EEG-57

AN APPRAISAL OF THE 1992 PRELIMINARY PERFORMANCE ASSESSMENT FOR THE WASTE ISOLATION PILOT PLANT

William W.-L. Lee
Lokesh Chaturvedi
Matthew K. Silva
Ruth Weiner
Robert H. Neill

Environmental Evaluation Group
New Mexico

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Lokesh Chaturvedi
Matthew K. Silva
Ruth Weiner
Robert H. Neill

Environmental Evaluation Group
7007 Wyoming Blvd., NE, Suite F-2
Albuquerque, NM 87109

and

505 North Main Street
Carlsbad, NM 88221

September 1994

FOREWORD

This is the Environmental Evaluation Group's (EEG) appraisal of the 1992 performance assessment for the Waste Isolation Pilot Plant. Performance assessments have been performed by Sandia National Laboratories for the U. S. Department of Energy to predict the long-term safety of the Waste Isolation Pilot Plant. The 1992 Performance Assessment, entitled *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992,* is in five volumes:

vol. 1: Third Comparison with 40 CFR 191, Part B;

vol. 2: Technical Basis;

vol. 3: Model Parameters;

vol. 4: Uncertainty and Sensitivity Analysis for 40 CFR 191, Part B;

vol. 5: Uncertainty and Sensitivity Analysis for Gas and Brine Migration for Undisturbed Performance.

This current appraisal incorporates EEG's preliminary comments on volumes 1, 2, and 3 transmitted to the U. S. Department of Energy on September 13, 1993, and volumes 4 and 5 received October 27, 1993.

The purpose of the New Mexico Environmental Evaluation Group is to conduct an independent technical evaluation of the Waste Isolation Pilot Plant (WIPP) Project to ensure the protection of the public health and safety and the environment. The WIPP Project, located in southeastern New Mexico, is being constructed as a repository for the disposal of transuranic (TRU) radioactive wastes generated by the national defense programs. The EEG was established in 1978 with funds provided by the U.S. Department of Energy (DOE) to the State of New Mexico. Public Law 100-456, the National Defense Authorization Act, Fiscal Year 1989, Section 1433, assigned EEG to the New Mexico Institute of Mining and Technology and continued the original contract DE-AC04-79AL10752 through DOE contract DE-ACO4-89AL58309. The National Defense Authorization Act for Fiscal Year 1994, Public Law 103-160, continues the authorization.

EEG performs independent technical analyses of the suitability of the proposed site; the design of the repository, its planned operation, and its long-term integrity; suitability and safety of the transportation systems; suitability of the Waste Acceptance Criteria and the generator sites' compliance with them; and related subjects. These analyses include assessments of reports issued by the DOE and its contractors, other federal agencies and organizations, as they relate to the potential health, safety and environmental impacts from WIPP. Another important function of EEG is the independent environmental monitoring of background radioactivity in air, water, and soil, both on-site and off-site.

Robert H. Neill
Director

EEG STAFF

Sally C. Ballard, B. S., Laboratory Scientist

William T. Bartlett, Ph. D., Health Physicist

Radene Bradley, Secretary III

Lokesh Chaturvedi, Ph. D., Deputy Director & Engineering Geologist

Paula Sue Downes, B. S., Assistant Environmental Technician

Patricia D. Fairchild, Secretary III

Donald H. Gray, M. A., Environmental Specialist

Jim W. Kenney, M. S., Environmental Scientist/Supervisor

Betsy J. Kraus, M. S., Technical Editor/Librarian

William W.-L. Lee, Sc. D., P. E., D. E. E., Senior Scientist

Robert H. Neill, M. S., Director

Jill Shortencarier, Administrative Secretary

Matthew K. Silva, Ph. D., Chemical Engineer

Susan Stokum, Administrative Secretary

Ben A. Walker, B. A., Environmental Technician

Ruth F. Weiner, Ph. D., Senior Scientist

Brenda J. West, B. A., Administrative Officer

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The Environmental Evaluation Group (EEG) has reviewed the WIPP*1992 Performance Assessment*. The Sandia team should be commended for both the substance of this work, and a sound theoretical foundation. Progress has been made towards assessing WIPP's compliance with the U.S. Environmental Protection Agency's Standards for high-level and transuranic waste. Our comments on the *1992 Performance Assessment* are organized into Major Issues, and Detailed Comments. Specific recommendations on major issues follow.

1. Claimed Improvements in the *1992 Performance Assessment.*
   - R-1.1 Apply available fully coupled codes to make explicit the relationship between the complex processes of gas generation, brine flow and room closure.
   - R-1.2 Abandon further statistical manipulation of transmissivity fields in the Culebra in favor of additional field and laboratory work to better define multi-well flow and transport characteristics, including flow and tracer tests (sorbing and non-sorbing) at additional locations.
   - R-1.3 Abandon claiming credit for matrix diffusion and corrensite sorption until experimental data can substantiate the claim.
2. Displaying Uncertainty in Final Results
   - R-2 Show the full uncertainty band of CCDFs when comparison with the containment requirement (40 CFR 191) is made.
3. Use of Judgment in Performance Assessment
   - R-3.1 As experimental solubility values become available (e.g. Nitsche *et al.,* 1992; 1993), use them in performance assessment.
   - R-3.2 Use only demonstrable retardation coefficients in performance assessment.
   - R-3.3 Discard the subjective probabilities for human intrusion used in the *1992 Performance Assessment* and adopt the specific suggestion in Section 3.4.
4. Computer Code Documentation
   - R-4 Establish a workable system to provide EEG with relevant documentation, so that EEG has reasonable access to perform its work.
5. The Culebra as a Natural Barrier
   - R-5 Quantify the extent of matrix diffusion and sorption through accelerated experimentation.
6. Effects of Gas Generation
   - R-6 In future analysis, the deleterious effect of gas generation should be included.
7. Correlation Among Variables
   - R-7 The performance assessment should either give reasons why physical correlations have been ignored, or show results with correlations.

8. Natural Resources Near the WIPP
   - R-8 Performance assessment reports should accurately reflect the status of resource development near the WIPP site.

9. Oil and Gas Production Near the WIPP
   - R-9 The performance assessment effort should use the latest and verifiable data on oil and gas production near the WIPP, because the extent of oil and gas resources in this area is likely to be an important determinant of inadvertent human intrusion, and oil and gas production can potentially affect the hydrogeology at the WIPP site.

10. Gas Generation
   - R-10a The gas generation calculations should include
     - (a) methane generation,
     - (b) radiolytically generated hydrogen.
   - R-10b The relationships in the gas generation model should be validated before the gas generation model is incorporated into BRAGFLO.

11. Unanalyzed Scenarios
   - R-11.1 The criticality issue needs to be thoroughly evaluated before it can be concluded that its effects are negligible.
   - R-11.2 Subsidence effects need to be evaluated in much more detail and incorporated, in some manner, into the human intrusion scenarios.
   - R-11.3 Provide results of the abovementioned analyses, and include contaminated brine flow to the ground surface in future versions of human intrusion scenarios.
   - R-11.4 Perform a complete analysis of a brine-slurry release scenario. In addition, variants of the brine-slurry scenario in undisturbed performance and in the E2 scenario need to be better understood.
   - R-11.5 Performance Assessment should not assume perfect plugging of abandoned oil and gas wells near the WIPP. For the human intrusion borehole, the range of degraded permeabilities should span sand and gravel.

12. Analysis of Direct Discharge to the Ground Surface
   - R-12 Future performance assessments need to include erosion of waste by helical turbulent flow and the effect of sediment erosion. Also needed is analysis of other relevant scenarios, such as the E1E2 with brine slurry discharge to the surface.

13. Inventory
   - R-13.1 Include ^{135}Cs, ^{129}I and ^{99}Tc and other fission product nuclides as appropriate in future performance assessments.
   - R-13.2 Show the basis for inventories used.

14. Solubilities

R-14 In future performance assessments, limit the sampling range to the error bands in experimental data.

15. Transport Modeling of Volatile Organics

R-15 Two-phase transport of volatile organic compounds through gas-fractured interbeds should be analyzed in the future.

16. Corrensite Retardation in the Culebra

R-16 Abandon claiming credit for corrensite sorption as well as additional experiments with corrensite, unless the extent of corrensite or other clay minerals can be quantified along postulated flow paths.

17. Ideal Gas Assumption in VOC Migration

R-17 Unless there is experimental evidence that VOC vapors move as ideal gases and move with the low-molecular-weight gases generated by radiolysis, corrosion, or microbial action, movement of VOC vapors should not be modeled as ideal gas flow in showing compliance with 40 CFR 268.

I. INTRODUCTION

The Environmental Evaluation Group (EEG) has reviewed the WIPP *1992 Performance Assessment* (Sandia WIPP Performance Assessment Department, 1992). Although this performance assessment was released after the October 1992 passage of the WIPP Land Withdrawal Act (PL 102-579), the work preceded the Act. For individual and ground-water protection, calculations have been done for 1000 years post closure, whereas the U.S. Environmental Protection Agency's Standards (40 CFR 191) issued in 1993 require calculations for 10000 years.

This is the third iterative performance assessment of the Waste Isolation Pilot Plant (Sandia WIPP Performance Assessment Department, 1992; 1991; Bertram-Howery *et al.*, 1990). EEG believes the Sandia team should be commended for both the substance of this work, and a sound theoretical foundation for performance assessment. The *1992 Performance Assessment* continues to assimilate improved understanding of the geology and hydrogeology of the site, and evolving conceptual models of natural barriers. Progress has been made towards assessing WIPP's compliance with the U.S. Environmental Protection Agency's Standards (40 CFR 191).

The *1992 Performance Assessment* has addressed several items of major concern to EEG, outlined in our July 1992 review of the 1991 performance assessment (Neill *et al.*, 1992). In particular, we are pleased that some key results in this performance assessment, shown in Chapter 5 of volume 1, deal with sensitivity of the calculated complementary cumulative distribution functions (CCDF) to alternate conceptual models proposed by EEG—that flow in the Culebra be treated as single-porosity fracture-flow; with no sorption retardation unless substantiated by experimental data. We look forward to results of additional analysis using scenarios and assumptions that EEG has suggested in the past and hereinafter.

Our review is organized into Major Issues, and Detailed Comments.

II. MAJOR ISSUES

1. Claimed Improvements in the *1992 Performance Assessment*

The overall conclusions of the *1992 Performance Assessment* are stated in chapter 9 of volume 4. Several improvements over previous assessments are noted, and we discuss the claimed improvements below.

1.1 While the first major improvement noted is the coupling of repository creep closure modeling to gas generation and brine flow, the coupling is not entirely satisfactory. The geomechanical closure calculated by SANTOS is passed onto BRAGFLO although the two computer codes use different conceptual models, geometries, and time scale.

Recommendation 1.1. Apply available fully coupled codes to make explicit the relationship between the complex processes of gas generation, brine flow and creep closure.

1.2 The *1992 Performance Assessment* accounts for spatial variation of transmissivity in the Culebra using improved methods. Table 8.4-1 in volume 4 shows that variation in Culebra transmissivity fields accounted for a mere 6% of the variation in total integrated releases. The respective solubilities of Am, Np, Pu, Th and U accounted for more of the variation in release rates.

Recommendation 1.2 Abandon further statistical manipulation of transmissivity fields in the Culebra in favor of additional field and laboratory work to better define flow and transport characteristics, including flow and tracer tests (sorbing and non-sorbing) at additional locations.

1.3 The *1992 Performance Assessment* accounts for radionuclide transport in the Culebra "more accurately" [sic]. To be accurate implies the existence of an unique and correct standard which does not exist in this case. The *1992 Performance Assessment* considers three radionuclide retardation mechanisms in the Culebra: equilibrium sorption, matrix diffusion and clay sorption. For equilibrium sorption, the second modification of the Consultation and Cooperation Agreement between the Department of Energy (USDOE) and the State of New Mexico specifies that retardation coefficients shall be set to zero unless there are experimental data otherwise. The *1992 Performance Assessment* offers no experimental evidence for matrix diffusion. No clear evidence is given for the extent of corrensite in the calculated flow paths. Moreover, clay in fractures can act either as an additional sorption agent, or serve to block mass transfer between the fracture and the matrix. The *1992 Performance Assessment* has eliminated the latter role [vol. 2, p. 7-23, line 11]. This is double counting for a mechanism which may not exist. We deal with the role of corrensite in detail in 16.

Recommendation 1.3 Abandon claiming credit for matrix diffusion and corrensite sorption until experimental data can substantiate the claim.

The *1992 Performance Assessment*

> ...accounts for the effects of passive marker systems through time-varying drilling intensities within the Poisson model for calculating intrusion probabilities [vol. 4, p. 9-1].

What this means is that subjectively elicited probabilities of drilling intrusion that are orders of magnitude below the USEPA guidance (40 *CFR* 191, Appendix C) have been used. The EEG objects to the use of these probabilities as elicited. We deal with this topic in 3b below.

The *1992 Performance Assessment* states that the following improvements will be made in future performance assessments:

- modeling pressure fracturing of anhydrite interbeds,
- modeling three-dimensional flow in the Rustler, especially the effects of subsidence of potash mine excavations,
- incorporating plug degradation,
- modeling spalling in drilling intrusions,
- acquiring experimental data on actinide solubilities and retardation,
- determining the most appropriate conceptual model for radionuclide transport in the Culebra.

We have called for these improvements for several years, and welcome the commitment.

2. Displaying Uncertainty in Final Results

In previous performance assessments, the USDOE noted that the calculated CCDF's were at least an order of magnitude below the allowable limits in the USEPA Standards (Sandia WIPP Performance Assessment Department 1991). In the *1992 Performance Assessment*, for the case of total release from repository/shaft barrier only, and a [0, 30] sampled intrusion rate, the mean CCDF comes to within a factor of two or three of the USEPA containment requirement [vol. 4, Fig. 9-1, curve 1]. This suggests several vectors of CCDF lie in the zone of violation of the containment requirement. This mean CCDF is not as conservative as it may appear because subjectively elicited solubilities are incorporated. The non-conservative basis of curve 1 in Figure 9-1 is illustrated in Figure 1. Using BRAGFLO-calculated brine flow from the repository up to the Culebra (70 vectors for both the E2 and E1E2 scenarios), all actinide solubilities at 10^{-3}, 10^{-5} and 10^{-7} M, and the human intrusion rate sampled uniformly between 0 and 30 boreholes/km^2/10,000 years, the mean CCDFs are shown in Figure 1, along with curve 1 from Figure 9-1 (vol. 4). If the extremely low subjectively elicited solubilities are **not** used, then the mean CCDF for the case of engineered barriers alone may not meet the containment requirement. See also 14 below.

The EEG has also suggested to the USEPA that for comparison with the containment requirement, that the 90% curve be used to be conservative.

Recommendation 2. Show the full uncertainty band of CCDFs when comparison with the containment requirement (40 CFR 191) is made.

3. Use of Judgment in Performance Assessment

3.1 Beginning with the *1992 Performance Assessment*, "expert judgment" is used to estimate

a. solubilities of actinides;

b. retardation coefficients of radionuclides; and

c. probabilities of inadvertent intrusion.

Experimental programs are underway to measure solubility and retardation coefficients, for conditions relevant to the WIPP.

Recommendation 3.1. As experimental solubility values become available (e.g. Nitsche *et al.*, 1992; 1993), use them in performance assessment.

3.2 The second modification of the Cooperation and Consultation Agreement between the Department of Energy and the State of New Mexico specifies that retardation coefficients be set to zero unless experimental data shows otherwise. Results using zero and nonzero retardation coefficients appear in chapter 5 of volume 1.

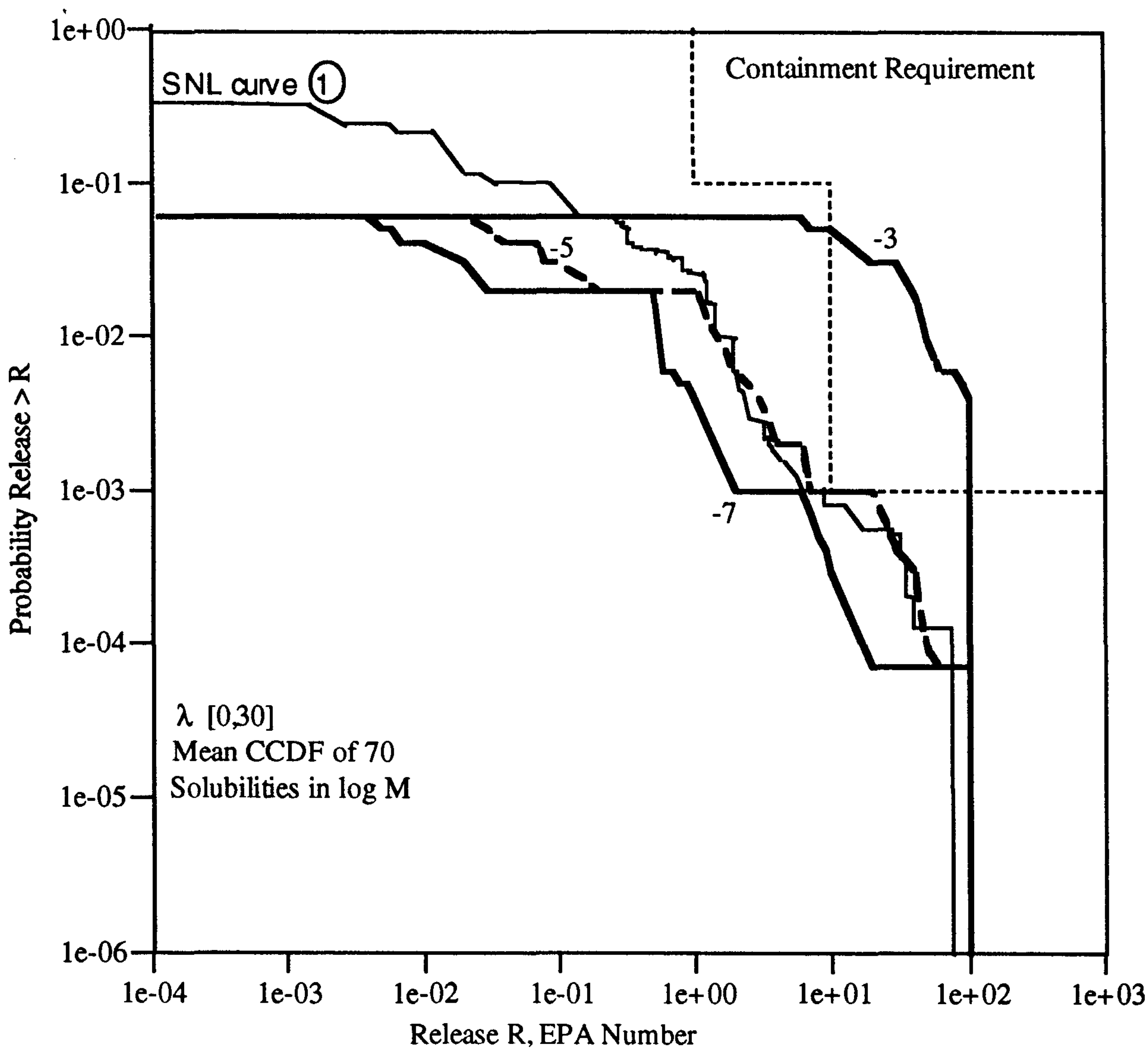

Figure 1. Comparison of mean CCDFs from the EEG scenario of direct ground discharge for all actinide solubilities set at 10^{-3}, 10^{-5}, and 10^{-7} M with Curve 1 from Figure 9-1 of SAND92-0700/4.

Recommendation 3.2. Use only experimental retardation coefficients.

3.3 EEG is concerned about the use of subjective probabilities in human intrusion analysis. While human judgment may be the only method of estimating these probabilities, we disagree with the procedure used in the *1992 Performance Assessment* to estimate human intrusion probabilities.

3.3.1 The disagreement between EEG and SNL centers around how the problem of subjective elicitation is to be formulated, whom to use as panelists and what information should be supplied to the panels. Elicitation should have been for the probability of future human intrusion by drilling for resources, the judges should have been people experienced in oil and gas and energy futures, and factual information should have been given to the judges during orientation.

Table I summaries the divergence.

Table I. Summary of Disagreement on Subjective Elicitation

Topic	SNL	EEG
Problem Formulation	Open	Focused
Required expertise	Knowledgeable in a subject	Knowledgeable in the focused subject
Briefing	Available information	Verified Information

SNL prefers to set no limits on the exercise, whereas EEG believes the problem must be well-defined. The divergence is clear from the SNL definition of an expert:

> An expert possesses exceptional knowledge about **a** subject [Hora to the Futures Panel, August 13, 1990 and to the Marker Panel, November 4, 1991].

EEG claims that the relevant definition should be

> An expert possesses exceptional knowledge about **the** subject.

3.3.2 The probabilities that have been elicited from panels for the purpose of estimating future intrusion intensity (Hora, von Winterfeldt and Trauth, 1991) are subjective probabilities. To call them "expert judgment" is to give them an aura of respectability they do not deserve. The methods for eliciting such probabilities come from statistics (Savage, 1954) and experimental psychology (Edwards, 1954). There are futurologists, such as Alvin Toffler or John Naisbitt, but the SNL Futures Panel was not composed of these people. While the elicitation of opinions is valid, the elicitation of expert opinion on the future is gratuitous. The WIPP Performance Assessment Department undertook an "extensive and impartial process" to select the panelists, but the process alone did not ensure the appropriateness of the chosen candidates. No attempt appears to have been made to establish the qualifications of the panel members as experts on the future. If the WIPP Performance Assessment Department had defined the problem properly, then it would be much easier to establish the expertise of the panelists.

3.3.3 The WIPP Performance Assessment Department invokes the interdisciplinary nature of an expert judgment panel as a reason to use such a panel. But "interdisciplinary" is not a synonym for "good" or "appropriate" any more than "single disciplinary" is a synonym for "bad" or "inappropriate." The advantage of multidisciplinary data interpretation over interpretation by an expert in a single discipline is not at all clear. For example, the marker panel (Rechard *et al.,* 1993; Table I) lists experts in materials science, architecture, linguistics, communications, etc. How is the judgment of a linguist on materials hardness and durability relevant? Either the linguist accepts the materials scientist's judgment, in which case the interpretation is not interdisciplinary, or the two differ in interpretation, in which case the materials scientist's interpretation is clearly the more valid and that judgment should not be diluted.

3.3.4 In the attempt to find general experts in lieu of futurologists, SNL might have empaneled representatives from diverse backgrounds, but failed to do so. The panels are not representative of modern United States, not representative of the modern world, and not representative of the historical continuity of the human race. While there were historians, sociologists and anthropologists, there was only one woman on the markers panels and none on the futures panels. There are no representatives of indigenous cultures of the southwestern United States.

In the USDOE response to the preliminary comments from the EEG, SNL stated

> The EEG should note, in fairness, that the range of organizations from which the experts were selected (Natural Resources Defense Council, universities, institutions,

> etc.) provides rich diversity in political and environmental organizations.

This statement is counter to the claim that panelists were selected on the basis of their individual qualifications.

3.3.5 The elicitation process used was open-ended. While it is true that what will be mined over 10,000 years is unknown, let alone where to mine it, the problem is simpler for a specific area with known minerals. For example the Outer Continental Shelf Lands Act allows oil and gas drilling in the sea beyond the three-mile limit, but includes a clause for "other minerals." When the Outer Continental Shelf Lands Act was first passed in 1953, "other minerals" referred to sulfur. By the mid-1970s the focus of other minerals became construction aggregates around coastal cities, and in the early 1990s, manganese crusts. At a specific location, with geologic information, we know what can be mined now and in the future. The minerals to be mined will change only if society's needs change dramatically. If that had been borne in mind, the problem would have been much more circumscribed, and the results more realistic and reliable.

In the USDOE response to the preliminary comments from the EEG, SNL stated

> This comment [above] proposes that the experts be directed as to what potentially intrusive activities to study. We believe that this is inappropriate and would not stand up under peer review due to extensive direction by the analytic staff.

All elicitations have to be circumscribed, if only to ensure that the problem is within the expertise of the judges. Figure 2 is a reproduction of a SNL viewgraph shown to the panelists, demonstrating how the SNL analysts defined the problem and may have biased the panelists.

3.3.6 Results of the open-ended elicitation process used by Hora (Hora, von Winterfeldt and Trauth, 1991) appear to have been used selectively. If a more circumscribed process had been used, then the methods available to combat cognitive bias (Tversky and Kahneman, 1974) could have been used. Unfortunately, the results used in the *1992 Performance Assessment* strongly reflect the intervention of the analyst. The final result used a form

$$\lambda_t = d(1 - p_1 p_2) \tag{1}$$

where λ is the intrusion intensity, number of holes per time, d is the raw drilling intensity number of holes per time, p_1 is the probability of markers surviving, and p_2 is the probability

How Will the Expert Judgments Be Used in the WIPP Performance Assessment?

- The findings of the expert teams will provide modes of intrusion. These modes will be grouped into similar types of intrusions and modeled.
- The frequencies of intrusion given by the experts will be encoded as rates and used as input to simulation studies.
- The expert judgments will be both analyzed separately and combined into a base case. The analyses will preserve the findings of the individual teams.

Figure 2. Reproduction of a viewgraph shown to the Future and Markers Panels by SNL, showing SNL's formulation of the problem.

that surviving markers are effective in deterring drilling, all functions of time. The paradigm was not elicited from any one panel, but the result is a mixture of results from the panelists, who may not have understood how their inputs would be used.

The USDOE response to the preliminary comments from the EEG referred to a SNL viewgraph (Figure 3) entitled "Logic Tree for Deterrence by Markers Given Time, Society, Mode of Intrusion, and Marker Criteria." If one defines each of the branches in Figure 3 as p_1, p_2, p_3 and p_4, then deterrence is

$$p_1 p_2 p_3 p_4 \tag{2}$$

and eq. (1) does not obtain. Eq. (1) does NOT appear anywhere in the hundreds of viewgraphs shown to the Futures and Markers Panels.

An example of the intervention of the analyst occurred when elicited probabilities of the Washington A and B Teams and the Southwest Team for the period 0 to 100 years after closure were ignored. Professor Hora states [vol. 3, p. A-87]

> In contrast, the two Washington teams gave assessment beginning immediately after closure and thus did not allow for the period of continuing administrative control. **The performance assessment, however, assumes that the drilling rate is effectively nil during the first 100 years after closure** [emphasis supplied].

Clearly these three teams would not have agreed with SNL's use of their opinion in meeting the USEPA Standards (USEPA 1993).

3.3.7 A flagrant and important abuse of the analyst-assessor role occurred when the WIPP Performance Assessment Department assumed that there will be no intrusions after 2000 years (vol. 4, p. 2-19, lines 4 and 20). For consequence calculations, the *1992 Performance Assessment* considered only a single intrusion at 1000 years. This is clearly counter to the spirit and letter of analyzing human intrusions for the entire 10000-year regulatory period. If one assumes that the computer program by Professor Hora [vol. 3, p. A-92ff] captures the essence of the Futures and Markers Panels (which we do not) Appendix D of vol. 3 of the *1992 Performance Assessment* contains 12 pages of realizations of drilling intensity functions. The graphs in Appendix D show the intrusion rate and cumulative number of intrusions as a function of time to 10,000 years. Showing these graphs to 10,000 years is misleading because the WIPP Performance Assessment Department discarded the Panels's

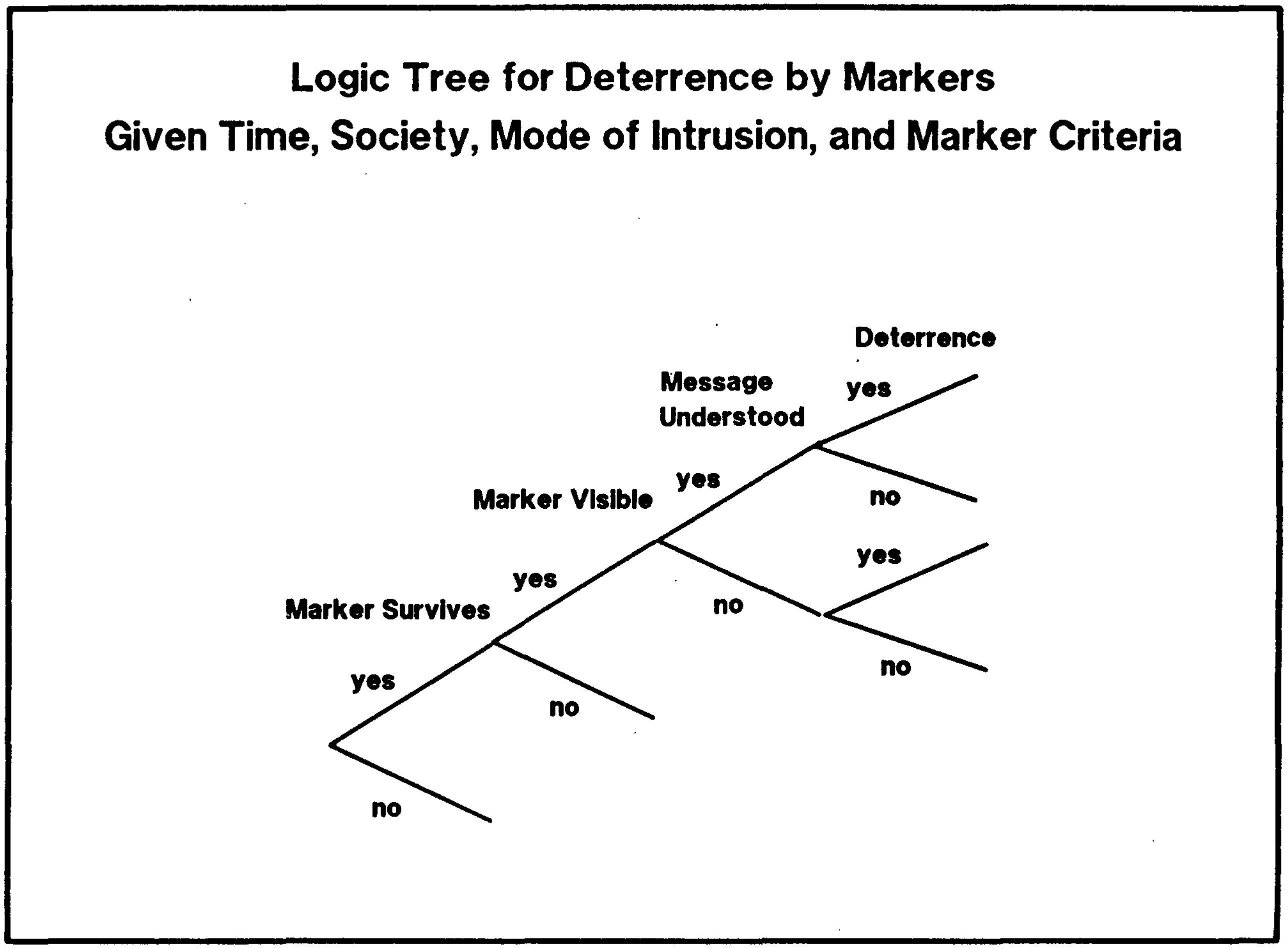

Figure 3. Reproduction of a viewgraph shown to the Future and Markers Panels by SNL, showing SNL's concept of the elicitation.

recommendations, assuming the intrusion rate to be zero after 2000 years.

3.3.8 The elicitation process is described in the Hora memo, vol. 3, pp. A-71 through A-99. The memo includes a FORTRAN program to sample among the panels, and produces realizations of intrusion intensities as functions of time for use in the 70 Monte Carlo runs. On page A-94, line 13, a three-dimensional array BOSTAB2 is undimensioned and undefined, thus the program cannot possibly work. In May 1993, EEG requested a working copy of this program, first from Professor Hora, then from WIPP Performance Assessment Department, and finally obtained a copy on December 31, 1993. This program creates Monte Carlo realizations of rates of human intrusion, drawn primarily from Prof. Hora's interpretation of the Futures and Markers Panels.

3.4 EEG suggests a simplified, focused and understandable alternative.

Figure 4 shows what EEG believes the exploratory drilling rate to be in any specific area, and illustrates the evolution of oil and gas drilling as a function of time.

Figure 4 shows a historical record of drilling in this area, a known rate, a holes per area per year, $a > 0$. The U.S. Environmental Protection Agency's guidance (40 *CFR* 141, Appendix C) of thirty boreholes per kilometer^2 over 10,000 years is such a rate.

Giving no credit for passive institutional control, because of recent experience (Silva 1994), we extend the historical drilling rate some time into the future, b years, $b > 0$. Geologic knowledge should be used for this extension. If there is current oil and gas drilling, then it is likely for the exploration and development to continue for some time. If there is no current drilling in this area, then there may not be any drilling until some new mineral is discovered in this area. This extension should extend beyond the period of active institutional control.

Given our present understanding of energy economics, we may postulate a decrease in oil and gas drilling, after a period of time, due to either exhaustion of the resource, or technological developments in some other fuel sources, or both. This decline can be represented by an exponential decay function, $y = y_0 \exp^{-ct}$. The rate of decrease is characterized by a single parameter, c.

For the long-term, there should be a rate of intrusion that is

(a) non-zero; and

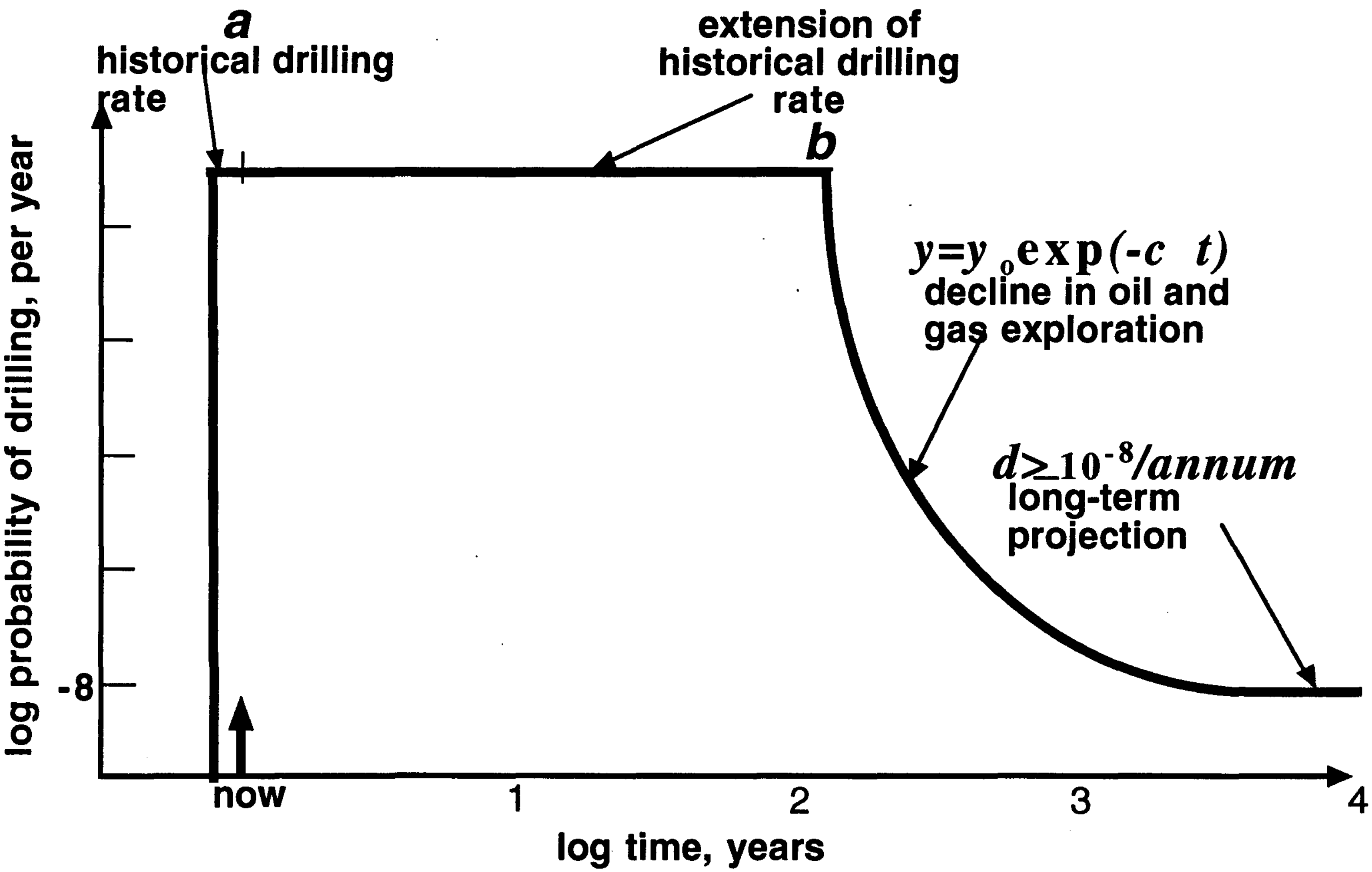

Figure 4. EEG's suggestion for a rate of human intrusion by drilling.

(b) above the USEPA threshold probability for events and scenarios to be considered, or 10^{-8} per year. Call the rate d holes per area per year, $d \geq 10^{-8}$ per year.

Because the waste will not have decayed to harmless levels after 10,000 years, and because the site may still contain resources, the intrusion rate should not be zero for any time within the regulatory period. To ignore such probabilities is to do an incomplete analysis.

The parameters a, b, c, and d completely specify the rate of inadvertent human intrusion in a readily understandable way. Subjective elicitation can now focus on these four parameters. The Department of Energy has experts in the history of oil and gas fields in the Energy Information Administration, and also experts in prospects for solar and other new energy sources.

In the USDOE response to EEG's preliminary comments, SNL stated four principles upon which to object to EEG's suggestion. In brief they are: Avoid Problem Definition, Avoid Bias, Put Rationale Before Results, and Do Elicitation Only on Physical Quantities.

A subjective elicitation requires problem definition. Figure 2 shows SNL's definition before the elicitations. Apparently SNL fitted the results of the elicitation into its preconceived structure. Although the EEG is not free of judgment, it focuses judgment on relevant parameters. SNL should heed its own advice about following USEPA's guidance and limit the elicitation to inadvertent drilling for minerals, without exploring irrelevant intrusion modes.

We will illustrate the bias that SNL imparted to the panelists on the topic of oil and gas resources at WIPP. In the orientations, SNL cited three different studies that there is no economically recoverable oil near WIPP, shown in Figures 5, 6, and 7, augmented by SNL's own conclusion that (Figure 8)

> Crude oil will not be the target for exploration unless the price is drastically higher than the present [1990].

Figure 9 shows the number of oil wells near the WIPP site in October 1993. Table II shows the recent history of wells in the same locations. Figure 9 and Table II belie the suggestion that there is no economically recoverable oil near WIPP. Actually, SNL did tell the panelists about oil and gas production near the WIPP. Figure 10 is a viewgraph shown to the panels by the speaker on cultural resources. That the panelists did not raise questions suggests that

TOTAL MINERAL AND ENERGY RESOURCES
(Brausch and others, 1982)

ESTIMATES ARE FOR ALL FOUR CONTROL ZONES

RESOURCE			
Caliche	185 MT	at surface	Not a reserve
Gypsum	1.3 BT	300-1,500 ft	Not a reserve
Salt	198 BT	500-4,000 ft	Not a reserve
Potash			
Sylvite	133.2 MT	1,600 ft	27.43 MT reserves
Langbeinite	351.0 MT	1,800 ft	48.46 MT reserves
Hydrocarbons			
Crude Oil	37.50 MB	4,000-20,000 ft	Not a reserve
Natural Gas	490 BCF	4,000-20,000 ft	44.62 BCF at 14K ft
Distillate	5.72 MB	4,000-20,000 ft	0.12 MB at 14K ft

Figure 5. Reproduction of a viewgraph shown to the Future and Markers Panels by SNL, showing the conclusion of a resource study.

ESTIMATES OF UNDISCOVERED HYDROCARBON RESOURCES--PROVINCE 092 (Mast and others, 1989)

RESOURCE	Mean	F95	F5
Crude Oil			
recoverable	0.02 BB	Negl.	0.05 BB
economically recoverable	0.02 BB	Negl.	0.05 BB
Natural Gas			
recoverable	0.24 TCF	0.05 TCF	0.67 TCF
economically recoverable	0.24 TCF	0.05 TCF	0.67 TCF
Natural-Gas Liquids			
recoverable	0.00	0.00	0.00
economically recoverable	0.00	0.00	0.00

Figure 6. Reproduction of a viewgraph shown to the Future and Markers Panels by SNL, showing the conclusion of a second resource study.

GEOLOGICAL CHARACTERIZATION REPORT
(Powers and others, 1978)

POTENTIAL RESOURCES EXAMINED

- **Caliche**
- **Gypsum**
- **Salt**
- **Uranium**
- **Sulfur**
- **Lithium**
- **Potash**
- **Hydrocarbons (crude oil, natural gas)**

CONCLUDED

Only potash and natural gas have potential as significant exploitable deposits.

Figure 7. Reproduction of a viewgraph shown to the Future and Markers Panels by SNL, showing the conclusion of a third resource study.

CONCLUSIONS ABOUT THE POTENTIAL FOR ECONOMICALLY IMPORTANT NATURAL RESOURCES AT THE WIPP

1. **Crude oil will not be the target for exploration unless the price is drastically higher than at present.**
2. **Natural gas in the Morrow Formation is the only hydrocarbon of potential economic importance in the area.**
3. **All currently recognized potash resources are confined to a zone above the waste-filled rooms and drifts.**
4. **Only the lowest grade of potash ore overlies part of two waste panels.**
5. **Other resources are present, but because of abundance and greater accessibility elsewhere, these resources at the WIPP are of no economic interest.**

Figure 8. Reproduction of a viewgraph shown to the Future and Markers Panels by SNL, showing SNL's conclusion on oil resources near the WIPP.

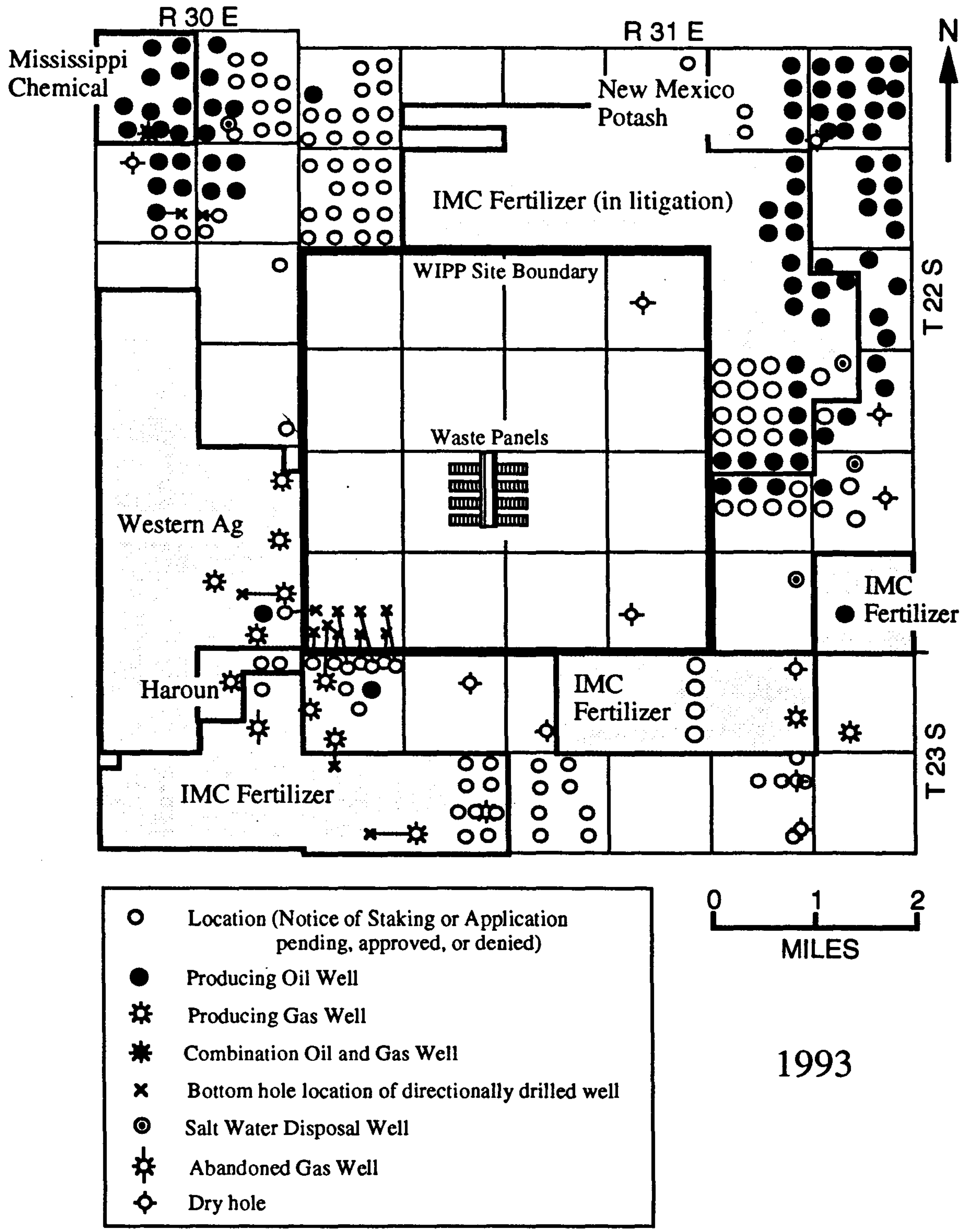

Figure 9. Oil and gas wells near the WIPP, October 1993.

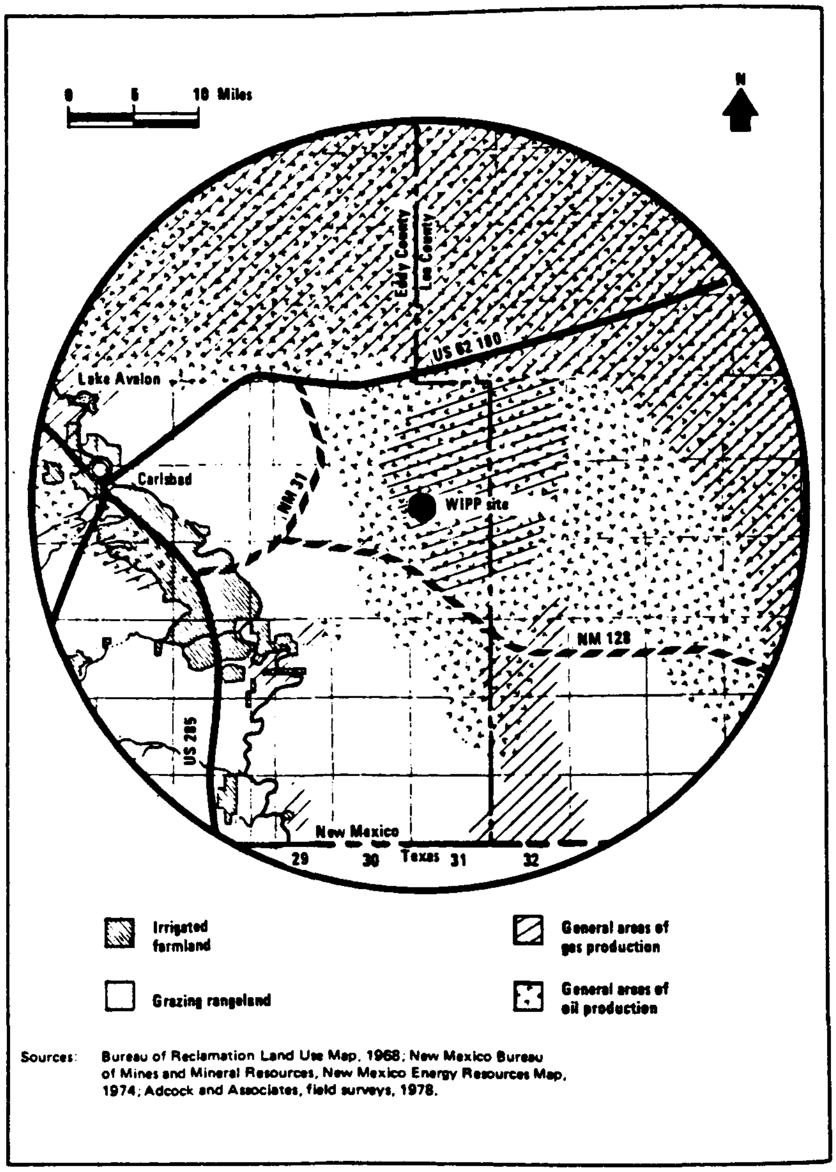

Figure 10. Reproduction of a map shown to the Future and Markers Panels by SNL, showing oil and gas resources near the WIPP.

Table II. Drilling rate for a 124 km^2 area immediately surrounding the WIPP*.

Year	Gas Wells	Oil Wells
1987	0	4
1988	0	2
1989	0	3
1990	0	13
1991	1	37
1992	1	23

*Source: Silva (1994)

SNL was successful in putting bias in the mind of the panelists.

To say that this elicitation puts rationale before numerical results belies the purpose of the effort. The emphasis on rationale may have prompted Prof. Hora to make arbitrary assumptions to obtain numerical results.

> The information for the drilling intensity from the Washington B team indicates that if minerals are extracted in the WIPP region, exploration will occur in the first 200 years or in the next 300 years, but not in both periods. **There does not seem to be adequate information from this team to model with dependence without making arbitrary assumptions**....[Sandia WIPP Performance Assessment Department 1992; vol. 3, p. A-87, emphasis supplied].

To object to elicitation for parameters without physical meaning is a surprise to us. One of the most frequently cited elicitation exercises is on perceived risk (Slovic, Fischhoff and Lichtenstein 1980), in which judges were asked to rank order risks from 40 technologies. The resulting ordinal ranking has no physical meaning. A greater surprise is that SNL would object to eliciting parameters on human intrusion when the entire Future and Markers Panels effort is attempting the same.

3.5 The Effect of Using Subjective Probabilities

We are now in a position to examine the consequences of using subjectively elicited probabilities. EEG has long maintained that a more reasonable conceptual model for intrusion would include a degrading plug, with the contaminated brine reaching the accessible environment at the ground surface, release Path b in Figure 11. Current oilfield practice in the Delaware Basin is to case the wells down to the top of the salt deposits, preventing contaminated brine from entering the water-bearing zones above the salt. Figure 12 shows CCDFs for the following conditions:

- Brine flow calculated for flow up the borehole, from the *1992 Performance Assessment*;
- Solubilities of all actinides set at 10^{-6} M;
- Intrusion probabilities from subjective elicitation, constant 30 boreholes/km^2/10000 years, or sampled between 0 and 30 boreholes/km^2/10000 years.

Figure 12 shows that if all actinide solubilities are 10^{-6} M, the mean CCDF of 70 would be very close to violating the containment requirement, unless subjective probabilities are used.

Recommendation 3.3. Discard the subjective probabilities for human intrusion used in the *1992 Performance Assessment* and adopt EEG's specific suggestion in Section 3.4.

4. Computer Code Documentation

4.1 The EEG has been concerned about the lack of documentation of computer codes used in the *1992 Performance Assessment*. Of the major codes used in the *1992 Performance Assessment*, as shown in vol. 1, Figure 4-4, only SANCHO and GENII-S have complete documentation. Ironically, no direct results from SANCHO and GENII are shown in the *1992 Performance Assessment*. In response to an EEG inquiry, USDOE provided the following schedule for complete documentation of computer codes shown in Figure 4-4 of vol. 1 (Arthur 1993):

Complete documentation is a requirement of Sandia's own software quality assurance program. For most of the codes shown in Figure 4-4, volume 1, only brief descriptions appear in the *1992 Performance Assessment*, and such descriptions do not present sufficient details for reviewers. As shown in our discussion of human intrusion, it is necessary to review the computational tools at that level of detail. In June 1994, EEG learned that complete documentation of all codes will be available by January 3, 1995.

Technical papers are no substitute for documentation, because technical papers and documentation have different purposes. Documentation is intended to communicate effectively

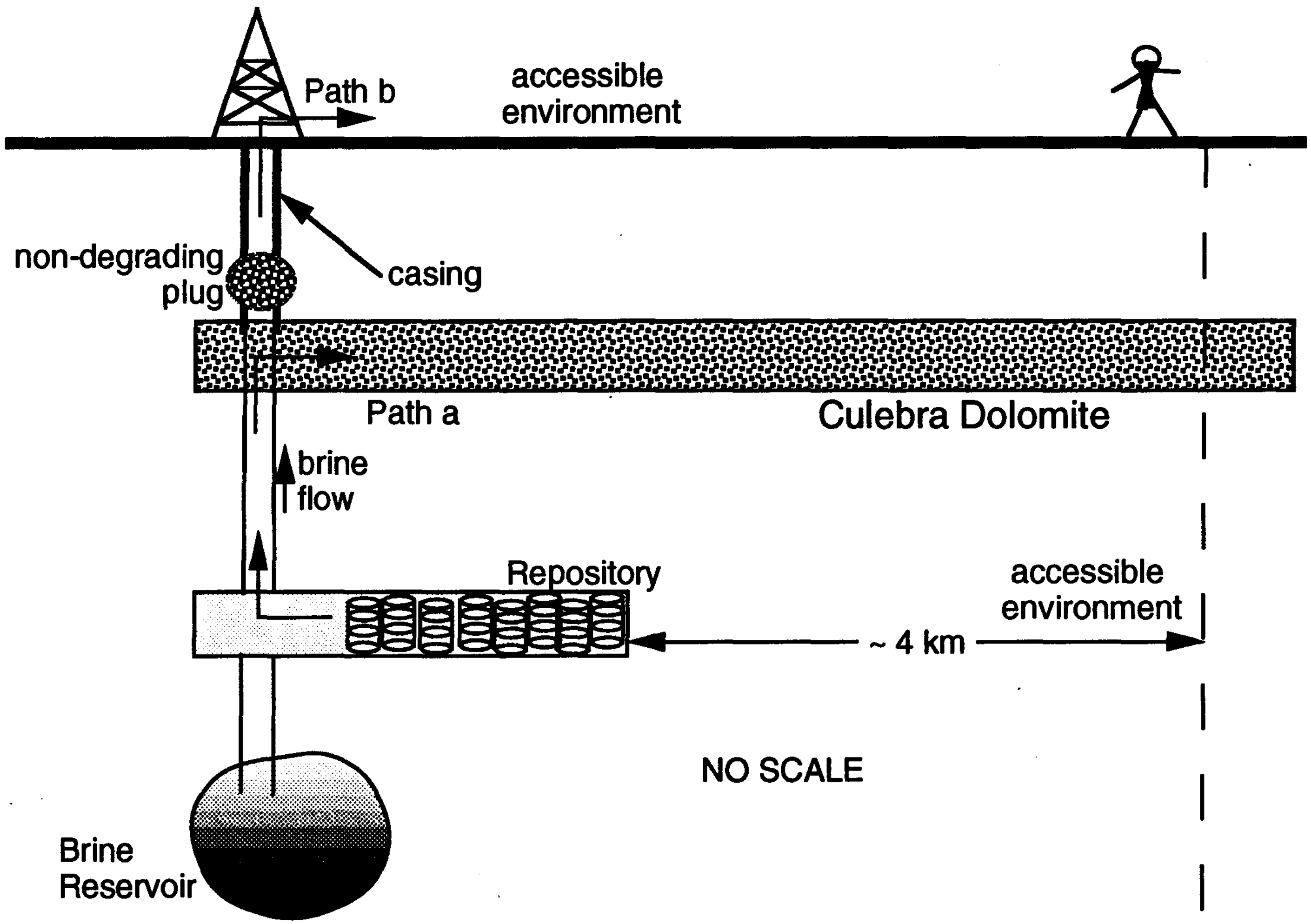

Figure 11. EEG scenario of direct discharge of contaminated brine to ground surface.

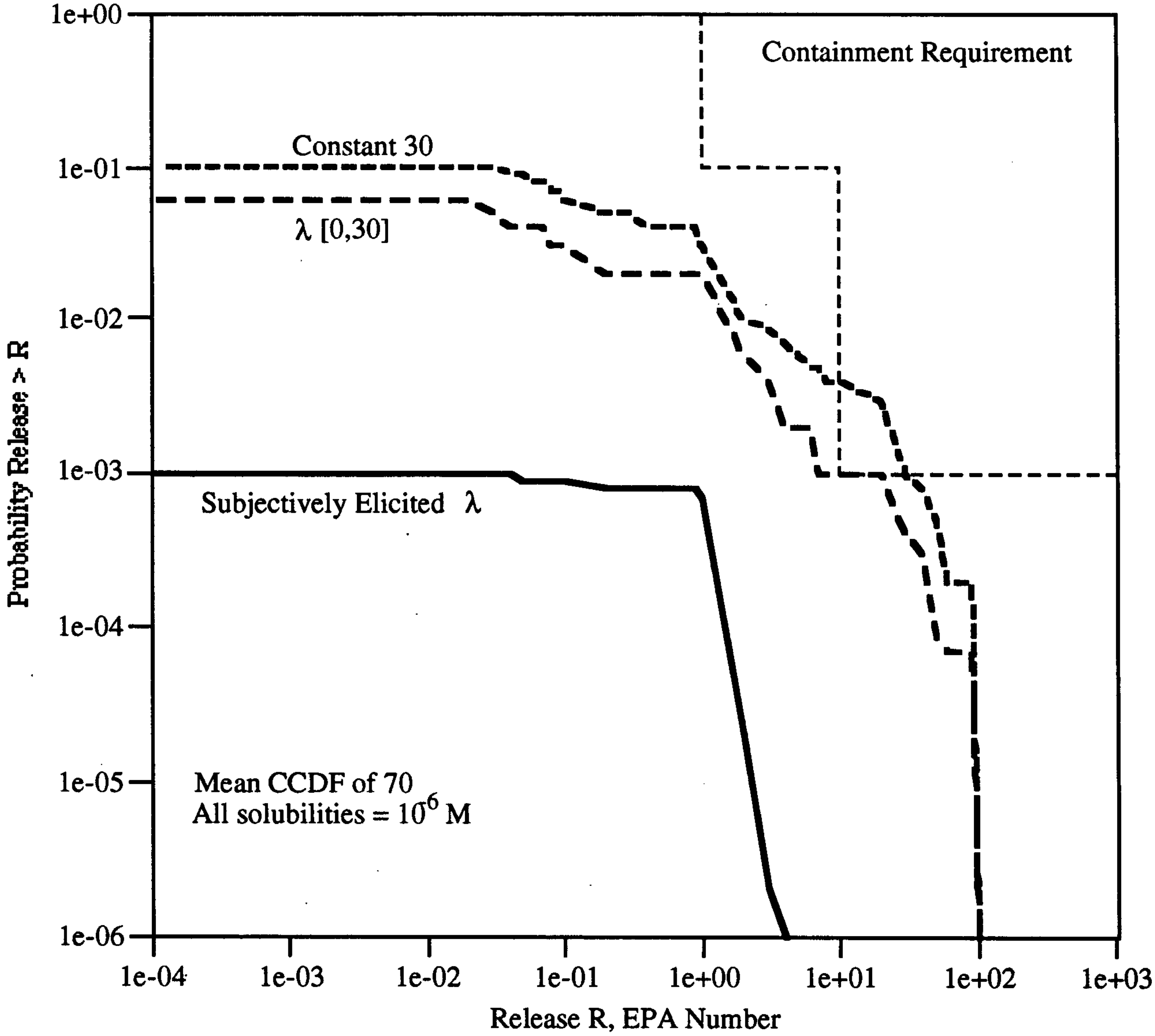

Figure 12. Mean CCDFs from the EEG scenario of direct ground discharge for all actinide solubilities set at 10^{-6} M, using 3 methods of deriving the rate of human intrusion, constant 30 boreholes/km^2/10,000 years, uniform sampling between 0 and 30 boreholes/km^2 /10,000 years, and subjectively elicited probabilites.

Table III. Schedule for Performance Assessment Computer Code Documentation

Code	Aug 9, 93*	Jun 10, 94*
BRAGFLO	DEC 97	Sep 1, 94
CCDFPERM	DEC 94	Dec 1, 94
CUTTINGS	DEC 96	Oct 1, 94
GENII	DEC 96	Jul 1, 94
PANEL	DEC 97	Oct 1, 94
SECOFL2D	DEC 97	Jul 1, 94
SECOTP2D	DEC 97	Jul 1, 94

* Dates of USDOE promise by letter.

the details of the code design and operation so that people with different interests can be convinced of the usefulness and validity of the computer code. Documentation presents the code's logical structure, equations and methods, assumptions and limitations affecting the code's applicability, essential for an effective review.

The brief descriptions in the *1992 Performance Assessment* are inadequate as documentation for the following reasons.

4.2 According to SAND92-0700/3, p. 1-36, PANEL calculates

$$\dot{M}_i = -QC_{di} - \lambda_i M_i + \lambda_{i-1} M_{i-1} \tag{3}$$

where M_i is the mass of the ith nuclide in dissolved form,
Q is the brine flow rate, and
λ is the nuclide's decay constant.

The concentration is calculated

$$C_{di} = \frac{M_i}{\sum_j M_j} S_i, \tag{4}$$

where S_i is the concentration in saturated solution, and this equation calculates the isotopic fraction of solubility over j isotopes.

According to the February 22, 1994 USDOE presentation to USEPA, PANEL actually solves

$$C_{di}(t) = \begin{cases} S_i, & \text{if } I_i(t)/V(t) \geq S_i \\ I_i(t)/V(t), & \text{if } I_i(t)/V(t) < S_i \end{cases} \tag{4a}$$

where $I_i(t)$ is the inventory of element i at time t, and

$V(t)$ is the brine volume in the panel at t. Eq. (4a) incorporates a different concept than eq. (4). This kind of information is needed to fully understand the *1992 Performance Assessment.*

4.3 The transport code SECOTP2D offers the best examples of the need for full documentation. Roache (1993) does not explain how the following important items are handled.

- SECOTP2D is a two-dimensional code. How does it handle the conversion of the source term from zeroth dimension, the solubility, to two dimensions? The source is Qc, where Q is the well injection rate. How is Q determined? Is Qc spread uniformly vertically, uniformly laterally to infinity, making it an infinite line source?

- Two types of matrix diffusion are claimed for the Culebra, in the dolomite and in the clay layer. Is the classic Neretnieks equation for matrix diffusion used for calculating these effects?

- Over the years several codes have been used for the calculation of flow and transport in the Culebra, such as SWIFT, and STAFF2D. Are there benchmarking results?

c. To further demonstrate the inadequacies of technical papers as documentation, the following comments are offered on the Roache paper.

- The paper touts the TVD algorithm but failed to define TVD.

- The algorithm begins with a variable transformation. A key variable J in the transformation is not defined.

- No results are given for verification of the dual porosity option.

Finally, it is often claimed that because a computer code is undergoing continuous development, its documentation cannot be released. This is simply not the case. A calculation done with a computer code is made with a specific version. Subsequent calculations may use the next version. However, for the purpose of documentation, a calculation and the tool (computer code) are inextricably intertwined. For a meaningful review, the code version used and the extant documentation must be made available.

Recommendation 4. Establish a workable system to provide EEG with relevant documentation, so that EEG has reasonable access to perform its work.

5. The Culebra as a Natural Barrier

The *1992 Performance Assessment* elucidates the role of the Culebra as an isolation barrier. Figure 5-6 of vol. 1, claims that WIPP can meet the USEPA's containment requirement (USEPA 1993) without the Culebra as an isolation barrier. That is, if the USEPA containment limit is applied where brine is diverted into the Culebra, WIPP would still be in compliance. With matrix diffusion and sorption, the Culebra would contribute additional isolation.

Recommendation 5. Quantify the extent of matrix diffusion and sorption through accelerated experimentation.

6. Effects of Gas Generation

While the USDOE has analyzed the beneficial effects of gas generation, the EEG continues to be concerned that the deleterious effect of gas generation, particularly the opening of new discharge pathways, has not been analyzed.

Recommendation 6. In future analysis, the deleterious effect of gas generation should be included.

7. Correlation Among Variables

No correlation has been assumed between sampled variables using Latin Hypercube sampling. In real life, many of the variables are related. For example, there is an inverse correlation between VWOOD, the fraction of waste that is wood, and VMETAL, the fraction of waste that is metal.

Recommendation 7. The performance assessment should either give reasons why physical correlations have been ignored, or show results with correlations.

8. Natural Resources Near the WIPP

The *1992 Performance Assessment* is unclear on the extent of natural resources extraction near the WIPP site, and particularly the possible impact of human intrusion. In vol. 1, Section 2.2 an incorrect statement is made:

> About 56 productive oil and gas wells are located within a radius of 16 km (10 mi) from the WIPP; the wells generally tap Pennsylvanian strata, about 4,200 m (14,000 ft) deep (p.2-4).

This statement is incorrect because there are many more oil and gas wells. The estimate of 56 producing oil and gas wells is based on 1986 data. EEG showed (Silva and Channell, 1992) that some of the 1986 data were incorrect. Furthermore, if the USDOE wishes to take credit for current and accurate public records, then USDOE should have used current information and not obsolete information. Given the importance of drilling for oil and gas on the performance assessment calculations, future iterations should use a more accurate representation of the drilling activity near the WIPP facility. One method of so doing is to show up-to-date and accurate locations of oil and gas wells on a map. Most of the oil and gas wells drilled in the last four years do not tap the deeper Pennsylvanian Formation, but produce from various shallow (1200 to 2400 m) zones within the Delaware Mountain Group Formation.

The statement in the *1992 Performance Assessment* continues:

> The hydrocarbon well closest to the land withdrawal boundary is about 3 km (2 mi) to the south-southwest of the waste panels, and has produced natural gas since 1982 (Silva and Channell, 1992). The surface location of the well is outside the land-withdrawal boundary, but the borehole is slanted to withdraw gas from rocks below the WIPP horizon within the boundary. Except for this well, resource extraction is not allowed within the proposed land-withdrawal boundary (vol. 1, p.2-4).

The 1992 WIPP Land Withdrawal Act recognizes the validity of two specific oil and gas leases in section 31, within the WIPP Site Boundary. The owner of one of these leases has recently filed an application for permits to drill eight directionally drilled oil wells that would be completed within the WIPP Site Boundary but at depths greater than 2,000 m (6,000 ft) to produce oil from within the WIPP Site Boundary. While there was no restriction on drilling within the WIPP Site Boundary contained in the Consultation and Cooperation Agreement between the USDOE and the State of New Mexico, the second modification restricted slant drilling.

The following statement appears in vol. 1, section 3.3.3 (p. 3-10):

> ... the DOE agreed to prohibit further subsurface mining, drilling, slant drilling under the withdrawal area, or resource exploration unrelated to the WIPP Project from the land surface to 6,000 feet (1,830 m) in the subsurface for the 16 square miles under DOE control.

The second modification to the Cooperation & Consultation Agreement has been incorrectly interpreted. The Agreement is not limited to the first 6,000 feet (2,000 m) of depth. The Agreement states "The DOE will not permit subsurface mining, drilling, ..."

Recommendation 8. Performance assessment reports should accurately reflect the status of resource development near the WIPP site.

9. Oil and Gas Production Near the WIPP

In vol. 1, section 5.3.5, the following statement is made regarding the Assurance Requirement (40 *CFR* 191.14) for natural resources:

> Future societies might attempt to exploit natural resources near the WIPP and thereby create the potential for a release of radionuclides into the accessible environment. These issues have been evaluated in several reports (USDOE, 1980, 1981b; USDOE and State of New Mexico, 1981, as modified; Brausch et al., 1982; Weart, 1983; USDOE, 1990a). A recent report summarizes these earlier reports (USDOE, 1991a), and the DOE will continue to document information about natural resources that was used in making the decision to proceed with the WIPP Project (I, p. 5-20).

A detailed reading of the references cited does not appear to support the text.

Silva and Channell (1992) showed that the *USDOE Implementation of the Resource Disincentive Plan in 40 CFR 191.14(e) at the Waste Isolation Pilot Plant* (USDOE, 1991a) is inconsistent in reporting the number of oil and gas leases within the WIPP Site Boundary and the production status of those leases.

The No-Migration Variance Petition (USDOE, 1990a) states:

> Oil and gas exploration has been and continues to occur around the WIPP site. The target horizons for this type of exploration are below the Castile. Oil and

gas exploratory drilling requires permits from the state, and it is unlikely that prospective future well drillers would not be informed about the existence of WIPP. As an additional protective measure, the DOE has purchased all oil and gas leases in the area of the WIPP site to prevent any exploration now and in the future (Section 6.3.2).

The last sentence above is incorrect. Weart (1983), Brausch *et al.* (1982) and Weart *et al.* (1991) failed to recognize the potential crude oil resources for this area. Crude oil is now being produced from the former control zone IV.

Recommendation 9. The performance assessment effort should use the latest and verifiable data on oil and gas production near the WIPP, because the extent of oil and gas resources in this area is likely to be an important determinant of inadvertent human intrusion, and oil and gas production can potentially affect the hydrogeology at and near the WIPP repository.

10. Gas Generation

10.1 BRAGFLO is one of the most important codes in the WIPP performance assessment. A brief summary of BRAGFLO is given in vol. 3, section 1.4.1. Equations 1.4.1-1 and 1.4.1-2 use rate constants and mole fractions (called "stoichiometry factors") to calculate the rate of gas generation. These factors, although not specifically referenced in this section, are referred to in the discussion on pp. 3-44 to 3-45. Median corrosion gas production rates are given as 6.3×10^{-9} moles H_2/m^2-s for inundated steel and 0.1 [-] for humid steel under aerobic conditions, and 0.5 [-] for inundated steel under anoxic conditions. An analogous set of rates are given for microbial gas generation, with units of moles of gas/kg cellulosics given only for inundated conditions. It should be noted that in the development of the equations on pp. 1-24 to 1-26, the rate constants and stoichiometric factors are given with acceptable units. Why aren't the dimensions the same for all these rates, if they are used for the same variable in BRAGFLO? How can a corrosion rate have the units of moles per unit area of exposed substrate in one case and no units in another? How can a dimensionless variable be used interchangeably with a variable with units?

10.2 A more serious question arises about the use of these results. The gas generation rates and stoichiometry factors cited are those calculated by a model and are thus the result of model inputs rather than experimental data. Table IV summarizes the results of the SNL scientific investigations into gas generation, and distinguishes model calculations from experimental measurements. Model results are only as good as model inputs. Some model inputs include unsupported assumptions, such as the failure to include methane. Experimental data exist – see Table IV– but have not been used in modeling. Moreover, as the Table IV shows, models give different gas generation rates when given different inputs and assumptions, and the median of such calculated rates has little validity.

Although the assumption that radiolysis will contribute only negligible hydrogen formation at WIPP appears to have found general acceptance, the data developed by Kosiewicz (1981) show this need not be the case. In fact, the gas generation problem was first noticed in stored drums of TRU waste in which hydrogen had been generated by radiolysis. Moreover, the microbial generation model does not recognize the dependence of the microbial gas generation rate on the initial and continued presence and availability of microbes. Radiolysis can be the principal source of gas from Pu-238 heat source waste.

Recommendation 10a. The gas generation calculations should include

(a) methane generation,

(b) radiolytically generated hydrogen.

Recommendation 10b. The relationships in the gas generation model should be validated before the gas generation model is incorporated into BRAGFLO.

11. Unanalyzed Scenarios

As Helton (1993) so aptly pointed out, the formulation of scenarios is an integral part of performance assessment. There are a number of assumptions used in the human intrusion scenarios to date that EEG believes need to be reconsidered and either changed or better justified. These have all been related to USDOE in previous written comments and discussed in meetings. For completeness of the record, all significant items are mentioned below.

Some scenarios not currently analyzed in performance assessment need to be considered. See especially the lower half of Figure 4-1 (vol. 2) in the *1992 Performance Assessment.*

Table IV. Gas Generation as Modeled and Tested

	Source	Gas From	Result moles/drum/a	Gas from 1050 drums in an alcove (moles/a)	Pressure P_0 (atm)	$P = nRT/V$ per annum (atm)	Gas Pressure at end of year one $P_1 = P_0 + P$
H_2	Brush *et al.*, (1993)	anoxic corrosion	2.0	2,100	1.0	0.0568	1.06
Total gas	Brush *et al.*, (1993)	microbio. deg.	1.0	1,050	1.0	0.0284	1.03
H_2 - 3 mos.	Brush *et al.*, (1993)	anoxic corrosion	1.97×10^{-6}	0.0	1.0	0.0	1.0
H_2 - 6 mos.	Brush *et al.*, (1993)	anoxic corrosion	1.72×10^{-6}	0.0	1.0	0.0	1.0
H_2 - 12 mos.	Brush *et al.*, (1993)	anoxic corrosion	1.23×10^{-6}	0.0	1.0	0.0	1.0
H_2 - 24 mos.	Brush *et al.*, (1993)	anoxic corrosion	9.9×10^{-7}	0.0	1.0	0.0	1.0
Total gas	Brush *et al.*, (1993)	aerobic microbes	0.5	525	1.0	0.0142	1.01
Total gas	Brush *et al.*, (1993)	anaerobic microbes	1.21	1271	1.0	0.0343	1.03
Total gas	Bixler (1989)		0.3	315	1.0	0.0085	1.01
Total gas	Molecke & Lappin (1990)	Calculated	0.05	52.5	1.0	0.0014	1.00
			0.5	525	1.0	0.06	1.06
			5.0	5,250	1.0	0.59	1.59
Total gas	Kosiewicz (1980)	radiolysis	0.3	315	1.0	0.04	1.04
			0.11	770	1.0	0.01	1.01
			0.016	115	1.0	0.0031	1.00

11.1 A Scenario Involving Nuclear Criticality

In 1984 S. Cohen, an EEG consultant, analyzed potential nuclear criticality in the Culebra Aquifer and concluded that this needed to be thoroughly evaluated by USDOE.

The potential nuclear criticality could occur if:

(1) sufficient quantities of a fissile radionuclide such as Pu-239 or U-233 are adsorbed on a large enough volume of aquifer matrix;

(2) there is sufficient hydrogen or other moderator available in the brine or matrix;

(3) the matrix or brine does not contain sufficient quantities of stable nuclides that can "poison" the reaction.

EEG's analysis indicated that, with the expected elemental composition of the brine and the Culebra aquifer matrix, nuclear criticality could occur in a block 7 m high x 0.5 m wide x 1 m long if the product of the distribution coefficient (K_d, mL/g) and plutonium solubility (S, moles/L) was greater than about 5.6×10^{-5} moles/g.

The possibility of a K_dS product of $> 5.6 \times 10^{-5}$ moles/g is credible. For example, the probability distributions for K_d and solubility from volume 3 of SAND 91-0893 (pages 2-104 and 3-64) have approximate probabilities of occurrence given in Table V.

Table V. Probabilities of Criticality From Sorbed Fissionable Species

Species	Probability $K_dS > 5.6 \times 10^{-5}$ moles/g
Pu^{5+}	0.025
Pu^{4+}	5×10^{-6}
U^{6+}	0.25
U^{4+}	0.11

In response to EEG's comments on the *1990 Preliminary Comparison*, SNL responded that

> A performance assessment task has been initiated to examine the potential for nuclear criticality from post closure processes.

Two pages were devoted to discussing nuclear criticality in the *1991 Preliminary Comparison* (vol. 1, page 4-52). SNL recognized that sorption can also occur in the backfill and at certain components of the seal system as well as in the Culebra Aquifer. The very remote possibility of a high-yield nuclear explosion is also discussed. We find no analysis of nuclear criticality in the *1992 Performance Assessment.* No schedule has been given for performing additional criticality evaluations.

EEG also believes the possibility of a high-yield nuclear explosion is very remote. One concern is with an instantaneous criticality excursion in which there is a brief burst of energy, neutrons, and gamma radiation. Perhaps more likely in this situation, where fissile material is being added very slowly in a solution, is a delayed criticality where the system does not become promptly critical. Such a system would behave much like a nuclear reactor and could produce fissions, perhaps in bursts, for extended periods of time. This phenomenon has occurred in several process criticality accidents in the U.S., e.g. at Hanford in 1962 one system boiled for 37 hours (Thomas 1978). The Oklo "natural reactor" in Gabon is believed to have operated in a similar fashion.

It is not obvious that a criticality accident would have a significant effect on a repository waste disposal system, even if a criticality accident occurs. Considerable heat would be produced, some brine would be vaporized, and minor amounts of fission products would be formed. It takes 8×10^{20} fissions to produce one curie of Cs-137. Also, the relatively high K_d values that would be necessary to make criticality possible are otherwise a benefit because they retard radionuclide transport.

Recommendation 11.1 The criticality issue needs to be thoroughly evaluated before it can be concluded that its effects are negligible.

11.2 Subsidence

Subsidence could occur in the area overlying the WIPP some time after repository decommissioning. Subsidence can also occur from nearby potash mining. The *1992 Performance Assessment* identifies an event **TS** which is subsidence from mining of potash, but **TS** has not been analyzed.

SNL discussed the potential for subsidence in the *1990 Preliminary Comparison.* They recognized that "subsidence could in turn conceivably affect the disposal system in three ways: by increasing hydraulic conductivity of the Salado Formation, by creating fractures through the Salado Formation, or by disturbing the surface drainage and groundwater flow in overlying units." The incorporation of the effects of subsidence into the performance assessment is still planned. In the *1991 Preliminary Comparison* SNL presented an analysis of possible caving and subsidence over the waste storage areas from room closure.

SNL's analysis of subsidence concluded that no problems were likely to result for the waste disposal system. The maximum subsidence at the surface was calculated to be only 0.13 meter over an area of 1.54×10^6 m^2. The affected area at the surface was determined by assuming an angle of draw of 35°. It was further stated that if the Rustler-Salado contact residuum had (historically) lost about 400 meters due to dissolution without disrupting the confined water-producing Culebra and Magenta dolomite aquifers, subsidence should not be a problem.

No evaluation has yet been made of subsidence from potash mining. There are significant potash resources within the WIPP site boundary. However, the USEPA Standards requires analysis of only resource exploration drilling on site. However, it is appropriate to consider subsidence effects from potash mining offsite.

Offsite potash mining is highly probable. There are reserves on all sides of the site. Sections to the south of the site are already leased, sections to the north and east are under litigation for potash leases, and the entire western border is leased or expected to be leased. Because the areas leased or expected to be leased to the north and south include the flow path of the Culebra Aquifer across the waste storage area, a potential exists for both upstream and downstream effects on the Culebra. Catchment areas could be formed to the north from subsidence and shafts could provide access to the Culebra for recharge. To the south there could be increased transmissivity from subsidence effects. With the assumption that mining occurs up to the site boundary and the angle of draw is 35° the extent of influence at the Culebra Aquifer horizon would be about 200 meters onto the site. Another possibility is that mining activity near the South Boundary could result in vertical drainage (via shafts or boreholes) from the Culebra Aquifer into underlying mined out areas. This could significantly increase the hydraulic gradient between the injection point of contaminated brine and the site boundary.

Recommendation 11.2 Subsidence effects need to be evaluated in much more detail and incorporated, in some manner, into the human intrusion scenarios. Some scenarios currently analyzed in performance assessment should be re-formulated.

11.3 Contaminated Brine Flows to the Surface

The E1, E2 and E1E2 scenarios assume that the only material reaching the surface is drill-bit cuttings and some "cavings" from the annulus about the drill bit in the waste storage room. Brine flowing to the surface from an encounter with a pressurized Castile brine reservoir was not assumed. EEG believes that brine flows to the surface should be assumed and that the consequences could be significant for the E1E2 scenario.

Sandia and USDOE have described typical drilling practices elsewhere (Appendix C of SAND 89-0462 and in USDOE February 7, 1990 response to EEG's comments on the Draft Supplement EIS). These responses explain how it is possible to have very little flow to the surface by closing in blow-out preventers within a few minutes, determining the pressure, and then preparing drilling mud of sufficient density to stop the flow before resuming drilling. For example, USDOE stated in a February 7, 1990 letter that only 51 barrels flowed at WIPP-12 before shut in by a blow-out preventer.

The February 7, 1990 USDOE letter went on to say that at WIPP-12 an additional 49,224 barrels flowed during deepening, geophysical logging, and further deepening before it was finally shut in for subsequent hydrologic testing. This additional flow was described as resulting from a "conscious decision."

Virtually every time a pressurized Castile brine reservoir was encountered in the vicinity of WIPP, "conscious decisions" were made to allow varying amounts of brine to flow to the surface. Table VI, extracted from two WIPP reports (USDOE 1981a; 1983), describes the remedial measures taken. Although the available data are not as detailed or as quantitative as one would like, it is clear that drilling practice through 1982 included release of brine at the surface whenever pressurized Castile brine reservoirs were encountered. There has been considerable drilling activity around the WIPP Site in the last few years, and brine has been reported in seven wells. In two of these wells brine was reported to have flowed for three hours before being stopped, and in another, brine flowed for at least 12 hours. Records did not indicate how long the remaining wells flowed. It appears that, in most cases, significant amounts of brine flow to the surface before being controlled and performance assessment scenarios should assume that any intruding driller will face similar situations. Also, minor flows may not always be recorded in drilling logs, or perhaps even recognized. Furthermore, it is likely that not all Castile brine encounters have been reported.

Drilling mud return flow would be expected to increase the effective radius of the borehole and bring waste to the surface in suspension and in solution. In the E1E2 scenario brine discharged to the ground surface is expected to be saturated in actinides.

In a November 3, 1992 response to EEG's concern about contaminated brine flow to the surface, SNL stated:

> We will repeat these subsidiary simulations using BRAGFLO for both release during drilling and long-term releases through abandoned boreholes. As you suggested at our previous meeting, there are four cases: (1) El or E2 during drilling, (2) El while Castile brine is allowed to flow, (3) El followed by E2 after Castile brine has been allowed to flow into the panel and then is available to flow through E2 during drilling, and (4) E1E2 after both have been abandoned.

EEG, in a November 9, 1992, letter to SNL, agreed these 4 cases were the appropriate ones to consider and urged SNL to perform the analysis.

Recommendation 11.3 Provide results of the abovementioned analyses, and include contaminated brine flow to the ground surface in future versions of human intrusion scenarios.

11.4 A Brine-Slurry Release Scenario

A brine-slurry release scenario should be analyzed. A brine slurry might result from brine inflow from the Salado salt or intrusion into a Castile brine reservoir. Such a brine slurry could be under greater than hydrostatic pressure and thus have a force capable of driving some or all of the slurry to the ground surface. The potential quantities of ejected brine might be less than that from the El scenario but the consequences could still be significant. The possible implications of a brine-slurry filled room were first raised by SNL in 1987 and were also evaluated in 1988 by EEG (Chaturvedi, Channell and Chapman, 1988).

SNL has responded that all evidence indicates that the possibility of a brine slurry existing in a waste storage room is essentially zero and can be ignored (SAND91-0893, vol. 1, Appendix B). Lappin *et al.* (1989) and the Final Supplemental Environmental Impact Statement (USDOE, 1990b) are cited as support for this conclusion.

The brine-slurry release scenario is related to undisturbed performance and cuttings release. Actually a similar, though probably less serious, release is considered in undisturbed perfor-

Table VI. Castile brine reservoir interactions in the WIPP area

Name of Well	Drilled	Initial Flow (bbl/day)	Remedial Action
Mascho-1	1937	8,000	No action to stop flow.
Mascho-2	1938	3,000	No action to stop flow.
Culbertson-1	1945		3,000 barrels estimated to flow to surface. No record of flow rate or duration.
Tidewater	1962	?	12 pound/gallon drilling mud did not stop. Finally controled by casing and cementing.
Shell	1964	20,000	Allowed to flow until artesian flow ceased.
Belco	1974	12,000	Brine flowed to surface for 26 hours with 14 pound/gallon drilling mud.
Gulf	1975	5,000	No records on total volume or duration of artesian flow.
ERDA-6	1975	660	WIPP hole. Estimate 19,000 barrels could be produced by artesian flow.
Pogo	1979	1,440	Initial flow was after 14.6 pound per gallon drilling mud had been added. Stopped after 4 days with 15 pound per gallon mud.
WIPP-12	1981	12,000	WIPP borehole. Over 79,000 barrels produced. Estimate 350,000 bbls producible by artesian flow.

Table VI Sources

- U.S. Department of Energy, 1981a. *Brine Pocket Occurrences in the Castile Formation, Southeastern New Mexico,* TME-3080.
- U.S. Department of Energy, 1983. *Brine Reservoirs in the Castile Formation, Southeastern New Mexico,* TME-3153.
- R. H. Neill *et al.,* 1983. *Evaluation of the Suitability of the WIPP Site.* EEG-23.

mance when the waste storage room became partially or fully saturated only in the lower portion of the room. An effect of partial saturation and incomplete consolidation of the waste could be to lower the shear strength and result in greater quantities of waste being brought to the surface than calculated with the current cuttings model (E2) assumptions.

Recommendation 11.4 Perform a complete analysis of the brine-slurry release scenario. In addition, variants of the brine-slurry scenario in undisturbed performance and in the E2 scenario need to be better understood.

11.5 Borehole Seals

The USEPA Standards requires human intrusion analysis that would create

> ... a ground water flow path with a permeability typical of a borehole filled by the soil or gravel that would normally settle into an open borehole over time... not the permeability of a carefully sealed borehole (40 *CFR* 191, Appendix C).

In the 1991 and 1992 *Performance Assessments* the resultant permeability of human intrusion boreholes was sampled lognormally between 10^{-11} m^2 and 10^{-14} m^2. This value was obtained from Table 2.2 of Freeze and Cherry (1979) for silty sand. The choice of silty sand is SNL's interpretation of USEPA guidance on borehole sealing cited above.

EEG has several problems with the SNL interpretation. Table 2.2 in Freeze and Cherry (1979) shows a permeability range for silty sand from about 8×10^{-11} m^2 to 8×10^{-15} m^2. The same table also shows ranges of 10^{-9} m^2 to 2×10^{-13} m^2 for clean sand and 10^{-7} m^2 to 10^{-10} m^2 for gravel. It appears that a strict following of the USEPA Guidance would require use of higher permeabilities, to include gravel in the borehole.

EEG believes that the assumption of borehole permeability described in the USEPA Standards is reasonable when considered along with the other assumptions in the guidance, but is not conservative in light of observed borehole sealing practices in the Delaware Basin. In 1989 the Bureau of Land Management found 6,527 shut-in and temporarily abandoned wells in New Mexico (USBLM, 1989). A temporarily abandoned well is simply abandoned, without plugging and sealing. The USBLM made the following statement about wells in the Carlsbad area:

> At Carlsbad, we reviewed the status of 2 shut-in and 11 temporarily abandoned

wells on a 15-well lease. These wells had been classified as shut-in or temporarily abandoned since the late 1960s without approval. There was no evidence these wells had been properly tested to ensure they were capable of producing oil or gas and properly classified. The operator of this lease stated that he did not perform well integrity tests because he estimated that it would cost about $2,000 per well. Additionally, he stated that he did not permanently plug wells because that would cost about $10,000 per well (USBLM, 1989).

Recommendation 11.5 Performance Assessment should not assume perfect plugging of abandoned oil and gas wells near the WIPP. For the human intrusion borehole, the range of degraded permeabilities should span sand and gravel.

12. Analysis of Direct Discharge to the Ground Surface

12.1 In the *1992 Performance Assessment*, the program CUTTINGS analyzes steady-state cuttings releases (Table VII) to the ground surface for the following processes

Table VII. Domain of the CUTTINGS program.

Laminar Flow		Turbulent Flow		Sediment-
Axial	Helical	Axial	Helical	Laden
Yes	Yes	Yes	No	No

EEG has examined the initial Reynolds numbers in the 70 vectors of CUTTINGS analysis for the *1992 Performance Assessment.* The distribution of these initial Reynolds numbers is shown in Figure 13. The mean of these initial Reynolds numbers is 7334 and the standard deviation is 87. These initial Reynolds numbers are well above the range for laminar flow. The analysis for erosion by laminar flow may be elegant, but it appears to be irrelevant. The exclusion of erosion by helical turbulent flow and the effect of sediment erosion is non-conservative.

12.2 In the *1992 Performance Assessment*, the program CUTTINGS analyzes only the E2 scenario. The E1E2 scenario was not analyzed. This was not stated in the *1992 Performance Assessment.*

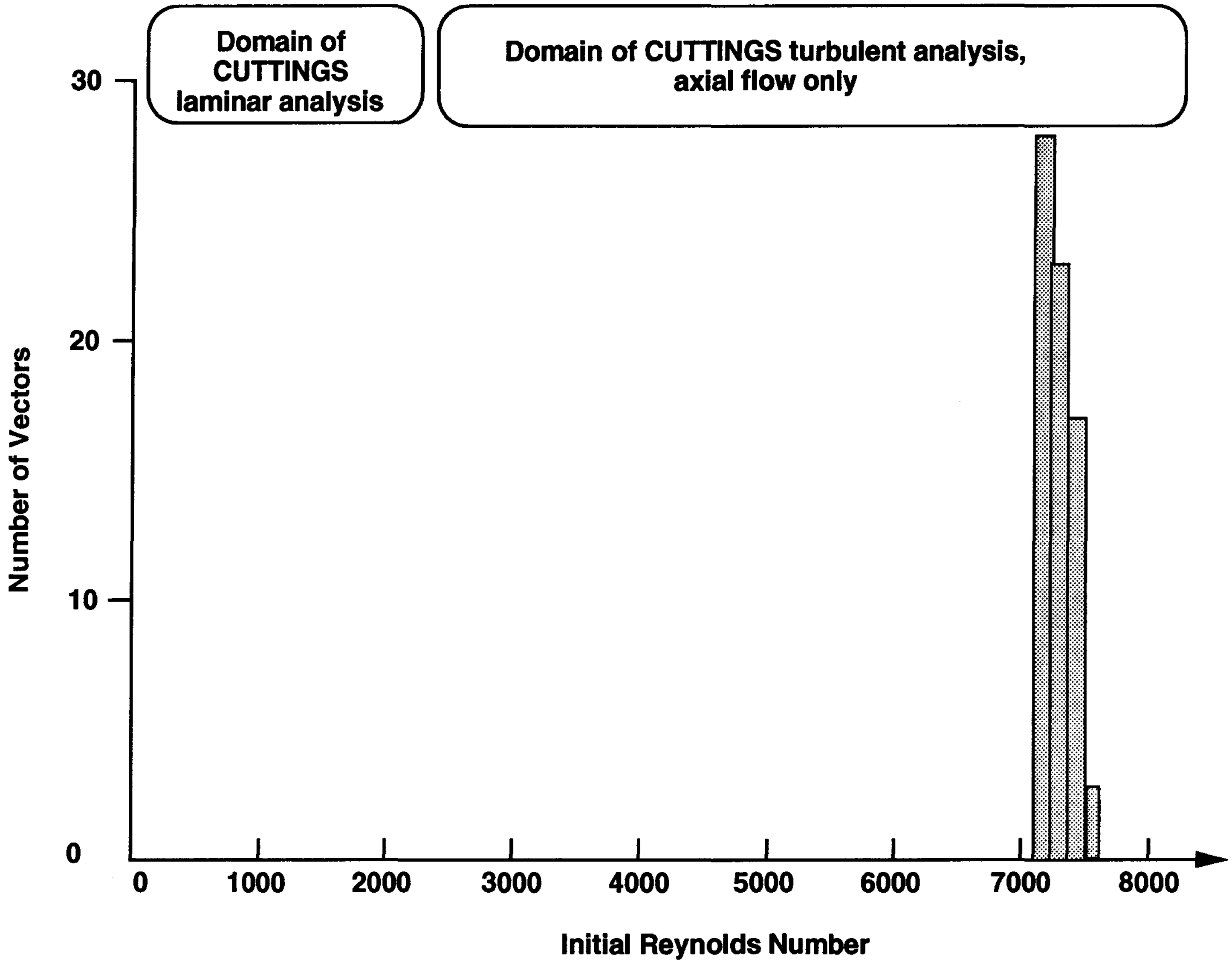

Figure 13. Distribution of initial Reynolds numbers in CUTTINGS vectors.

Recommendation 12. Future performance assessments need to include erosion of waste by helical turbulent flow and the effect of sediment erosion. Also needed is analysis of other relevant scenarios, such as E1E2 and brine slurry discharge to the surface.

13. Inventory

13.1 The radionuclides included in consequences analysis included only actinides plus ^{90}Sr, ^{137}Cs and ^{147}Pm. Missing notably are ^{135}Cs, ^{129}I and ^{99}Tc which are the most important nuclides in most other total system performance assessments. Inventories of these nuclides are available.

13.2 The *1992 Performance Assessment* used five activity levels for contact-handled TRU waste. The cited source is a SNL internal memo by Peterson [vol. 3, Appendix A, pp. A-135-140]. It is not possible to reproduce the results. Using data from input to the 1991 *Integrated Data Base,* (USDOE 1991b), we compare our results for categorizing contact-handled standard waste boxes against Peterson's in Figure 14. It is obvious the two do not match. SNL needs to explain how the results were obtained. The memo by Peterson was dated October 28, 1992, well after most of the computations for the *1992 Performance Assessment* had been completed. SNL should explain what inventory was actually used in calculations.

13.3 The inventory used in the *1992 Performance Assessment* is to be detailed in a report in preparation by Peterson. As of June 30, 1994, that report has not been published.

Recommendation 13.1 Include ^{135}Cs, ^{129}I and ^{99}Tc and other fission product nuclides as appropriate in future performance assessments.

Recommendation 13.2 Show the basis for inventories used.

14. Solubilities

Sandia calculates the flux of radionuclides from the waste by [vol. 3, p. 1-36]

$$\dot{M}_i = -QC_{di} - \gamma_i M_i + \gamma_{i-1} M_{i-1} \qquad (3)$$

where M_i is the mass of the i^{th} nuclide in dissolved form,
C_{di} is the dissolved concentration of the i^{th} nuclide,

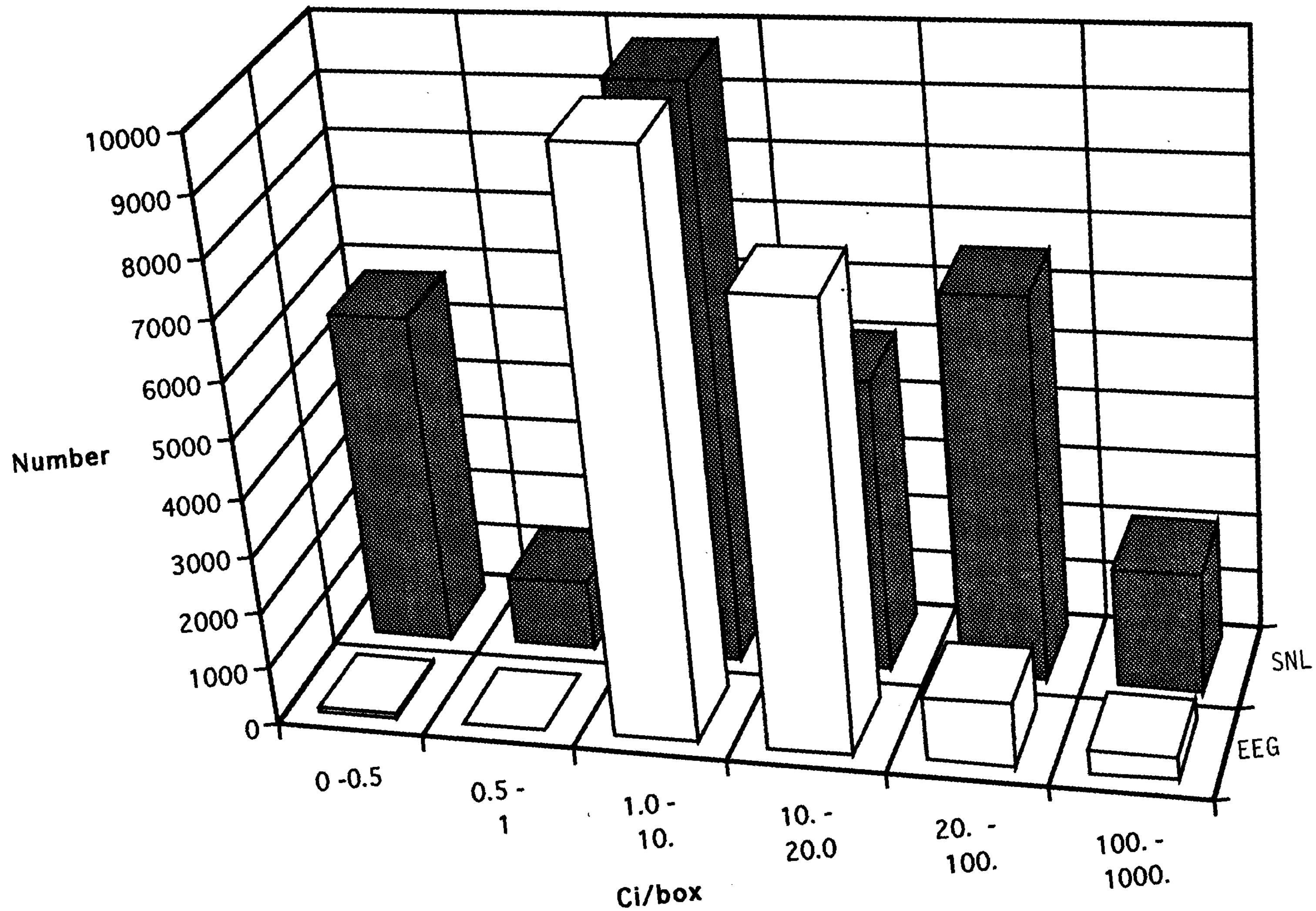

Figure 14. Radioactivity levels in standard waste boxes calculated by EEG and SNL.

Q is the brine flow rate, and

γ is the nuclide's decay constant.

The concentration is calculated as

$$C_{di} = \frac{M_i}{\sum_j M_j} S_i \tag{4}$$

where S_i is the concentration in saturated solution, and this equation calculates the isotopic fraction of solubility over j isotopes.

From these equations, it is clear that solubility would be an important parameter in the calculation of consequences.

Experimentally measured solubility should be used in eq. (4), but few relevant measured actinide solubilities exists. Geochemical calculations, using either experimental or estimated stability constants, could be used. In the *1992 Performance Assessment*, Sandia used neither of these approaches. Instead Sandia used subjective elicitation. A panel of outsider scientists was asked to make estimates. The resultant estimates span a wide range. For instance, the estimated plutonium solubility spans 12 orders of magnitude.

When these wide, subjective estimates are used in Latin Hypercube Sampling of input values, non-conservative solubilities in consequence calculations may result. We shall examine the case for plutonium. In the *1992 Performance Assessment*, the sampling range for plutonium solubility was 5.5×10^{-4} mole/L to 2.5×10^{-17} M [vol. 3, p. 3-40], based on subjective elicitation, as shown in Figure 15. The black circle is the median and the open circle is the mean of the elicited distribution.

Solubility measurements are available at WIPP for Culebra water from the air intake shaft (Nitsche *et al.,* 1992), and for Brine A, a simulant of brine expected to inundate the repository (Nitsche *et al.,* 1993). Nitsche's solubility measurement experiments lasted several hundred days, and were started with various oxidation states of plutonium. Results are also shown in Figure 15. For the various initial oxidation states the steady-state concentration estimates are plotted, assuming the results are normally distributed, and the 25 and 75 percentiles are the edges of the boxes or ends of the arrows. The experimentally measured solubilities are generally greater than 10^{-7} M. However, when one examines the values of plutonium solubilities used in the 70 realizations in the Monte Carlo analysis [vol. 4, p. C-10], one finds

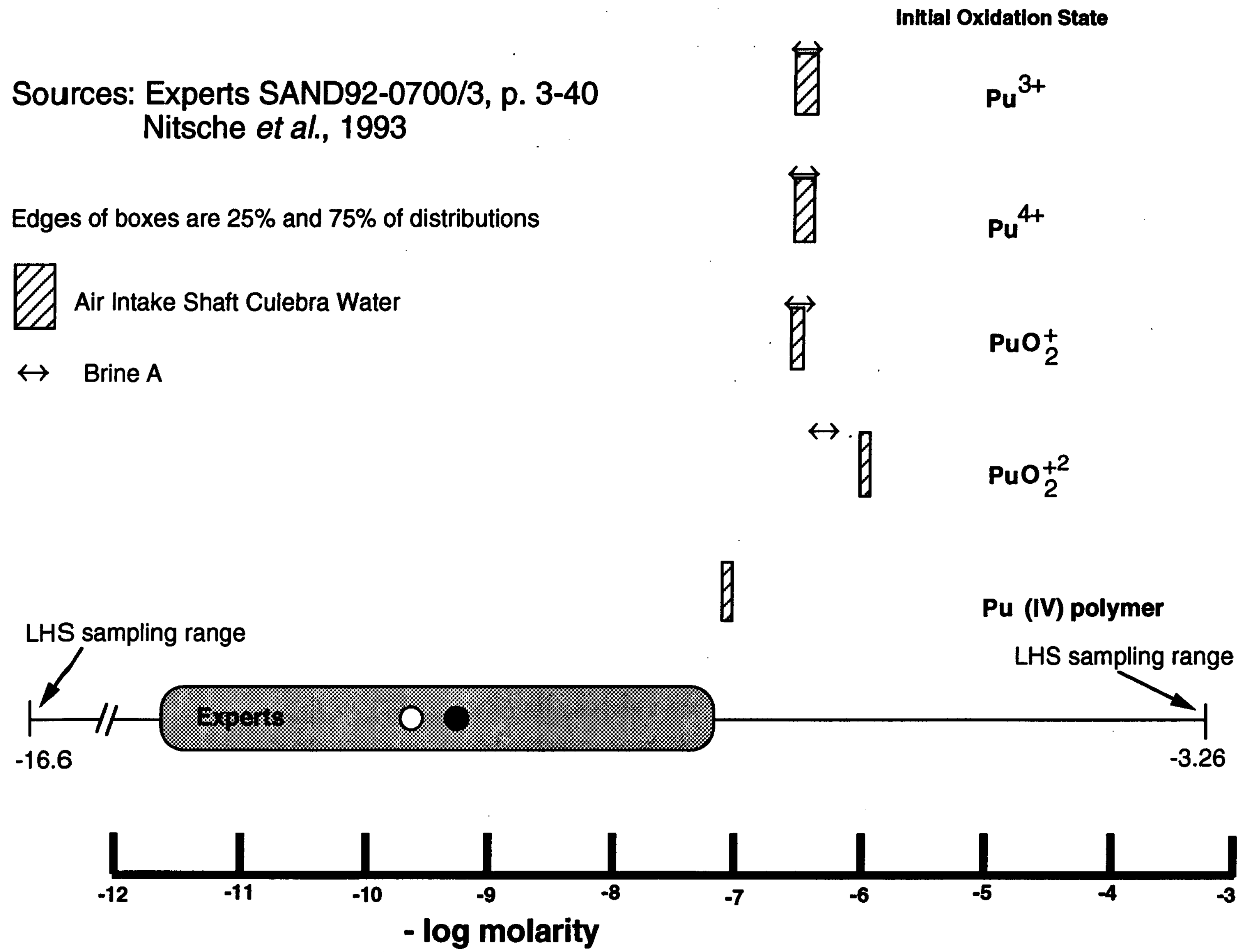

Figure 15. Comparison of subjectively elicited plutonium solubility and experimental solubility.

out that only 14 of the 70 realizations had a plutonium solubility of 10^{-7} M or higher, or 20%. The use of subjective elicitation apparently resulted in a downward bias in estimating plutonium solubility, leading to non-conservative consequences.

Recommendation 14. In future performance assessments, limit the sampling range to the error bands in experimental data.

15. Transport Modeling of Volatile Organics

In the analysis of compliance with 40 CFR 268, there has not been a transport analysis [vol.4, p. 4-38, line 25]. The conclusions in volume 5 are inferences using a flow model.

Recommendation 15. Two-phase transport of volatile organic compounds through gas-fractured interbeds should be analyzed in the future.

16. Corrensite Retardation in the Culebra

The *1992 Performance Assessment* identifies sorption on clay fracture-linings as one of three retardation mechanisms for radionuclide transport through the Culebra. Corrensite was addressed briefly in Recommendation 1.3. We elaborate here.

The concept of corrensite sorption is based on x-ray diffraction and analytical electron microscopy analysis of cores samples from clay-rich layers of the Rustler Formation, from wells drilled primarily in Nash Draw. This concept originates from the work of Sewards and others at the University of New Mexico under contract to the Sandia National Laboratories (Sewards 1991; Sewards, Glenn and Keil, 1991; Sewards, Williams and Keil, 1991; Siegel *et al.,* 1990).

16.1 Review of Corrensite Data

Sewards, Glenn and Keil (1991) presented mineralogical analysis of core samples from a single well, WIPP-19, and made no claim for clay-filled fracture linings in the Culebra.

Sewards (1991) gave data on "whole rock" as well as "fracture surface" compositions of core samples collected from six wells (WIPP-26, 27, 28, 29, 30, 32) in Nash Draw, one borehole (WIPP-33) between Nash Draw and the WIPP site, and three boreholes (WIPP-12,13, and 34) in the northern part of the WIPP site. Clays are expected to be present in the Nash Draw cores because of extensive dissolution, weathering, and erosion in that area. WIPP-33 is located in a sink hole and dissolution, weathering, and erosion are expected. Boreholes 12, 13 and 34 are located north of the WIPP repository and upstream from the expected direction of flow of water in the Culebra. Furthermore, cores are from these wells are in sections with known clay seams. For example, the only sample from WIPP-12 (CS-1) came from the zone 254.09 m (838.5 ft) to 254.15 m (838.7 ft) below the surface. The Basic Data Report for WIPP-12 (SNL and D'Appolonia, 1982) identifies mud seams at 253.85 m (837.7 ft) and 254.76 m (840.7 ft) depths.

Sewards, Williams and Keil (1991) presented mineralogy of 107 core samples from eight wells, three of which are located in the WIPP site. However, clay fraction separates ($< 2\ \mu m$) were obtained for only three samples: WIPP-12 #3, a clay-poor dolomite; WIPP-12 #16, a clay-rich dolomite; and H6B #3, a shale. X-ray diffraction analysis was performed on the clay fractions from these three samples, and one sample (H6B #3) was analyzed under the electron microscope. The electron microscopy on this one sample casts doubt on the results of the x-ray diffraction

> There is, however, a discrepancy between the results of the quantitative XRD analysis and the results of the AEM investigation of sample H6B #3. In that sample, the XRD results show that the sample contains approximately 50% corrensite. When imaging was attempted on the AEM, it was extremely difficult to find any corrensite at all; the dominant phases appeared to be serpentine, illite, and chlorite (Sewards, Williams and Keil (1991); p. VII-19).

The conclusion of this report does not follow from the data analyzed:

> The fact that corrensite is the dominant phase in the Culebra samples is important. Corrensite has a high cation exchange capacity (CEC) and high surface area, thus it is able to sorb radionuclides very efficiently in the event of a low pressure breach in the WIPP facility. Although the clay minerals of only three samples were investigated, the results of Sewards, Glenn and Keil (1991) show that mixed-layer chlorite/smectite is the dominant clay phase throughout the Rustler Formation, so it is reasonable to suggest that the same is true in the Culebra unit (Sewards, Williams and Keil (1991); p. VII-19).

Sewards, Glenn and Keil (1991) made no claim for clays lining fractures in the Culebra. Corrensite was interpreted to be present in some of the samples, as one mineral among many, when powdered bulk samples were analyzed by x-ray diffraction.

Sewards *et al.,* (1992) presented mineralogical analysis from 47 samples. Of these, 17 samples were taken from the Culebra, and of these only nine are from the WIPP site: six from the Air Intake Shaft and three from WIPP-12. The report states:

> Only small amounts of clay can be sampled from the Culebra fracture coatings; therefore, initial technique and model development for adsorption studies on WIPP clays (Park *et al.,* in review) were carried out with material from a black shale layer in the unnamed member. This material, so-called CorWIPP, is 94% corrensite and is described as Sample AIS-15 in this report. Corrensite has a high cation exchange capacity and affinity for the uranyl ion in dilute solution (Park *et al.,* in review) and could provide significant radionuclide retardation in fractures in the Culebra (Sewards *et al.,* 1992).

The above quotation clearly identifies the problem with using Sewards' work to conclude that corrensite clay-lined fractures in the Culebra may provide retardation for radionuclide migration through the Culebra. The argument is based on a sample from a "black shale layer" obtained from the lower part of the Rustler Formation, below the Culebra, because not much clay could be sampled from Culebra fracture coatings. And yet, information from this sample is used to conjecture that "significant radionuclide retardation in fractures in the Culebra" could be present! This is the basis for continuing research on the adsorption properties of corrensite, model developement for retardation in the Culebra, and the assumptions of additional retardation.

16.2 Corrensite in the *1992 Performance Assessment*

Input to the *1992 Performance Assessment* has correctly evaluated the concept of corrensite retardation:

> Sewards (1991) measured and reported clay abundance for eighteen Culebra samples; thirteen from locations to the north and/or west of the WIPP site, and five from the north end of the WIPP site. None of these samples was from wells along fast transport paths. Because Sewards (1991) was focusing on clay abundance and compositional analyses, it is likely that samples were selected for analysis based on visual appearance of clays. Thus, these data may not be representative of clay abun-

dance on fracture surfaces in the area of interest for transport modeling (Novak, Gelbard and Papenguth, 1992).

Given the above analysis, why did SNL assume additional retardation from corrensite in the *1992 Performance Assessment*?

Recommendation 16. Abandon claiming credit for corrensite sorption as well as additional experiments with corrensite.

17. Ideal Gas Assumption in VOC Migration

In the *1992 Performance Assessment*, all gases are assumed to have the properties of hydrogen (vol. 5, p. 2-9) and behave like an ideal gas. While this assumption may be good for CO_2 and even for CH_4, it is not a good assumption for the volatile organic (VOC) gases regulated under 40 CFR 268. These gases have critical pressures well below lithostatic pressure, so that at lithostatic pressure they would not be expected to behave at all like ideal gases. In Table VIII, we show the ratio of the critical pressures of four prevalent VOC in TRU waste (Reid, Prausnitz and Poling, 1987) to lithostatic pressure of 15.2 MPa.

Table VIII. Ratio of Critical Pressures of Selected VOC to Lithostatic Pressure at Repository Horizon

COMPOUND	P_c (MPa)	P_{lith}/P_c
Carbon Tetrachloride, CCl_4	4.56	3.3
Dichloromethane, CH_2Cl_2	6.30	2.4
1,1,1-trichloroethane, CCl_3CH_3	4.30	3.6
Trichloroethene, $Cl_2C=CHCl$	5.05	3.0

Table VIII shows that these four important VOC will not behave like ideal gases.

Recommendation 17. Unless there is experimental evidence that VOC vapors move as ideal gases and move with the low-molecular-weight gases generated by radiolysis, corrosion, or microbial action, movement of VOC vapors should not be modeled as ideal gas flow in showing compliance with 40 CFR 268.

III. DETAILED COMMENTS

Volume 1

Sec. 3.1 p. 3-3 This section says that USEPA expects the implementing Agency to use the same assumptions. But it does not say whether USDOE does or does not.

Table 3-1 p. 3-14, line 15 In this Table, techniques are given for assessing and reducing various kinds of uncertainties. For conceptual model uncertainty, an additional method of assessing its extent is to analyze alternate conceptual models. If alternate conceptual models can be rejected with confidence, then the favorite conceptual model has a better chance!

Table 3-1 p. 3-14 In Parameter Values and Variability, the use of expert judgment is said to be a method of assessing and reducing uncertainty. The fact is that the panel on solubilities greatly EXPANDED the uncertainty range.

Sec. 4.1.1, p. 4-2, line 28 The description of undisturbed performance should include a statement that the deleterious effects of gas fracturing have not been considered. The probability of gas fracturing is clearly above 10^{-4} in 10,000 years. Sandia's own experimental data suggest that without fracturing, the gas pressure is likely to reach and exceed lithostatic in hundreds of years.

Sec. 4.2, p. 4-8, line 38 Why is the maximum number of holes in the 70 simulations only 20 per km^2 when Latin Hypercube is used to sample uniformly (I presume) over interval [0,30]? Isn't the key advantage of Latin Hypercube to "ensures full coverage of the range of each sampled variable." (p. 4-14, line 10)?

Sec. 5.1.2.1.1, p. 5-3, line 27 Is λ really random in both space and time? As implemented it appears to be only a variable of time.

Sec. 5.1.2.1.2, p. 5-4 , line 35 It is not clear why the intrusion and subsurface release times are specified rather than random. If intrusion and release times are random, the source strength can be calculated in PANEL using eq. 1.4.4-11 in vol. 3. Are these six times of intrusion possible times of intrusion, or must the intrusions occur?

Sec. 5.1.2.2, p. 5-6, line 25 Given our comments on the subjective elicitation process in the preceding pages, we do not consider any of the results using λ_t to be valid.

Sec. 5.1.2.2, p. 5-6, line 27 When releases are calculated for six intrusions, is it six holes? Does this correspond to S(4,1,0,1,0,0) in Table 3-2 of SAND 91-0893/1?

Volume 2

Sec. 1.3.2, p. 1-4, line 26 CAMCON controls 75 codes for WIPP Performance Assessment. However, the key codes BRAGFLO, SECOTP2D and CUTTINGS are run outside of CAMCON, and also probably SANTOS-SANCHO. Does this make CAMCOM a general without troops?

Sec. 2.3.2.1, p. 2-47, line 2 The word should probably be "pyrophoric."

Sec. 2.3.2.1, p. 2-47, line 2 The second half of this sentence appears to be incorrect. The limit for pyrophoric ingredients is probably 1% of the weight of the waste, not 1% of the weight of an empty container.

Sec. 2.3.4.1, p. 2-54, line 20 To use ionic-strength corrected data from Well J-13 from Yucca Mountain as the median needs justification.

Sec. 2.3.4.2, p. 2-55, line 4 The laboratory measurements of plutonium solubilities and sorption coefficients in brines fall short for several reasons:

- solubilities and sorption coefficients in Culebra water are needed;
- for the spectrum of possible conditions, calculations are better.

Sec. 2.3.4.2, p. 2-55, line 6 It is not clear how the results of the Source Term Testing Program will be useful or used in performance assessment. The current performance assessment uses the actinide solubility. The LANL experiments give a release rate, rather than a solubility. The LANL release rate will be proportional to inventory. The performance assessment department should state how it intends to use the two different sets of data.

Sec. 2.3.5, p. 2-55, line 13 The statement is made that at decommissioning, free brine will not be present within the emplacement area. Experience over the history of WIPP indicates that brine *may* be present throughout the disposal phase.

Sec. 4.2.3.1, p. 4-11, line 11 Do these plastic containers meet the Waste Acceptance Criteria?

Sec. 4.2.3.2, p. 4-13, line 33 "All borehole plugs... degrade into material with properties similar to those of silty sand." Why not the plug above the Culebra?

Sec. 5.2, p. 5-2, line 22 Prof. Helton's method of calculating intrusion probabilities is not trivial. The full explanation is worthy of a journal paper. The brief explanation here raises more questions than answers. As a matter of fact, this summary is incomprehensible and confusing.

Sec. 5.2, p. 5-4, line 16 Hora's algorithm gives drilling rates in units of holes/mi^2/10000 years, not holes/km^2/10,000 years.

Sec. 7.2.3, p. 7-3, line 19 Should combustibles be organic?

Sec. 7.2.3, p. 7-3, line 21 Do you mean "biodegradation of organic materials only?" Non-combustible organics may still be biodegradable.

Sec. 7.6.1.2, p. 7-16, line 26 How is the scaling factor chosen? Who decides that it is reasonable? The same questions apply to the choice of A_R, θ, and ϕ in (7-14). Where are the results of climate change shown?

Sec. 7.6.2, p. 7-18, line 5 The numerical model for solute transport is 2-dimensional. The conceptual model shown in Figure 7-4 is 3-dimensional.

Volume 3

Sec. 1.2, p. 1-8, line 9 In the upper right plot in Figure 1.2-1, why is the median/mean of a standardized normal distribution 0.500001?

Sec. 1.4, p. 1-24, line 43 In eq.(1.4.1-9b) and eq.(1.4.1-11), the big dot used here for multiplication is confusing, and it is not needed. The dot is used on the previous two pages only for the dot product.

Sec. 1.4.4, p. 1-34 Instead of using two pages to explain what PANEL does not do, why not just present eq. (1.4.4-10) and explain that C_{di} is treated as a known constant.

Sec. 1.4.5, p. 1-38, line 11 Same comment on the big dot.

Sec. 2.3.3, p. 2-24 The data-source category of "engineering lore" is used here and in other places. "Engineering lore" is not defined on p. 1-13. In this case, the source is a refereed journal paper, which may well be "non-WIPP Literature Data."

Sec. 2.6, p. 2-78, line 14 The equation here does not make sense, and the definition of probability is not proper. For x as a random variate, try

$$P\left[\frac{b_c}{b}\right] = \begin{cases} 0, & 0 < x < 0.5 \\ x{-}0.5, & 0.5 \le x \le 1.0 \end{cases}$$

Sec. 2.6, p. 2-83 Why is the median given here not equal to the median given on the previous page, line 13?

Sec. 2.6, p. 2-93, 94 These are curious tables. The range of partition coefficients extends to a region of no significance. One can calculate the lowest value of K_D which will give a positive retardation coefficient, using

$$R = \frac{\epsilon}{1-\epsilon}\rho K_D$$

where $\epsilon = 0.145$, from p. 2-82, $\rho = 2.82$, from p. 2-76, which gives $K_D > 2.09$, and $\log K_D > 0.32$. Examination of these tables says none of the nuclide's median partition coefficient will give a positive retardation. Why bother? Just forget retardation.

Sec. 3.3, p. 3-22, Table 3.1 A more correct term for "activity conversion" is "specific activity."

Sec. 4.2, p. 4-6. line 7 Certainly this refers to a regular borehole, However, Figure 4.2-2 refers to changes in permeability as a function of "time after intrusion." This legend cannot be correct. Should it be "time after sealing?"

Sec. 4.2, p. 4-6, line 11 Surely the concrete plugs do not have **initially** the permeability and porosity of silty sand. On p. 3-14, the permeability of concrete is given as $2.7\times10^{-19}\text{m}^2$, where the permeability of silty sand has a median value of $3.16\times10^{-12}\ \text{m}^2$.

Sec. 4.2.1, p. 4-4, line 38 Reference is made to the New Mexico Energy, Minerals, and Natural Resources Department, Oil Conservation Commission as the state agency responsible for negotiating plug and abandonment specifications and conducting inspections. The Oil Conservation Commission has not performed this function since 1978. On March 31, 1978, Division Order No. R-5709 established the Oil Conservation Division to take over the responsibilities of the Oil Conservation Commission and left the Oil Conservation Commission remaining in name as an appellate board. Many people in the industry still refer to OCD as OCC, but that is not technically correct.

Volume 4

p. 2-16, line 1 Assumption 1 states there are no synergistic effect between intrusions, except for the E1E2 scenario. However, on line 25, the statement is made that

> ...there is little reason to believe that the release taking place from one waste panel would affect the release taking place from another waste panel.

This presumes that brine entering one panel would not affect brine in another panel because of perfect panel seals which have not been designed or verified experimentally.

p. 2-16, line 6 The current assumption is that an E1E2-type scenario can only occur in the time interval $[t_{i-1},\ t_i]$. Indeed the *1992 Performance Assessment* only considered E1E2 at the same time. Should an E1E2 scenario occur at say 1995 and 2010 (years after closure), they would be analyzed as two E2, with quite different consequences.

p. 2-16, line 9 Assumption 3 is unsupportable. In the *1992 Performance Assessment* both BRAGFLO and PANEL considers one waste panel at a time. For an E1E2, BRAGFLO and PANEL would calculate Qc, the product of the brine flux Q, and the solubility c. If there are three intrusions, with two E2 holes hitting different panels, the resultant subsurface release is not the same as that of an E1E2 pair. It is likely to be $Q_1c + Q_2c$. Thus this is not an acceptable assumption.

Section 2.3 The current Poisson model assumes that the intrusions are independent, that is, one intrusion does not affect the probability of another. Does one intrusion increase or decrease the probability of additional intrusions? One does not drag a drill rig into an area and just drill one hole! Even the hydropads for WIPP have several wells on each. Exploration geophysicists operate on knowledge of geologic structures. If geologists tried a structure in 1997 AD, they are more likely to return in AD 2097 and try the same structure. Thus some built-in correlation is credible.

p. 2-18, eq. 2.4-14 This should probably read

$$cS^{+-}(l; t_{i-1},\ t_i) = \sum_{j=1}^{5} 2rC_{i,\ell(j)} + rGW2_i,$$

p. 2-18, line 47 A reason given for considering the consequence of only a single intrusion at 1,000 years is "increased radioactive decay." Many actinides have long half life:

Pu-239	24,000 years
Pu-242	376,300 years
Th-230	7,700 years
U-233	158,500 years
U-238	4.468 $\times 10^9$ years.

Not much decay would have occurred in even 10,000 years!

p. 3-4, line 35 The range of LAMBDA is given as [0,1.0] while in Figure 3-1. p. 3-14, the range of LAMBDA is given as [0, 0.4].

Section 4.2.4 Here there are two possible representation between saturation and permeability and capillary pressure. They can be considered two different conceptual models, rather than mixing them 2/3 and 1/3.

p. 4-26, line 37 A reason given for using the van Genuchten equation is to simulate fingering. If fingers are at the scale of centimeters, and BRAGFLO's grid blocks are tens of meters, is this sufficient resolution to see this phenomenon?

p. 7-5, line 37 Should this be Figure 7.2-1?

p. 7-9, line 30 Solving eq. (7.2-5) analytically appears to be possible. Eq. (7.2-6) needs to be solved iteratively.

p. 7-7, Fig. 7.2-2 How is τ_{fail} determined?

p. 8-57, Figure 8.5-1; p. 8-58, Figure 8.5-2 What is the difference between a - and a blank in these tables.

p. 8-43, Figure 8.4-11 In the upper right frame, the mean CCDF is to the northeast of the 90% CCDF. This deserves more explanation. Please also explain why the mean CCDF starts at 8 $\times 10^{-3}$ on the probability scale, when there is a vector with probability of 0.5. According to p. 8-44, line 21, there are 21 vectors with releases, for the case of chemical retardation, matrix diffusion and no clay. Dividing 0.5 by 21, the minimum probability should be 2.38 $\times 10^{-2}$.

p. 8-60, line 31 This discussion of the effect of considering human intrusion for the full 10,000 years should be applied to Figure 9-1, especially Curve 1.

Volume 5

Is MBPERM gas or brine permeability?

p. 2-7, line 28 The word "scaled" should probably be "sealed."

p. 2-8, line 10 The porosity of the damaged rock zone increases from that of intact salt to that of highly fractured rock at time zero. Shouldn't this increase begin when the damage to the salt occurs, at $t = -50$ years, the time of initial excavation?

p. 2-8, line 35 Sensitivity analyses show that BRSAT is the most important parameter in undisturbed performance, and the second most important parameter in 191B performance, yet the range that BRSAT is sampled from is "somewhat arbitrary?" Moreover, the reduction of the high end of the sampling range is because of computational concern! What would the results look like if this sampling is optimized?

p. 5-2, line 4 A different set of permeabilities is used in the first 200 years. Is the first 200 years after closure, or after adminstrative control?

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ACRONYMS

AEM	analytic electron microscopy
BB	billion barrels
bbl	barrels
BCF	billion cubic feet
BT	billion tons
CCDF	complementary cumultive distribution function
CFR	*Code of Federal Regulations*
EEG	Environmental Evaluation Group
LANL	Los Alamos National Laboratory
M	mole/litre
MB	million barrels
MT	million tons
SNL	Sandia National Laboratories
TCF	trillion cubic feet
TRU	transuranic
USBLM	U. S. Bureau of Land Management
USDOE	U. S. Department of Energy
USEPA	U. S. Environmental Protection Agency
VOC	volatile organic compounds
WIPP	Waste Isolation Pilot Plant
XRD	x-ray diffraction

Computer Codes Mentioned

BRAGFLO
CUTTINGS
SANCHO
SECOTP2D
SWIFT
CAMCON
PANEL
SANTOS
STAFF2D

Variable Names

LAMBDA VMETAL VWOOD