event, should be made more

rigorous and the arguments should be more carefully documented.

3.3 Scope and Structure of the PA Effort

The CMUG has raised and will continue to raise many difficult questions, both about conceptual models of the WIPP environment and about selection of scenarios for PA evaluation. It is likely that similar questions will be raised by the in-house modeling group proposed above as well as by regulators, interveners, and other interested parties. The present PA effort cannot respond to all of these questions, partly because of staff and time constraints and partly because WIPP's PA process is designed primarily to demonstrate compliance in a narrow probabilistic sense. It is possible that this emphasis on probabilistic compliance, as demonstrated by simulation-based probability distributions (CCDF's), is short-sighted. EPA's regulations make it clear that actual compliance depends on the scientific credibility of the performance assessment as well as the results of probabilistic scenario evaluations. The difficult questions raised by the CMUG and others will probably need to be addressed in some form before the approval process is completed. Consequently, WIPP should begin to consider how it can deal with conceptual modeling issues which do not fit neatly into the existing PA framework.

The most obvious way to address the conceptual modeling issues raised by the CMUG is to incorporate previous and on-going site characterization (or 'test plan') studies into the PA. The existing PA reports could be accompanied by a set of issue papers or reports which deal (in some depth) with the four basic conceptual modeling topics considered by the CMUG. These reports could be prepared by teams of WIPP investigators drawn from the test plan or research groups most closely involved with each topic.

Given time and resource limitations, the conceptual modeling reports would have to rely heavily on existing WIPP technical literature. Conversations with WIPP personnel indicate that many of the topics considered by the CMUG have been investigated in the past. The results of these investigations have, for various reasons, not found their way into PA documents and have often not had much influence on PA simulations. This situation needs to be corrected as soon as possible. Otherwise, WIPP may find that it has no formal way to reply to regulators, interveners, and others who question the basic premises of the PA simulations.

It is time for the WIPP PA to step back from its simulations and to consider the scientific justification for its overall approach. The PA is attempting to base an analysis of a very complex physical system on a very limited data base. It seems unreasonable to expect the uncertainties in such an analysis to be handled exclusively by a set of Monte Carlo simulations. It also seems unlikely that planned refinements in the PA simulations will have a major impact on PA conclusions. WIPP should deemphasize its simulation efforts and concentrate instead on producing more thoughtful discussions of relevant hydrologic, geologic, and geochemical issues. The resources to do this are available within WIPP if they are properly mobilized.

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SANDIA WIPP PROJECT MATRIX DIAGRAM

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