**Final Agenda: 61st WIPP QUARTERLY REVIEW MEETING**

Revision 2.0

January 29, 1998

2040 S. Pacheco Street, Santa Fe, New Mexico

Messages: 827-595  FAX: 827-1150

<table>
<thead>
<tr>
<th>Time</th>
<th>Overview Presentation</th>
<th>Presenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:30 AM</td>
<td>Welcome and Opening Remarks</td>
<td>10 min. Steve Zappe, NMED</td>
</tr>
<tr>
<td>8:40 AM</td>
<td>U.S. DOE: Status/Activity Report</td>
<td>20 min. George Dials, DOE/CAO</td>
</tr>
<tr>
<td>9:00 AM</td>
<td>EEG: Status/Activity Report Including Future Role and Activities</td>
<td>20 min. Robert Neill, EEG</td>
</tr>
<tr>
<td>9:40 AM</td>
<td>RCRA Permit Status/Activity Report</td>
<td>20 min. Steve Zappe, NMED</td>
</tr>
<tr>
<td>10:00 AM</td>
<td>Break</td>
<td>15 min.</td>
</tr>
</tbody>
</table>

**WASTE CHARACTERIZATION ISSUES**

<table>
<thead>
<tr>
<th>Time</th>
<th>Overview Presentation</th>
<th>Presenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:15 AM</td>
<td>Proposed Methods to ID non-RCRA waste</td>
<td>20 min. DOE/CAO</td>
</tr>
<tr>
<td>10:35 AM</td>
<td>Generator Site/Certification Status: Outstanding CARs</td>
<td>20 min. Kent Hunter, DOE/CAO</td>
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<tr>
<td>10:55 AM</td>
<td>Meeting with EPA and DOE on December 31, letter re: proposed ruling of 40 CFR, Part 191, Subpart B</td>
<td>20 min. Lokesh Chaturverdi, EEG</td>
</tr>
<tr>
<td>11:15</td>
<td>Open Discussions (i.e., Waste Inventories, RFETS residue &amp; scrap alloy, Advanced Waste Treatment Facility)</td>
<td>15 min. EEG, DOE/CAO</td>
</tr>
<tr>
<td>11:30 AM</td>
<td>Lunch</td>
<td>1-¼ hr.</td>
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**PERFORMANCE ASSESSMENT TOPICS**

<table>
<thead>
<tr>
<th>Time</th>
<th>Overview Presentation</th>
<th>Presenter</th>
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</thead>
<tbody>
<tr>
<td>1:00 PM</td>
<td>Spalling Scenario; GASOUT Code; Stuck Pipe/Gas Erosion</td>
<td>40 min. Dale Rucker, EEG</td>
</tr>
<tr>
<td>1:40 PM</td>
<td>Air Drilling and Fluid Injection South Eastern New Mexico</td>
<td>20 min. Mathew Silva, EEG</td>
</tr>
<tr>
<td>2:00 PM</td>
<td>Solubility Parameter Values</td>
<td>20 min. Matthew Silva, EEG</td>
</tr>
<tr>
<td>2:20 PM</td>
<td>J. Bredehoeft’s Air Drilling Report</td>
<td>20 min. Weart/Shephard, DOE/CAO</td>
</tr>
<tr>
<td>2:40 PM</td>
<td>Discussion of P.A. Issues</td>
<td>30 min. EEG, DOE/CAO</td>
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<tr>
<td>3:10 PM</td>
<td>Break</td>
<td>15 min.</td>
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**OPERATIONAL ISSUES**

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<tbody>
<tr>
<td>3:25 PM</td>
<td>SAR/ORR Status and Plans</td>
<td>15 min. Kent Hunter, DOE/CAO</td>
</tr>
<tr>
<td>3:40 PM</td>
<td>Privatization: WIPP Transport Services</td>
<td>15 min. Tim Sweeney, DOE/CAO</td>
</tr>
<tr>
<td>3:55 PM</td>
<td>Action Items/Closeout</td>
<td>15 min. NMED</td>
</tr>
<tr>
<td>4:16 PM</td>
<td>Adjourn</td>
<td></td>
</tr>
</tbody>
</table>
LXI QUARTERLY MEETING

U.S. Department of Energy
N.M. Energy Minerals and Natural Resources Dept.
N.M. Environmental Evaluation Group
N.M. Environment Department
N.M. Attorney General

Robert H. Neill

January 29, 1998
Santa Fe

Providing an independent technical analysis of the Waste Isolation Pilot Plant (WIPP), a federal transuranic nuclear waste repository.
EEG Status

- Focus since last Quarterly on EPA Proposed Rule approving disposal
  - Deadline for comments 2/27/98
  - EEG provided feedback to EPA and DOE
    - 12/10/97 Meeting
    - 12/31/97 Letter
    - 1/98 Hearings
    - 1/26/98 Meeting

- Will cover later today
  - Solubility
    - FMT Code
    - Nesquehonite
    - Oxidation State Analogy
  - Fluid Injection
  - Air Drilling
  - Gasout

- ORR Review
- SAR Review
- EEG Lab Facility and training provided to Westinghouse - Not mentioned by W. at Hearings
• Review of the RFP Pu residues and scrap alloy DEIS
  • Not provided by CAO until 70% of 42 day review process elapsed (23% of WIPP Pu)

• CAO January 1997 TF Report - not provided by DOE until 1/98

• Waste Characterization
  • Continuous substantial changes
  • Additional Pu in residues at SRS, LANL
    (2.8MT = 22% increase in Pu inventory)

• Future Emphasis
  • Waste Characterization 12 B$/19 B$ Total
  • Confirmation experiments and analyses
  • Processing waste
  • Load Management Issues
  • Variances issued for safeguard termination limits and waste acceptance criteria without input from EEG and other affected parties
# EXISTING CH-TRU WASTE

(M³)

<table>
<thead>
<tr>
<th>Source</th>
<th>Basic Inventory BIR Rev. 3 6/96</th>
<th>NTRUWM Plan 9/96</th>
<th>NTRUWM Plan Rev. 1 12/97</th>
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<tbody>
<tr>
<td>Hanford</td>
<td>12300</td>
<td>16407</td>
<td>16127</td>
</tr>
<tr>
<td>LANL</td>
<td>11050</td>
<td>7770</td>
<td>8255</td>
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<tr>
<td>INEEL (incl. ANL-W)</td>
<td>28157</td>
<td>65102*</td>
<td>64575</td>
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<tr>
<td>SRS</td>
<td>2880</td>
<td>9165</td>
<td>11725</td>
</tr>
<tr>
<td>RFETS</td>
<td>4890</td>
<td>1043</td>
<td>1505</td>
</tr>
<tr>
<td>Mound</td>
<td>300</td>
<td>239</td>
<td>241</td>
</tr>
<tr>
<td>ANL-E</td>
<td>25</td>
<td>83</td>
<td>94</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>61787</strong></td>
<td><strong>102025</strong></td>
<td><strong>104,400</strong></td>
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*Includes 27,000 M³ Alpha LLW
# EXISTING RH-TRU

(M$^3$)

<table>
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<tr>
<th></th>
<th>Basic Inventory</th>
<th>NTRUWM Plan</th>
<th>NTRUWM Plan Rev. 1 12/97</th>
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<tr>
<td>ORNL</td>
<td>2470</td>
<td>962</td>
<td>1268</td>
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<tr>
<td>INEEL</td>
<td>20</td>
<td>86</td>
<td>86</td>
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<tr>
<td>Other</td>
<td>896</td>
<td>893</td>
<td>312</td>
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<tr>
<td>TOTAL</td>
<td>3366</td>
<td>1941</td>
<td>1666</td>
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## PROJECTED CH-TRU WASTE

**M³**

<table>
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<tr>
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<th>Basic Inventory BIR Rev. 3 6/96</th>
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<th>NTRUWM Plan 12/97</th>
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<td>17811</td>
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<td>MOUND</td>
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<td>6</td>
</tr>
<tr>
<td>ANL-E</td>
<td>180</td>
<td>12</td>
<td>109</td>
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<tr>
<td>BETTIS</td>
<td>170</td>
<td>123</td>
<td>114</td>
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<td>SNL</td>
<td>10</td>
<td>6</td>
<td>44</td>
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<tr>
<td>PADUCAH</td>
<td>8</td>
<td>0</td>
<td>0</td>
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<td><strong>TOTAL</strong></td>
<td><strong>73014</strong></td>
<td><strong>38437</strong></td>
<td><strong>56972</strong></td>
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## PROJECTED RH-TRU (M$^3$)

<table>
<thead>
<tr>
<th></th>
<th>Basic Inventory BIR Rev. 3 6/96</th>
<th>NTRUWM Plan 9/96</th>
<th>NTRUWM Plan Rev. 1 12/97</th>
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<tr>
<td>Hanford</td>
<td>29200</td>
<td>2420</td>
<td>1582</td>
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<td>LANL</td>
<td>130</td>
<td>230</td>
<td>128</td>
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<tr>
<td>INEEL (incl. ANL-W)</td>
<td>1720</td>
<td>53</td>
<td>53</td>
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<tr>
<td>ORNL</td>
<td>600</td>
<td>193</td>
<td>100</td>
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<td><strong>TOTAL</strong></td>
<td><strong>31660</strong></td>
<td><strong>2818</strong></td>
<td><strong>2268</strong></td>
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</table>
PU RESIDUE ISSUE

- ~ 3100 Kg Pu at RFETS, 2800 Kg elsewhere
- ~ 60% shippable to WIPP in pipe components in TRUPACT-II
- ~ 40% above Safeguard Termination Limits (STLs) even after 1996 modification
- Some of residues would need STL variances to come to WIPP even after treatment
DOE ACTIONS

- WIPP CCA (10/96) included RFETS residue inventory but did not address STL issue
- WIPP SEIS-II did not address STL issue
- CAO Pu Residue Task Force (1/97) recommended all residues be treated and shipped to WIPP with STL variances as needed
- Draft EIS on RFETS Residues (11/97) has 3 alternatives: (1) no action; (2) treat and ship to WIPP with STL variances; (3) process some residues to remove Pu so can ship to WIPP without variances
EEG CONCERNS

- Was not informed until 12/97

- STL modifications and variances made in DOE with little input

- CAO Task Force proposes changing WAC FGE limit from 325 to 2800

- CAO considering shipping some residues in drums rather than pipe components

- Possible criticality and other operational problems

- Possible long-term implications

- Possible terrorist sabotage or diversion during transport
6/5th WIPP Quarterly

George Duls
Then the gate in 98
Reviewed Action items from 6/6th. Disposal decision plan revised to indicate ROD 1/98
asked for a copy of ROD. Chris H. asked about SNL shipping to LANL. Why not mobile systems? (6 m^3 to 40m^3) - kept options open. May use mobile systems (political, not technical issue).

Operations Status - contractor ORR 1/23/98. DOE review 3/16/98. DOE (George) declared readiness 3/31/98. No known show stoppers identified.

EPA hearings, comments until 2/27, certification end of April.

Verifying very carefully the quantities of nonmixed TRU especially at LANL. Believes its rational equipment's decision to dispose TRU waste, not to worry about solvents used. Lindsay asked if RPA had decided to proceed w/ non mixed, George avoided.

Bob Neil 9.5 M/kg to dispose


RFETS P& E insides/scrap alloy -> 23% of WIPP R & W waste. Cherv - increase in P& E estimate. Total waste cherv estimated to be 6125 out of 598 total to dispose all waste. DOE has published a disposal phase R&D plan.

DOE perhaps to modify WAC limits - transportation is disposal, seeking variances (Kent said none planned).
Every time I think about our experience in AK, it's easy to remember the joy and friendship we found there. AK has a special place in my heart, and I always look forward to returning. This year, I plan to go with my family and explore more of the beautiful scenery.

Our time in AK was filled with unforgettable moments, from the stunning landscapes to the warm hospitality of the local community. The experiences we shared will be cherished memories for a lifetime.

I cannot wait to see what new adventures await us in AK this year. The anticipation is building, and I'm already planning the details of our trip. Whether it's hiking, fishing, or simply enjoying the scenic beauty, AK has something for everyone.

I hope this letter finds you well and that you are looking forward to your own adventures. Until we meet again in AK, keep exploring and making memories that will last a lifetime.

Yours sincerely,
[Your Name]
Carbon fiber room limit 7500 ppm, prep is 100 ppm. 100% HSG on legacy waste, maybe not for treated newly generated waste (ie, vitrified). No VE to determine RCRA constituents tied to confirming radiography only (lower exposure).


Lokesh: Report on EPA meetings - 4 to date 12/10/97 - present comments to EPA (us observ.) 1/21/98 - at SNC to discuss GASOUT code. 1/22 - at EEG office to discuss 12/81/97 letter. 1/26 - at EPA HQ to further discuss... ... (no substantial feedback)


Dale Rider: Spellings - 2 mechanisms not considered (gas cross, stack pipe). PA Engineer Frank Hensen rebuttal from SNC - put into perspective.


Propose call 2/18, content control 6/15 &5 for 11/15.
Also pass risk to contractor (can loser money too)
Racine - cost savings ($600,000) cut cost & use material
DOE Cruxy, local, in local, Went up & down
Corrections - responsible 1st go - fix 
strong price contract
In severe fluctuation of 01/7 transportation
Support of 2/18
The post stop a decile redress by 2/12, then DOE
A plan not a weird in 01/5-03/10, until the close
no objection - report out 2/6
is the post findings 23 post Short S.
Counter DRK Steers line complete 1/23/68
Performance by in exceed end goal 1/23/68
6/12 - long chemical, innermost processes depend 1/23/68
vs SER (Safety Evaluation Report) updated 1/23/68
Let things SAR 01 approved 1/23/68 after extensive review

2/2
Ist Quarter Action Items

Rob

1-3 Vol 1 RF DEIS - 325 fee to 2800 fee
Ask for written response (?)

EEG wants to meet on inventory variations, while DOE wonders about what is public safety issue. EEG thinks it is a public confidence issue. Meeting to discuss spell [ sic ] between EEG + SRL.

DOE comments on RFETS DEIS to EEG

EEG DAUSBFB comments wip? ERR [ sic ]
<table>
<thead>
<tr>
<th>Name</th>
<th>Org</th>
<th>Phone</th>
<th>Email</th>
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<tbody>
<tr>
<td>Steve Zappe</td>
<td>NMED/HRMB</td>
<td>(505/334-1380)</td>
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<tr>
<td>George Evans</td>
<td>CAO</td>
<td>(505) 828-1003</td>
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<tr>
<td>Jim Chennell</td>
<td>EEG</td>
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<tr>
<td>Kent Hunter</td>
<td>CAO</td>
<td>(505) 234-7456</td>
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<tr>
<td>Michael McFadden</td>
<td>NM/EEG</td>
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<td>Matthew Silva</td>
<td>EEG</td>
<td>(505) 828-1003</td>
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<td>Bill Bartlett</td>
<td>EEG</td>
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<td>Dale Rucker</td>
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<td>Chris Wente</td>
<td>State of NM</td>
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<td>Tom Tatkin</td>
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<td>Lindsey Lovejoy</td>
<td>NM/ATTY GEN OFF</td>
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<td>Robert S. (Sr.) Amiwalie</td>
<td>NMED/HRMB</td>
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<td>Jim W. Kenney</td>
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<tr>
<td>Leif Eriksson</td>
<td>CIVIA INDUSTRIES, INC</td>
<td>885-7475</td>
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<td>Jack Nugent</td>
<td>WID</td>
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<td>Catherine Jette</td>
<td>Santa Fe Citizen</td>
<td>952-3650</td>
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<tr>
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<td>606-766-8270</td>
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<td>Deborah Reade</td>
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<td>John McKay</td>
<td>NMED Gen Corp</td>
<td>824-2750</td>
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<td>Wendell Hauck</td>
<td>Sandia Natl Lab</td>
<td>505-834-7599</td>
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<tr>
<td>Charles Faulkner</td>
<td></td>
<td>612-371-4711</td>
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Waste Characterization and Certification Status

Kent Hunter
Carlsbad Area Office
January 29, 1998
Audits, Surveillance, and Evaluations

* Conducted audit of INEEL in April 1997
* Conducted audit of LANL in May 1997
* Conducted audit of RFETS in July 1997
* Conducted LANL audit in August 1997
* Los Alamos National Laboratory certified for TRU waste shipments to WIPP September 1997
Audits, Surveillance, and Evaluations

* Conducted RFETS Acceptable Knowledge Audit
  December 1997
  - 1 outstanding CAR
    » Records Storage

* Conducted INEEL Acceptable Knowledge audit in
  January 1998
  - 3 outstanding CARs
    » AK Procedural
Planned Audits, Surveillance, and Evaluations

* RFETS Final Certification Audit in February 1998
* INEEL Final Certification Audit in February 1998
* Planned certification of Idaho National Engineering and Environmental Laboratory for TRU waste shipments to WIPP in March 1998
* Planned certification of Rocky Flats Environmental Technology Site certified for TRU waste shipments to WIPP in March 1998
* LANL Recertification Audit in August 1998
Mixed/Non-Mixed Waste Determination for Debris Waste
Using Acceptable Knowledge

Does AK identify prohibited wastes?
PCBs >50 ppm Corrosives
Ignitables Reactives
Non-defense

YES
Not WIPP eligible

NO

Does AK identify listed hazardous waste constituents?

YES

Does its use require assignment as a listed waste?

YES
Mixed Waste

NO

NO

Does AK identify the presence of Toxicity Characteristic waste constituent?

YES

Does AK show the concentration is less than the RL?

YES
Mixed Waste

NO

NO

Acceptable Knowledge
Mixed/Non-Mixed Waste Determination for Debris Waste (cont.)

Headspace Gas Analysis

A

Conduct headspace gas sampling and analysis

Are headspace gas UCL₉₀ results greater than the PRQL for hazardous constituents? NO

Has AK explained the presence of the constituent? NO

Potential Mixed Waste, Reassess AK

YES

Has AK explained why the hazardous waste code is not required? NO

Potential Mixed Waste, Reassess AK

YES

Non-Mixed Waste
STATE OF NEW MEXICO'S RADIOACTIVE WASTE TASK FORCE:

UPDATE ON WIPP ACTIVITIES

Presented at

61st WIPP QUARTERLY REVIEW between
U.S. DEPARTMENT of ENERGY and the
STATE of NEW MEXICO

Santa Fe, New Mexico
January 29, 1998

By

CHRIS J. WENTZ
COORDINATOR
N.M. RADIOACTIVE WASTE TASK FORCE
TASK FORCE ACTIVITIES SINCE LAST MEETING

• CONTINUED MONTHLY MEETINGS OF THE TASK FORCE’S WIPP WORKING GROUP; TRANSPORTATION SAFETY AND EMERGENCY RESPONSE PREPAREDNESS IS THE KEY FOCUS

• SPONSORED A JOINT PUBLIC MEETING BETWEEN THE TASK FORCE AND THE INTERIM RADIOACTIVE AND HAZARDOUS MATERIALS COMMITTEE OF THE NEW MEXICO STATE LEGISLATURE IN SANTA FE (November 3, 1997)

• CONTINUED TO ENHANCE COORDINATION/COMMUNICATION WITH INDIAN TRIBES AND PUEBLOS ON WIPP PREPAREDNESS

-- PRESENTED INFORMATION ON THE WIPP TRANSPORT SAFETY PROGRAM AT THE ANNUAL MEETING OF THE NATIONAL CONGRESS ON AMERICAN INDIANS (NCAI) IN SANTA FE (November 18, 1997)

-- PARTICIPATED IN THE PUEBLO OF POJOAQUE’S WIPP EMERGENCY RESPONSE EXERCISE (December 6, 1997)

-- PROVIDED CITY OF SANTA FE OFFICIALS WITH THE NAMES OF INDIAN TRIBAL LEADERS TO INVITE TO ITS WIPP EMERGENCY RESPONSE EXERCISE (March 14, 1998)

• BRIEFED VARIOUS NEW MEXICO STATE AGENCY PUBLIC INFORMATION OFFICERS (PIOs) ON THE WIPP TRANSPORTATION SAFETY PROGRAM (January 5, 1998)
TASK FORCE ACTIVITIES SINCE LAST MEETING
(continued)

- EXECUTED AN AGREEMENT AMONG THE TASK FORCE, CITY OF SANTA FE, AND DOE-CAO PERTAINING TO WIPP TRANSPORTATION SAFETY. THE AGREEMENT:
  -- RESTRICTS WIPP SHIPMENTS THROUGH THE CITY TO MONDAY-FRIDAY, 1:00-5:00 A.M.
  -- PROVIDES FOR CITY OF SANTA FE POLICE ESCORTS
  -- PROHIBITS SHIPMENTS ON NATIONAL/LOCAL HOLIDAYS

- TASK FORCE CHAIR, JENNIFER A. SALISBURY, PRESENTED TESTIMONY AT THE EPA PUBLIC HEARING IN SANTA FE ON ITS PROPOSED WIPP CERTIFICATION DECISION (January 8, 1998); WRITTEN COMMENTS TO BE SUBMITTED.

- PARTICIPATED IN A MEETING OF DOE’S TRANSPORTATION EXTERNAL COORDINATION WORKING GROUP (TEC/WG) IN LOST WAGES, NV (January 20-22, 1998)
  -- SIGNIFICANT DOE EFFORT UNDERWAY AT COMPLEX-WIDE INTEGRATION REGARDING WASTE TREATMENT, STORAGE, TRANSPORT AND DISPOSITION
  -- NATIONAL TRANSPORTATION PROGRAM UNDER DEVELOPMENT, LED BY DOE/HQ, DOE-ALBUQUERQUE, AND DOE-IDaho
  -- ON-LINE “PROSPECTIVE SHIPMENTS MODULE” DUE OUT IN MARCH 1998
STATE OF NEW MEXICO'S
WIPP TRANSPORTATION SAFETY PROGRAM

• WIPP PUBLIC OUTREACH EFFORT: 1997

-- EFFORT FOCUSED ON SCHEDULED EVENTS AND
ACTIVITIES, AS WELL AS COMMUNITY INTEREST

January 6-10: WIPP Supplemental EIS hearings (ABQ & Santa Fe)

March 17: DeVargas Junior High--3 science classes (Santa Fe)

April 11-12: EMS Region III Conference (Ruidoso)

June 10-13: N.M. Association of Counties Annual Meeting (Raton)

July 15-17: DOE's Transportation External Coordination Working Group (ABQ)
July 17-19: N.M. Emergency Medical Services Annual Conference (ABQ)

August 4-8: Annual Fire School at N.M. Fire Academy (Socorro)
August 11-14: N.M. Emergency Managers Annual Conference (Roswell)
August 25-29: Commercial Vehicle Safety Alliance Inspection Course (ABQ)
August 27-29: N.M. Municipal League Annual Meeting (Las Cruces)

September 23: Rotary Club (Santa Fe)

October 3: Los Alamos Comm. Radiation Monitoring Group (San Juan Pueblo)
October 6: Grants City Council (Grants)
October 20-21: Environmental Health Fair (ABQ)
October 29-30: State Employees (Santa Fe)

December 3-4: Governor's Career Development Conference (ABQ)

• PARTICIPATED IN A DOE PRE-PROPOSAL CONFERENCE IN
ALBUQUERQUE ON ITS PRIVATIZATION INITIATIVE, ENTITLED
"CH-TRU WASTE TRANSPORTATION SERVICES" (Dec. 16, 1997)
STATE OF NEW MEXICO'S WIPP TRANSPORTATION SAFETY PROGRAM (continued)

- PROCEDURES/CONTACTS IN WESTERN GOVERNORS' ASSOCIATION WIPP TRANSPORTATION SAFETY PROGRAM IMPLEMENTATION GUIDE BEING UPDATED AND FINALIZED

- NEW MEXICO WIPP EMERGENCY RESPONSE TRAINING
  -- ALL LEVELS OF TRAINING ARE CONTINUING
    ▶ INTEGRAL COMPONENT OF EXERCISE PROGRAM
    ▶ SITES: TRAINING ACADEMIES & COMMUNITY-BASED
  -- 1997 EMERGENCY MEDICAL TRAINING AT 12 NEW MEXICO HOSPITALS CONCLUDED
    ▶ REAC/Ts AND N.M. DEPARTMENT OF HEALTH
    ▶ ONE-DAY COURSE, WITH ON-SITE DRILL
  -- NEW EMERGENCY MEDICAL COURSE, ENTITLED “EMS OPERATIONS FOR HAZARDOUS MATERIALS,” PILOT TESTED AND READY FOR PRESENTATION

- WIPP EMERGENCY RESPONSE EXERCISES
  -- CITY/COUNTY OF SANTA FE WIPP EXERCISE PLANNED FOR MARCH 14, 1998 (near junction of N.M. 599 and Airport Rd.)
    ▶ TABLE-TOP DRILL ALREADY HELD (January 16)
    ▶ FUNCTIONAL DRILL SCHEDULED (February 19)
WIPP TRANSPORTATION ISSUES

• PERFORMANCE DRY RUN: IN PROGRESS

  -- TRANSCOM TEST CONDUCTED (January 13, 1998)

    ▶ PRELIMINARY RESULTS FAVORABLE
    ▶ FURTHER TESTING SCHEDULED
    ▶ "WINDOWS" VERSION DUE OUT IN APRIL 1998

  -- REAL-TIME TESTING OF TRANSPORT SAFETY
     PROCEDURES AND PROTOCOLS PLANNED

• DOE-STATE COORDINATION ON PUBLIC OUTREACH:
  IMPROVEMENTS NOTED

• PRIVATIZATION OF WIPP TRANSPORTATION SERVICES: MAJOR
  CONCERNS (TIMING AND QUALITY OF SERVICE) ADDRESSED

• COMPLETION OF DOE’s WIPP TRANSPORTATION PLAN: IN
  PROGRESS

• PREPAREDNESS FOR CIVIL DISOBEDIENCE: IN PROGRESS
Introduction

Throughout this decade, we at the Department of Energy have been changing the way we do business. The emphasis in our mission has shifted from nuclear weapons production toward safely managing wastes that have accumulated at our sites over a large portion of this century; toward cleaning up contaminated water, soil, and buildings at our sites; and toward establishing a strong program to protect public health and the environment as we enter the next century.

Although each of our sites and laboratories are unique in their capabilities, their problems are shared throughout the DOE complex — how best to treat, store and dispose of various types of radioactive and hazardous waste and bring contaminated sites to acceptable cleanup levels. Accordingly, we are proceeding to integrate existing unique capabilities and develop new technology at our sites in order to do business efficiently and to apply the best available technologies and resources to achieve common objectives.

This means sharing across sites — consolidating treatment, storage, and disposal of wastes where it makes good sense; applying innovative technologies among sites; and working to assure consistency in reporting data such as waste inventory and generation, as well as available packaging and transportation for shipments of waste and nuclear materials — i.e., integration.

Relationship of Integration to Key Decisions

DOE's established decision-making processes include the following important elements.

Established Decision Process
- NEPA
- Compliance Agreements
- Budget

DOE Evaluation of Integration Opportunities

Integration Recommendations

Relationship of Integration to DOE's Decision and Planning Process

The National Environmental Policy Act (NEPA) Process

The NEPA process ensures that potential health and environmental impacts of alternative approaches are thoroughly analyzed, that public input is considered, and that Records of Decision are issued. For example, the Waste Management Programmatic Environmental Impact Statement (WMPEIS) and its upcoming Records of Decision for transuranic, mixed low-level, low-level, high-level, and hazardous wastes represented the first nationwide programmatic evaluation and integration of treatment, storage and disposal activities throughout the DOE complex. Other NEPA activities are underway for disposition of plutonium and highly-enriched uranium and for site-specific activities.

Compliance Agreements and Consent Orders

These legally binding agreements are key bases for the decisions that DOE needs to make and how those decisions will be implemented.

Congressional Authorizations and Appropriations

Congressional authorizations and appropriations provide specific direction and allocate funds for carrying out programs within DOE. DOE's budget levels necessitate that the programs continue to seek efficient ways of carrying out its decisions and activities.

Consideration of Public Feedback

During the NEPA process, the public has multiple opportunities to provide formal feedback to DOE on proposed decisions.

Additional opportunities exist to provide feedback to DOE for ongoing consideration in making decisions. These include Site-Specific Advisory Board meetings; educational workshops; transportation planning meetings; and meetings with Tribal Nations, State and local governments, and regional coordinating bodies.

(continued on page 2)
Opportunities for Complex-Wide Integration

DOE will use its established decision process to identify, evaluate and select opportunities for program integration across DOE’s environmental management program. To implement its decisions effectively, the following efforts are underway:

Accelerating Cleanup: Focus on 2006

Last year, DOE’s Assistant Secretary for Environmental Management challenged the program to develop plans for cleaning up as much of the weapons complex as possible within ten years.

To attain this ten-year vision, DOE developed a Discussion Draft Accelerating Cleanup: Focus on 2006 (the 2006 Plan). The 2006 Plan is not a decision-making document. But, as Records of Decision are issued, decisions will be reflected in the sites’ 2006 plans and baselines. To involve stakeholders prior to issuing these decisions, DOE is continuing its discussions with national, regional, and local groups on cross-site issues. These stakeholder groups include the National Governors’ Association, Site-Specific Advisory Boards, the State and Tribal Government Working Group, the Energy Communities Alliance, the Transportation External Coordination Working Group, the National Association of Attorneys General, and local citizens in the National Dialogue Pilot Workshops. A Draft 2006 Plan will be issued for additional public comment in early 1998, and an initial Plan will be issued in mid-1998.

Independent, Contractor-Led EM Integration Team’s Recommendations

During preparation of the Discussion Draft 2006 Plan, DOE’s Assistant Secretary for Environmental Management challenged senior executives of DOE’s contractor organizations to independently identify, analyze, and recommend technical opportunities which reduce costs, significantly accelerate cleanup schedules, and further the goals of the 2006 Plan.

The team’s recommendations were summarized in the June 1997 Discussion Draft 2006 Plan. Some recommendations pertain to multiple sites, while other recommendations address opportunities for cost savings and cleanup at specific DOE sites.

DOE Evaluation of Contractor EM Integration Recommendations

DOE will implement the recommendations only after an intensive review of their underlying assumptions and rationale, and a detailed evaluation of such factors as: cost and schedule savings; initial investment; risk to workers, the public, and the environment; and perceptions of equity on the part of stakeholders. An internal DOE EM Integration Team is coordinating this evaluation with Headquarters and sites. The evaluation must ensure that all necessary reviews have been completed under NEPA (e.g., programmatic, site-specific, or project-specific environmental reviews) and/or within other applicable regulatory requirements.

Some of the recommendations fall within existing legal and regulatory requirements, while others are based on changes to such requirements. DOE’s evaluation will include a review of the potential cost and timing factors that could be associated with such constraints prior to acceptance for future implementation.

Stakeholder Feedback on the Integration Recommendations

During DOE’s evaluation, DOE will consider feedback from stakeholders on any or all of the recommendations. To date, only three of the recommendations (which had previously been accepted for implementation and had met legal requirements) have been accepted for planning, as stated in the Discussion Draft. These include the following: (1) use mobile systems for transuranic waste, (2) accelerate transuranic waste shipments and closure of WIPP, and (3) minimize storage and treatment of low-level waste. Evaluations have not been completed for implementation of the other recommendations, and, as such, they are not included in sites’ baselines and draft plans.

Opportunities for providing input on the recommendations will be available at site advisory board meetings, during DOE’s ongoing discussions with state regulators and national/regional groups (e.g., National Governors’ Association), and during review of the Discussion Draft 2006 Plan.

As needs for conducting additional reviews of the recommendations under existing environmental regulations may be identified, the recommendations would again be presented to the public as part of established decision processes, such as those under NEPA for ensuring environmental compliance.
What is the National Transportation Program (NTP)?

- The NTP, the corporate center of packaging and transportation expertise, located and managed within EM, supports infrastructure and coordinates transportation activities for all non-classified shipments of hazardous materials, including radioactive, mixed wastes, and other commodities such as coal, other fuels, maintenance materials, supplies, etc.

- The NTP is responsible for ensuring the availability of safe, secure, and economical transport services, consistency in regulatory implementation, coordinated outreach and emergency preparedness. The NTP is managed by a joint Headquarters, Albuquerque, Idaho Operations Offices Team through the establishment of Transportation Center of Excellence at Albuquerque, New Mexico and Transportation System Engineering Center of Excellence at Idaho Falls, Idaho.

- The NTP manages the science-based transportation technology program to resolve complex transportation system (including packaging), confront regulatory excesses, and present the DOE technical position before regulators and consensus standards bodies.

- The NTP develops and maintains integrated transportation and packaging tools for Headquarters and field applications. This includes the application of systems and automation technology to DOE’s transportation and packaging activities.

- The NTP develops and provides transportation and packaging management and safety training including domestic and international regulations, SARP preparation and implementing DOE Orders, guidance and standards.

- The transportation infrastructure and base technology which NTP develops and maintains for the Department supports the packaging and transportation needs of the EM Ten-Year Plan and other DOE program offices/field offices.

How is transportation managed in the Department?

- The Department's packaging and transportation program is managed through Program Offices for policy direction and oversight; and Field Offices implement day-to-day transportation operations. RW manages commercial spent fuel transportation programs, DP manages weapons components and subassemblies transportation, NE/NR manages transportation of naval spent fuel and isotopes, EM manages transportation of spent fuel, special nuclear materials and radioactive and hazardous waste materials, and NN manages transportation of special classified shipments.

- Field Offices are responsible for shipments and full regulatory compliance, and provide the focal point for local public and stakeholder interactions.
How does DOE ship its material?

- DOE transports its materials by all modes of transportation through commercial and private carriers. In FY 1996 the distribution of shipments was: Air 77%, Motor 22%, and Rail <1%.

- The Department uses DOT-authorized packagings for its non-defense transportation activities. These packagings are designed to minimize the risk of materials release during transportation. The Nuclear Regulatory Certified packagings are used for spent fuel shipments. Departmental quality assurance program determine the appropriateness of the packagings for transportation.

- The Department follows DOT routing regulations and coordinates with States and Tribes for identification of alternative routes. In addition, rail route selection is based upon best track, fewest rail interchanges, and programmatic requirements.

How much does DOE ship annually?

- In FY 1996, DOE transported 430,000 shipments of non-defense related materials, which consisted of 412,000 (96%) non-hazardous shipments, 18,000 (4%) hazardous materials, of which 5,200 (<1%) was radioactive. These radioactive materials shipments are less than 1% of total shipments. However, DOE ships 75% of all curies shipped in the United States.

- Forecasted shipments, over the next 12 months, are: 700 shipments of low-level waste, 16 shipments of mixed waste, and 39 shipments of spent fuel (included foreign research reactor spent fuel).

What are the external regulations the Department follows for transportation activities?

- DOE is subject to DOT transportation regulations for non-defense shipments. These regulations cover packaging and transportation of hazardous materials on public highways, airways, and waterways. These non-defense shipments are also subject to applicable State, Tribal, and local government requirements.

How does DOE involve stakeholders and the public in transportation?

- The NTP has established several forums to involve key stakeholders in transportation activities. Stakeholders include internal and external parties. Internal coordination is accomplished through the Senior Executive Transportation Forum which is composed of senior managers from all programs with transportation activities and the Office of Congressional and Public Affairs. The Transportation Internal Coordination Working Group brings program and field staff together to discuss transportation policy and program issues impacting all programs and recommends actions to resolve issues.

- External Coordination is achieved through several forums including the Transportation External Coordination Working Group(TEC), which is composed of State, Tribal and local
organizations, industry, and professional and technical associations. The TEC meets twice a year in January and July to identify and discuss issues of concern regarding DOE transportation activities. Issues include planning for transportation, routing, emergency preparedness and training, and technical assistance. TEC is co-chaired by EM and RW.

- Regional Associations of States, such as the Western Governors' Association work with programs, sites and the NTP on detailed planning for high visibility shipments. A working group is formed with DOE to develop a transportation plan for specific shipments. The Transportation Plan details roles and responsibilities of all parties, including the state, tribal or local government, the Department and the carrier, and other Federal agencies. Information plans are developed as part of the Transportation Plan and details how the general public will be informed.

- The Local Government Network (LGN) enables local officials to meet with DOE program and field offices to discuss how DOE ships its materials and inform them of information and technical assistance, including training, that is available to them to support local needs. The LGN also issues a quarterly newsletter to about 5,000 local officials nationally. This and other information products are also available and distributed through the world wide web as a homepage on the Internet.

What kinds of technical or financial support is provided to external stakeholders for transportation related activities?

- Approximately $750,000 is provided annually to manage and provide attendee travel assistance (approximately 60 people per meeting) to two TEC meetings, support three local government workshops, and the other program activities of the LGN. Regional state associations (four) are funded by NTP at $50,000 each for meetings with DOE. Joint funding (approximately $50,000-$300,000) is also received by the regional groups from RW, WIPP and programs such as the Spent Fuel program.

What notification does DOE provide for shipments of hazardous materials?

- Generally, formal notifications for highway route controlled quantity of radioactive materials, are performed through the Field Offices to the NRC, DOT, States and Tribes. This notification is equivalent to that which is required by the NRC. Local governments are not formally notified by DOE of these shipments, however, States may notify local officials on a need-to-know basis.

- No notifications are made formally to State, Tribal, and local governments for routine low-level hazardous materials shipments. Field Offices may have informal agreements to inform officials of these shipments.

- DOE performs real-time shipment tracking of high visibility materials through the satellite-based automated system called TRANSCOM. The NRC, DOT, States, and Tribes have access to this system to track shipments within their respective jurisdictions.

- Generally, DOE does not notify about shipments of classified materials.

http://www.ntp.doe.gov/q&a.html
What happens in the event of an accident involving a DOE radioactive shipment?

- State, Tribal, and local governments respond to any accident involving DOE shipments. The local responders are responsible for safety and enforcement within their jurisdictions. The local responder contacts National Response Center, Chemical Transportation Emergency Center (CHEMTREC), or any DOE Office for assistance.

- DOE maintains a 24-hour emergency point-of-contact at each Field Office. The appropriate point-of-contact for the shipment is listed on the shipping papers as required by DOT regulation.

- During and after an accident DOE provides response advice, radiation monitoring, and other support as requested by State or Tribal governments.

- DOE transportation emergency preparedness program provides the guidance and training that emergency responders need to safely, efficiently, and effectively respond to radioactive material shipment accidents.

What resources does DOE have available for the NTP?

- The NTP for non-defense activities consists of 11 specialists at HQ, and 11 traffic managers at the Field Offices.

- A contract outlay program of about $19,800,000 is used to support transportation management, emergency management, and packaging certification.

- The redeployment of the NTP staff by FY 1998 will result in: 3 specialists at HQ, 7 at Albuquerque Field Office, 3 at Idaho Field Office, and maintaining the current 11 traffic managers at their respective Field Offices.
Solubility-Overview

- EPA Review of the FMT Code
- Oxidation State Analogy
- Actnide Solubility Uncertainty Range
- Nesquehonite vs. Hydromagnesite
Solubility-The FMT Code

- EPA’s review used SNL computers, codes and databases, and obtained same numerical values.
- Was the FMT tested on benchmark problems?
- Was the thermodynamic database verified? For example, FMT predicts more $\text{Th(CO}_3\text{)}_5^{6-}$ for the Castile brine, than expected.
• deviations from the oxidation state analogy are well known in natural and experimental systems. Substantial experimental verification will be needed to establish the limits of this analogy (NAS WIPP Committee Report, Dec. 1996, p.129)
• Use of Th(IV) values for all actinide (IV) species is questionable
Solubility-Uncertainty Range

- No calculations for An(VI)
- EPA cited problems with An(IV) data
- III and V uncertainty distributions based on Nd (III), Am (III), and Np (V). Pu (III) not included, although used for Pitzer coefficients.
- Inconsistencies in speciation for Th in FMT suggests that -2 to +1.4 log units may not be broad enough.
<table>
<thead>
<tr>
<th></th>
<th>Salado (Molar)</th>
<th>Castile (Molar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCA</td>
<td>4 E-6</td>
<td>6 E-9</td>
</tr>
<tr>
<td>No Backfill</td>
<td>5 E-4</td>
<td>7 E-5</td>
</tr>
<tr>
<td>Hydromagnesite</td>
<td>1 E-8</td>
<td>4 E-8</td>
</tr>
<tr>
<td>Nesquehonite</td>
<td>6 E-4</td>
<td>1 E-3</td>
</tr>
</tbody>
</table>
Solubility-Nesquehonite or Hydromagnesite?

- DOE’s experiments never identified Hydromagnesite as a reaction product.
- SNL’s 4/23/97 report identifies a poorly characterized MgCo₃.3H₂O·MgCl(OH) phase as hydromagnesite-like. It is actually more like Nesquehonite (MgCo₃·3H₂O) than Hydromagnesite [(MgCo₃)_4·Mg(OH)₂·4H₂O].
- Solubility of IV actinides is higher with Nesquehonite present than with no backfill.
Fluid Injection Scenario-Overview

- Screened out by DOE on the basis of low consequence.
- EPA has argued in favor of low probability.
- EEG is not convinced that the issue has been sufficiently explored and analyzed.
Stoelzel and Swift (1997) conceptual models for leaky well scenario does not represent the Hartman scenario.

The outflow is divided into a number of layers, when in the Hartman case, the flow occurred through a single layer.

Assumption of radial flow does not represent the incident at the Hartman Bates lease.

The high well-bore permeability assumption does not compensate for these non-conservative conceptualizations.
Fluid Injection-Low Probability

- EPA calculates a probability of 1 in 667 million that an injection well will leak and impact the repository (III-B-22, Table Q).
- This value is based on optimistic anticipated performance rather than actual experience.
- Obtained by multiplying several very low probability assignments for assumed independent events, to get $1.5 \times 10^{-9}$ number.
- How does one explain hundreds of documented water flows in the New Mexico oil fields?
Fluid Injection-Related Issues

- Flow Paths in the Hartman Scenario
- Unexplained Culebra Water Level Rises
- CO₂ Fluid Injection
- Natural Gas Storage
- Solution Mining
Rhodes-Yates (Hartman vs. Texaco)

Evidence related to the case was not reviewed. A case summary was reviewed by EPA.

EPA (p. 31) maintains:
"Though a jury found the waterflood operator guilty of common law and statutory trespass in the Rhodes-Yates Field, flow paths were not identified with certainty."

But plaintiff's Exhibit 211 and expert testimony of Van Kirk (pages 640 to 706), based on drilling records, well logs, and injection records, clearly identify a 36 foot wide zone just above the Cowden Anhydrite Marker as the flow path.

Bottom line - The relevance of the case was identified to EPA, but neither DOE nor EPA studied the technical evidence in Hartman's case.
Structure: EPA Dip Theory

<table>
<thead>
<tr>
<th>WIPP</th>
<th>Rhodes-Yates</th>
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<tbody>
<tr>
<td>100 ft/mile</td>
<td>(EPA cites localized trends)</td>
</tr>
<tr>
<td></td>
<td>250 ft/mi. at Rhode Yates</td>
</tr>
<tr>
<td></td>
<td>150 to 200 ft/mi. at Bates</td>
</tr>
<tr>
<td></td>
<td>100 ft/mile between</td>
</tr>
<tr>
<td></td>
<td>Rhodes Yates and Bates</td>
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</tbody>
</table>

If EPA intended to advance this argument, then EPA should have also identified the dip for the hundreds of waterflows of record in waterflood areas for southeast New Mexico.
CULEBRA WATER LEVEL RISES

"The statement "they remain unexplained" is insufficient, particularly if the reason for the rise could be interpreted to affect long-term hydrologic conditions within the Culebra or be caused by ongoing oil and gas exploration and development activities, such as brine disposal into underlying units."

EPA to DOE, August 14, 1996.

Presented by Matthew Silva at the EPA-DOE technical exchange on October 10, 1996 (also EEG-62).
CO₂ Fluid Injection

"DOE has discussed the limited [emphasis added] potential for CO₂ enhanced oil recovery operation in the vicinity of WIPP..."

EPA Card 23, p. 132

"....[EPA] does not anticipate that CO₂ injection for oil recovery will be widespread practice in the future near WIPP for the following reasons...."

EPA Card 23, p. 131
Note: No references given to support EPA position.

• Success of Delaware Basin CO₂ floods discussed in EEG-62.
• DOE sponsored research at the University of Texas at Austin.

"....This project will conduct a study to demonstrate that determining the characteristics of a reservoir using 3-dimension seismic data and reservoir simulation can optimize infill drilling and CO₂ flooding in Class 3 reservoirs. The study will be in the Geraldine Ford Field that produces from the Upper Permian Bell Canyon Formation and West Ford field that produces from the Upper Permian Cherry Canyon. Both fields are located in the Delaware Basin..... The volume in oil to which these techniques can be extended exceeds 10 billion stock tank barrels of mobile and residual oil."

http://oil.bpo.gov/10172.html
'At this time, the only examples of CO2 injection enhanced recovery techniques are some distance from the WIPP site and under much different geologic conditions (Magruder, 1990; Thrash, 1979).'

EPA Technical support Document
TSD III-B-22, vol. 1

Example of successful carbon dioxide flood in Twofreds field in the Delaware Basin producing from the Delaware Mountain Group (as described in detail in EEG-62).
‘There are no natural gas storage horizons in the Salado Formation’ EPA Card 32-71

From map presented at EPA Technical Exchange October 10, 1996
Solution Mining

<table>
<thead>
<tr>
<th>Brine</th>
<th>Bounded by low consequence?</th>
</tr>
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<tbody>
<tr>
<td>Potash</td>
<td>Lack of fresh water?</td>
</tr>
<tr>
<td></td>
<td>No solution mining for langbenite?</td>
</tr>
<tr>
<td></td>
<td>Bounded by subsidence?</td>
</tr>
</tbody>
</table>
SPALLINGS SCENARIO

by Dale Rucker
EEG
January 29, 1998
OVERVIEW

- Definition of Spallings
- Prediction of Spallings in CCA
- Verification of Spallings
- EEGs’ Remarks on Spallings
- Effects of Spallings On CCDFs
- Conclusions
Spallings Definitions

• Spallings
  - waste into the drilling fluid caused by the release of waste-generated gas escaping to the lower pressure borehole
  - 3 Mechanisms of Spallings
    • Blowout - Considered in CCA
    • Gas Erosion - Not Considered in the CCA
    • Stuck Pipe - Not Considered in the CCA
Spallings Definitions

- **Blowout**
  - high rate of gas removal from the repository through an intruding borehole.
  - will cause the drilling fluid (mud column) to be expelled from the borehole
  - will entrain failed waste from borehole cavity
  - Main cause - high waste permeability, high repository pressures
Spallings Definitions

- **Gas Erosion**
  - spalled (failed) material in the repository that is eroded by the drilling mud due to repository pressures slightly higher than pressures exerted by the drilling mud
  - may release waste into the drilling mud at a rate that may be undetectable by the driller
  - main cause - low waste permeability, high repository pressures
Spallings Definitions

• Stuck Pipe
  - spalled material that presses against the drill string sufficiently hard to prevent normal drilling.
  - a jammed bit will be pulled up to start drilling again, and may happen several times
  - may introduce high amounts of waste into the drilling mud
  - cause - low waste permeability, high pressures
Spallings as defined in the CCA (from Berglund (1994))
Prediction of Spallings in CCA

• Blowout was Invoked in CUTTINGS_S Model
  – Calculated Spalled Volumes Ranged from 0.5 m$^3$ to 4.0 m$^3$
  – The model was found by the DOE’s Conceptual Models Peer Review to be inadequate, but results from the code were accepted as reasonable
  – Spallings releases had the highest releases in the CCA’s CCDF
Prediction of Spallings in CCA

![Graph showing probability of release greater than R vs. summed normalized release, R. The graph includes curves for total, spallings, cuttings and cavings, and direct brine release.](image-url)
Verification of Spallings

• Semi-analytic Approach
  – Numerical 1-D gas flow from repository to borehole annulus
  – Analytic solution for stress/strain field near borehole
  – Implemented in the code: GASOUT
Verification of Spallings

- **GASOUT**
  - Calculated a maximum 0.27 m$^3$ of spalled material - assumed blowout of all material
  - Used "typical" repository parameters
    - permeability
    - repository pressure
    - viscosity
    - mud density
    - waste strength
Verification of Spallings

- Quasi-Static Approach
  - Based on Spreadsheet Analysis
  - Calculated a spalled volume of 1.17 m$^3$ for GASOUT's 0.07 m$^3$ under same conditions
  - Based on sensitivity analysis of the Quasi-Static Approach, blowout stopped at waste permeabilities less than 1x10^{-14} m$^2$
Verification of Spallings

Spallings as defined by the Quasi-Static Mode
(Adapted from Hansen et al. (1997))
Verification of Spallings

• Pure Numerical Approach
  – Spalled volume was not calculated
  – Verified pressure profile within waste
    • Calculated homogeneous and heterogeneous waste
    • Heterogeneous waste had higher pressure gradient
    • Lower permeability had higher pressure gradient
    • Mean Effective Stress used for tensile failure calculations (spalled volumes) in GASOUT, which depend on the pressure gradient
EEGs’ Remarks on Spallings

- Calculated spalled volumes based only on GASOUT
  - GASOUT is very limited in its use
    - Narrow range of permeability
    - Narrow range of gas viscosity
    - Narrow range of mud density
  - Calculated volumes much lower than quasi-static model
EEGs’ Remarks on Spallings

Range of Meaningful Results

Waste Strength
- 10 psi
- 15 psi
- 20 psi

Tensile Failed Volume (m³)

Waste Permeability (x10⁻¹³ m²)
EEGs’ Remarks on Spallings

![Graph showing the relationship between mud column density and tensile failed volume for different waste strength levels (10 psi, 15 psi, 20 psi). The y-axis represents tensile failed volume in m³, and the x-axis represents mud column density in kg/m³. The graph indicates a trend where higher waste strength levels lead to increased tensile failed volume at higher mud column densities.]
EEGs’ Remarks on Spallings

- Is it possible for parameter values to fall outside range of applicability for GASOUT?
  - CCA value of $1.7 \times 10^{-13} \text{ m}^2$ was based on calculated waste types: 40% metals, 40% combustibles, 20% sludges
  - Conceptual Models Peer Review Group found an error in calculating permeability, and the actual value should be $2.4 \times 10^{-13} \text{ m}^2$
EEGs’ Remarks on Spallings

- The effects of MgO was never considered.
  - 25.5\% by volume in repository
  - Sorel Cement permeability equivalent to Portland Cement ($\sim 1 \times 10^{-16} \text{ m}^2$)
  - With MgO and parallel flow calculation: permeability $= 1.8 \times 10^{-13} \text{ m}^2$
  - With MgO and perpendicular flow calculation: permeability $= 2.5 \times 10^{-16} \text{ m}^2$

- New measured permeability by Hansen et al. (1997) show “typical” $= 4 \times 10^{-15} \text{ m}^2$
EEGs’ Remarks on Spallings
Spallings as defined by the Quasi-Static Mode
(Adapted for Hansen et al. (1997))

![Diagram showing hydrostatic pressure and repository pressure with different permeability regions: CCA Permeability, Measured Permeability, GAS EROSION, STUCK PIPE, No Spall, BLOWOUT.]

- Repository Pressure (MPa)
  - 6 to 7
  - 8
  - 9 to 10
  - 11 to 12
  - 13 to 15

- Waste Permeability ($m^2$)
  - $10^{-17}$ to $10^{-18}$
  - $10^{-15}$
  - $10^{-13}$ to $10^{-14}$
  - $10^{-12}$

- Hydrostatic Pressure
  - $10^{16}$
  - $10^{15}$
  - $10^{14}$
  - $10^{13}$
  - $10^{12}$
EEGs’ Remarks on Spallings

- Calculated release of spalled material due to gas erosion or stuck pipe
  - EEG has not calculated releases
  - DOE has estimated releases (Berglund, 1994)
    - Stuck pipe ranges from 43 to 238 m$^3$
    - Gas erosion ranges from 44 to 356 m$^3$

- Potential Effects on CCDF
  - Spallings will add to the total, moving it closer to the EPA limit
Effects of Spallings on CCDFs

![Graph showing CCDFs with different spallings and normalized releases](chart.png)
Effects of Spallings on CCDFs

- Modeling shows that a uniform distribution of spalled volume reaching the surface ranging from 8 to 64 m$^3$ will violate EPA standards.
Conclusions

• GASOUT cannot model expected repository conditions
  – Permeability is expected to be lower than $1.7 \times 10^{-13}$ m$^2$
  – Viscosity can vary from pure Hydrogen values
  – Mud density can vary, depending on what brine and additives used
Conclusions

• Numerical analysis (Hansen et al., 1997) shows that heterogeneity of waste using lower permeabilities will create higher pressure gradients

• Lower permeabilities may prevent blowout, but if waste fails then it will be introduced into the return drilling fluid giving rise to the Stuck Pipe or Gas Erosion Scenario
Recommendation

- Modify the GASOUT code to be applicable to the whole range of expected parameter variations
- Calculate releases through Stuck Pipe and Gas Erosion Scenarios in a new PAVT
January 9, 1998

To: U.S. Environmental Protection Agency
Office of Radiation and Indoor Air
401 M Street SW
Washington, D.C. 20460

From: David T. Snow, Ph.D., P.E.
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144 Harvard SE
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Re: Reply to DoE Comment Responses dated July 3, 1997 on the DoE CCA

On July 3, 1997, DoE submitted to EPA a set of responses to CARD's March, 1997 Comments on the Compliance Certification Application. If DoE had applied normal consideration, copying its submission to CARD at that time, the following reply to those responses could have been prepared in more timely fashion for your consideration. DoE has labeled Card's comments Nos. 1 to 24, and the below replies follow that organization and pagination.

Comment 1, p. 1

There is no contention with CARD's item 1, that is, DoE admits to the development of aqueous solutions and suspensions of actinides in the repository. Contention remains over items 2 and 3, and these are still unrefuted by DoE in their responses of July 3, 1997. They have asserted that the salt seals will have consolidated and DRZ fractures will have rehealed before repository fluid pressures act across them. Apparently DoE, its consultants, advisors and reviewers are content to conceptualize the seal system sustaining pressures that are below lithostatic for all levels in shafts and boreholes. At such pressures, CARD agrees that it is possible to defend the discharges (e.g., 1 m/10,000 years) through intact seals with small, continuous hydraulic conductivities attained in plugs of crushed salt and clay after decades of consolidation by salt creep. But that model is unrealistic of seals that have been subjected to pressures that will hydrofracture the materials, part them at their contacts and erode channels as fluids bypass them.

To ignore the eventuality of failure by hydrofracture is to ignore geological analogues as well as theory. Hydrothermal alteration and epigenetic mineralization occurs when an aqueous solution separates from a magmatic silicate melt undergoing crystallization and differentiation. The volatile solutions rise from the melt where their pressures are equal and lithostatic, hydrofracturing the solid containment because lithostatic pressure decreases with altitude more rapidly than does the hydrostatic pressure. Likewise, in absence of an aqueous phase, magma that is hotter thus lighter than its containing rock fracs its way to the surface of a volcano. Just so will gasses or brine in the upper parts of the repository surpass lithostatic when salt closure ceases at the downdip extremity of the facility. Communicating via anhydrite beds over pillars and panel seals, the gas pressures
will be first to exceed lithostatic. The concrete plug at the shaft bottom is permeable, so its fluids attain pressures at even greater exceedance over lithostatic the higher they penetrate above the repository. Contact hydrofracture and salt hydrofracture past salt and asphalt seals will propagate unstably upwards. Since disposal in salt was first conceptualized, the fundamental mechanics of displacement of a low-density fluid inclusion in a plastic, high-density medium has remained intact.

From the moment it became evident that the repository would collect appreciable brine during closure, the concept of nuclear waste disposal in plastic salt has remained indefensible. The NSF did not envision liquids when it recommended salt as a geologic medium for permanent containment of dry waste. Gaseous hydrofracture and discharge is not a fatal flaw, but escape of brine solutions in excess of what can be sequestered by engineered barriers in the repository cannot be prevented.

Comment 2, DoE response, 1st line, p. 5

If the proposed seals represent an established design, then DoE should present precedents for them, with details of emplacement and performance, preferably during centuries of closure of salt, documenting containment of fluids under high pressures. More accurately, it should be said that the proposed seals have been established only in the minds of the designers, neither fixed in concept nor detailed in design. An engineer should affix his seal to DoE's shaft sealing plans only if he believes that structural failure after his life-span is not his responsibility.

Comment 2, p. 6

There is no certainty that the tentative seal design will be successful in preventing entry of water from the Rustler to the repository. Since the shafts are eccentric to the paneled repository area, subsidence during the decades after sealing will exert shears along any rigid shaft contacts, such as concrete linings. Mine flooding has occurred by reason of dissolution along such contacts. But as the closure rate diminishes when repository pressures approach lithostatic at those depths, neither the salt seals nor the natural ground can be certified to prevent escape of fluids upwards along hydrofractures. In short, the containment of fluids in a large salt cavern is impossible, and has always been so. The concept of nuclear waste disposal in salt was compromised fatally upon discovery of brine seeps into the trial repository rooms at WIPP. DoE has persistently ignored the inevitable need to abandon the project because such containment is required. Succeeding research expenditures have made it no more acceptable because the liquids that can convey radionuclides have not been wholly eliminated.

Comment 3, 3rd para., p. 11

DoE has attempted to use PA as a crutch for ignorance, and few realize the lies engendered: Monte Carlo sampling is a powerful, accurate means of combining terms of a function, each of which is uncertain in magnitude because it ranges over a definable PDF. However, DoE has employed Monte Carlo sampling to also include uncertain alternative magnitudes and competing concepts, both illegitimate applications.
For example, matrix diffusion, as opposed to other mechanisms of species retardation, has been deduced from tracer testing in fractured Culebra dolomite. The range of retardation factors from such local tests cannot be uniformly applicable to other areas, particularly where dissolution channeling minimizes diffusive interchange with wallrock pore spaces. Likewise, sorption derived from tests on crushed rock samples of dolomite cannot be uniformly applied (in absence of field tests) to transport paths of far smaller specific surface area, such as dissolution-enhanced fractured media, or karst channels in salt, anhydrite or siltstone.

Suppose one concept never leads to failure (i.e., to an unacceptable CCDF), while another concept or process, deemed less likely, would, if true, so greatly influence flow that it would inevitably lead to failure. By allowing, say, 10% of the PA runs to follow the adverse concept, averaging its influence with other distributions, the CCDF remains favorable. By sampling distributions independently, the correlations between functions such as diffusive and sorptive retardation with conduit size distribution have been neglected by PA. The process hides the fact that there would be a 10% chance of failure. There is no substitute for the correct concept; each must be judged correctly to be right and admitted, or wrong and rejected. Correct assumptions and concepts are required if PA is to be valid. It cannot ameliorate an unlikely but fatal process or concept by biasing results towards favorable concepts through an averaging process like Monte Carlo sampling.

Comment 3, 1st subpara., p. 12

Insignificant Salado interbed flows have been computed on the basis of flow-tests conducted at low pressures in the anhydrite marker beds adjacent to the test rooms. The equivalent porous-media conductivities are low because they were conducted in an environment already depressurized by drainage to the rooms. BRAGFLO has incorporated fracture conductivity as a function of effective stress, but far greater fluxes would occur as hydraulic fracture exceeds elastic limits and opens clay partings at salt/anhydrite contacts and within the salt beds, or as existing anhydrite fractures open upon reaching fluid pressures at or above lithostatic. Furthermore, creep closure will stretch the anhydrite beds above and below the rooms, panels and the repository, opening steep fractures appreciably, and enhancing continuity.

Comment 3, 2nd subpara., p. 12

The DoE response suggests that the waste will have the strength to support the weight of the overburden rock. It can be argued that it will first compact (expel air), then saturate and consolidate (expel brine and dissolved waste). Because salt is plastic, when forces transmitted through waste drums attain local loads in excess of lithostatic when calculated over the contact areas, there will be continuing creep of salt towards the spaces where only fluid pressure opposes the motion. Only when the fluids attain lithostatic does creep cease. As stated by DoE in the next subparagraph, closure ceases when the voids are completely saturated with brine. To this must be added, "at lithostatic pressure".

In that sense, not all rooms will act alike. Abrupt roof falls and floor heaves will connect all spaces
to the marker beds above and below the repository rooms, which will provide continuity to panel and repository scale subsidence fractures and thus throughout the repository plan. Brine accumulating on the floor of all rooms may largely drain to the downdip rooms, which will saturate soonest, while updip rooms may attain lithostatic gas pressures in absence of collected brine, venting first by fracturing the highest, weakest parting, propagating the fracture updip and ups section.

Comment 3, last full para., p. 12

It is understood that BRAGFLO computes two-phase displacement along marker beds, incorporating smoothly increasing conductivity as effective stress across fractures decreases. But it does not anticipate a sudden opening and a dramatic increase of flow as a parting opens. The model idealization is believed adequate until lithostatic pressure is approached, whereupon experience such as the Hartman case suggests an abrupt escape of fluids via a single fracture that will curve upwards or jump step-wise upwards to the Rustler. Containment of fluids within anhydrite beds is not to be expected, nor can “isolation” be relied upon.

Comment 3, last subpara., p. 13

It is stated that for error (in BRAGFLO discharges) to be significant, brine inflow (during closure) would have to be large in comparison with the mild seepage data. In the undisturbed repository, gravity drainage of brine to the lowest rooms should influence modeling, progressive but incomplete saturation from down-dip to up-dip rooms occurring, coupled with gas generation until brine discharge along upper level hydrofractures permits further closure.

Comment 4, last para., p. 14, 1st para., p. 15

DoE claims that shaft performance calculations indicate that releases from cuttings, cavings spallings of an intrusion borehole are the greatest contributors to the CCDF, a prediction based on the assumed integrity of the seals. Conversely, the attainment of lithostatic pressures at the bottom of shaft seals will test the contact weaknesses of fully consolidated shaft or borehole seals, or hydrofractures along marker beds may open to the Rustler or to boreholes open to the Rustler. Thus the seal system is implicated in undisturbed release scenarios as well as disturbed cases involving Castile and Bell Canyon fluids.

Under normal circumstances, concrete placed against the walls of a hole drilled through salt, or concrete forming the bottom plug of the shaft seal system will attain radial lithostatic pressure a few years after plugging, and the contact may be envisioned to be as tight as the undisturbed salt. But air propagating (fingering) slowly updip at about repository pressure will be opposed by decreasing rock pressure. If air can open a parting at the repository, it can prize a fracture at any contact, such as salt against concrete, opening first elastically, then increasing by plastic creep. No borehole seal design is leak-proof against a rising column of gas, nor of brine, which is even more unstable because of dissolving power. The claims of negligible seal leakage (2nd subpara., p. 15) assume vanishing permeability of consolidated salt, unrealistic of behavior in the presence of fluids
exceeding lithostatic pressures.

Comment 4, p. 16

DoE, its consultants at Sandia National Laboratories and scientists of the Peer Review Panel and National Academy of Sciences have evaluated seal design as though they have had experience to support their judgement of its adequacy. They seem to be of accord in the belief that an impermeable fill of consolidated salt in impermeable wall rocks of annealed salt in the DRZ, all at an isotropic pressure equal to the overburden cannot be breached by air at higher pressures. Apparently such proponents of DoE's proposed seals, or of the typical oil-field abandonment seals, have bought the claim that such materials will not hydrofracture to the surface.

Conversely, this reviewer expects failure by hydrofracture, and has experience to support it. In 1977, experiments in piezometer seal performance were conducted under the writer's direction at Lawrence Berkeley Laboratory, preparatory to application at Stripa, Sweden. The annulus between concentric steel pipes was filled with “Piezoseal”, a Portland cement, 20% bentonite mixture, then cured. When one end was connected to a tank of nitrogen at 50 psi, it developed an audible leak and a gradient to the atmospheric end, as recorded at piezometers placed in intermediate sand intervals. Since leakage could not be through the steel nor the bentonite-doped cement, it was concluded that gas pressure had invaded the contact, elastically deforming the steel pipes and or fillings to open a fracture. It seemed such an obvious consequence as to deserve no publication.

The analogy to the salt-filled WIPP shafts is close enough to cast doubt upon seal integrity as gas pressures from below approach lithostatic. Salt has a lower elastic modulus than either materials in the above-described experiment. All rock materials have heterogeneities facilitating air penetration, including a change of granularity at the contact, or a film of dust on the original wall. After air invasion, the salt can deform plastically, enhancing the aperture. Because seal designs such as that proposed for WIPP are wholly untried, it must be assumed that they will behave adversely at such pressures.

Comment 5, p. 19

DoE's response to comments about hydrofracture through the Salado reflects a view on pore-pressure in such evaporite rocks that differs in a significant way from that of the writer. The belief is expressed (1st para.) that the native pore pressure in salt is less than lithostatic because "the rocks themselves support some portion of the overburden pressure". While the statement is true for rocks that exhibit strength, if rock salt is a true plastic, incapable of sustaining shear without eventual strain, then any fluid-filled cavity must attain lithostatic pressure equal to the isotropic pressure in the adjoining salt. Laboratory observations that salt creep is not initiated until some threshold deviatoric stress is imposed are mainly attributable to observational periods too brief to observe the deformation. The size of natural fluid inclusions, on the scale of a millimeter, is a measure of the long-term threshold stress difference salt can sustain.
When the Salado anhydrite beds were formed, erosional channels interrupted them, then infilled with salt. In the subsurface, the anhydrite beds are therefore inclusions in the salt, suggesting that anhydrite may deviate little from the all-around lithostatic stresses of adjoining salt beds. After disturbance, such as the deformations due to current mining activities, stresses deviate from lithostatic, especially as closure of rooms develops extensional roof and floor strains. Fractures in brittle anhydrite are stiff, capable of sustaining normal loads with lesser fluid pressures in the fractures, at least until minute flows from salt to anhydrite equilibrate pressures. Intimate contact of fluids in anhydrite fractures with bounding plastic clay lamina and salt suggest that pore pressures must also approach lithostatic.

Fracture porosity in anhydrite beds is probably small, likely \(<10^{-3}\), so a borehole interception readily diminishes the pore pressures. If the hole were subsequently resealed with an impermeable material other than concrete, pore pressure would slowly recover if it is possible to drain the adjacent clay and salt. In the undisturbed state, if any anhydrite beds have pore pressure less than lithostatic, fluids from the salt would eventually flow to the anhydrite fractures. Though the steep fractures in anhydrite beds probably contain and convey most of the brines in the Salado, they are so short and in such intimate contact with salt that their pressures must have had abundant time to have equilibrated with the salt. The clay laminae bounding anhydrite beds may be residual, not depositional, reflecting the dynamics of changing fracture porosity with tectonics and salt deformation. Brine migration and salt regellation may produce fracture fillings of pure salt and corresponding residual clay along the adjoining impure halite beds. So native fluid pressures in anhydrite should be assumed essentially lithostatic, not the 12.5 MPa adopted by DoE for use in BRAGFLO. The impermeable salt-filled channels limit repository-related flows to the far-field. Potential outflows are extremely limited until hydrofracture pressure is attained. That is a direct consequence of the interpretation that observed pressures are always sub-lithostatic because of sampling disturbance.

DoE’s position reflects a trust in the observations of Salado fluid pressures that are always at least 2 MPa below lithostatic. Given that condition, it would seem demonstrable that pneumatic pressure in the repository would approach but not exceed lithostatic because it would bleed off through the slightly-pervious anhydrite beds. The next logical deduction is that hydrofracture will not occur. The writer disagrees with that line of reasoning, because of the afore-mentioned native lithostatic pressures.

There are compelling reasons for a more prudent approach to the risk of hydrofracture, reasons that are both economic and safety-related. Failure of containment and a breach to the environment may perhaps not occur for hundreds of years. Radiation health damage may then occur suddenly and without warning. Thereafter, re-entry and remedial removal of the crushed drums of waste would be exorbitant. Prudence is required also because the complexity of repository design considerations in an earth environment of ill-defined properties supports the contention that failure by hydrofracture is likely. Though DoE claims conservatism, it is certainly unconservative to assume that Salado pore pressure is below lithostatic, since the converse would have dictated project abandonment years ago. Project continuance and DoE management goals since inception
have swayed the judgements of innumerable success-oriented persons, and dissenters have disappeared for lack of financial support for the scientific efforts that proof to the contrary demands.

Comment 5, para. 3, p. 19

DoE claims the integrity of seals between panels and of pillars between rooms. As indicated, the DRZ around rigid seals will heal promptly, and stress above lithostatic in pillar regions will locally inhibit hydrofracture. The writer's comment (1st para., p. 17 of DoE response) that coalescence of the DRZ can occur by hydrofracture across pillars should be amended accordingly. However, because slab failures in the roof and floor of rooms will access the interbeds, continuity from room to room and panel to panel will follow the naturally-fractured anhydrite beds, since they extend across panel seal regions and stressed pillars. Along anhydrite beds below the repository strata, brines will drain to down-dip rooms. Air and generated gasses will migrate along roof anhydrites to up-dip rooms at pressures that will increase towards lithostatic as creep closes the deepest, partially-filled rooms. The considerable closure energy of the entire repository volume that is filled with compressed air and gas is available to drive a single pneumatic fracture. Thus failure of the sealed undisturbed repository will be by sudden rupture and discharge to the atmosphere. It will not be, as envisioned by DoE and modeled by BRAGFLO, a gradual bleed-off to the far-field via the marker beds. Whether the pneumatic venting will follow weak partings up-dip (N) and upstructure to the Rustler, or alternatively, along more steeply oriented subsidence-induced fractures is conjectural, and probably moot. Either would compromise geologic containment.

Comment 5, p. 21

As measured at some boreholes, the Rustler/Salado contact zone is tight, compared to the Culebra dolomite. Elsewhere, it is an aquifer of importance. The contact zone is an interval of accumulated clay, evidently residual after dissolution of salt. The presence of clay breccia could reflect either depositional or residual formation. The stratum of residuum varies from inches to a few feet in thickness within the LWA, but increases to about 20 feet at the Culebra Bluffs outcrop, where the Salado salt is missing. Gypsum underlies the residual clay at that exposure, whereas there is no gypsum within the residual clay. Apparently the dissolution has removed not only the salt, but also the anhydrite interbeds, after their hydration to gypsum. One cannot argue that the underlying gypsum represents the thin Salado anhydrites pancaked together, because residual clays after salt beds cannot have migrated to the thick clay accumulation. The 20+ feet of residual clay without included gypsum could not have accumulated unless the gypsum interbeds had been dissolved. Proceeding eastward from the outcrop area, one must be able to find, in less advanced states of dissolution, the gypsum interbeds lying within the residual clay. Dissolution does not occur uniformly over the area. Not only is it more complete as one traverses westward, but its distribution must be irregular. Patches of salt, patches of gypsum or unaltered anhydrite should remain in areas otherwise altered to the terminal clay residuum. The variable removal of strata gives rise to differential displacements of the overburden, producing by their irregular recurrence a pattern of randomly-oriented steep-dipping subsidence fractures superimposed upon the tectonic pattern, northeast and northwest oriented.
Nor does dissolution occur uniformly at the top of a salt formation. At any time, it is concentrated at local channels of ribbon-like shape, with residual products deposited in, and briefly arched over them. Upon collapse, flow in such channels shifts laterally to attack areas formerly protected. Anhydrite grains and chips and grains of clay particles are transported by the conduit channel flows and redeposited. These processes have been observed by the writer at various stages of development, during studies of the flooded K2 Mine in Saskatchewan. Because the processes have reached conclusion at Culebra Bluffs, with no more salt to be removed, there must be, in the transition zones extending eastward across Nash Draw and the LWA towards the line of no salt dissolution, a region of active channels that typifies an evaporite karst. Though undetected east of the WIPP-33 chain of sinkholes, open channels probably extend east from the discharge area in Nash Draw, across Livingston Ridge and into the LWA, as surface morphology suggests (Phillips, 1987 and March, 1997). They may be oriented preferentially parallel to the northwesterly and southwesterly fractures, with dissolution controlled by the paleo-gradient and its variations over the span of time of formation. Their traces as conduits could be intersected by a gently-dipping hydrofracture propagating upwards from the repository through the remaining thickness of Salado salt.

Comment 6, last para., pp. 24-25

If EPA has concluded that the potash above the repository would not be mined under current economic conditions, that judgement should be reviewed. As recently as 1990, the AMAX Mine was operated by Horizon Corp. by opening an apparently sub-economic 4-ft bed of the McNutt after the original 10-ft bed was exhausted. Because its location uniquely serves all agriculture surrounding the Gulf of Mexico, the potash resource over WIPP should be assumed to be exploited as soon as institutional controls cease to prevent mining.

Because mining subsidence produces steeply oriented fractures across the overlying interbedded salt, anhydrite and elastic sediments, it is folly to rely upon an EPA ruling that only the 7m thick Culebra dolomite will be changed in the process of fracturing. Mining subsidence within or adjacent to the LWA will breach a significant interval of the confining beds to aquifers within the environmental boundary. Consider the conceptual error introduced by EPA's criterion. They have given substance only to enhanced transmissibility of the Culebra dolomite, assumed to be confined, that it may randomly increase as much as 1000-fold. That produced little change in PA, because spatial elements of the Culebra were modeled with random increases of the transmissibility, by factors of 1. to 1000, whose geometric mean, 100, most closely indexes the velocity change attributed to mining. Combined with other non-conservative transport functions, such as sorptive and diffusive retardation inapplicable to concentrated flow in channels, the CCDF remained within EPA limits. No consideration has been given to the certain effect of a few subsidence fractures, typically dipping 60 to 75 degrees, open passages that would concentrate conduction across the upper Salado interval, except for the 75m lying between the repository and McNutt horizons. The EPA's concept still requires an intrusion borehole to connect the repository to the Culebra, whereas the occasion of mining would develop widespread vertical connections above the mine, even into the LWA from mines outside its boundary. The 40CFR154 conditions are minimum considerations, not conservative at all.
Due to displacements induced by mining subsidence, steep fractures may not readily heal in the anhydritic salt formation. Furthermore, there would be no control over the technology of shaft and borehole sealing above a future mine. So containment would be breached thereafter from the mine to the Culebra and to the surface. But to breach from the repository to the mine horizon would require either hydrofracture (undisturbed conditions) or a borehole intrusion. Thus, mining as a certainty outside the LWA and as a probability inside it has not strongly modified the CCDF, and would not do so unless a more certain, calculable time of hydrofracture is included in PA. Mining could provide brine storage during venting if hydrofracture from the repository occurs before creep closure of the mine. The presence of a nearby or overlying mine, however, shortens a hydrofracture-established path, connecting the repository more immediately to the surface. Given a mechanism of hydrofracture, by attainment of lithostatic pressure in the repository or more readily at the top of a permeable concrete plug at the shaft bottoms, the conditions to breach 50m of salt would readily breach the rest of the cover. A nearby or overlying mine augments the hazard, therefore.

Comments 7 to 22. Synopsis. p. 27. 4th bullet:

It is noteworthy that DoE has chosen not to respond in detail to comments concerning the Rustler hydrology, including implications of the fracture system in the Culebra, nor to the karst features of the Rustler and Dewey Lake Red Beds. Because the conduit system geometries along various parts of the path are undefined, the transport computations based upon continuous-media properties and generalized gradients suffer from the age-old problem of unknown effective porosities. Consequently, contaminant travel-times may err by orders of magnitude. In fractured and karstic formations, there is great likelihood that transmissibility tests, few in number and limited in dimensions and coverage, have missed the occasional, steep planar fracture conduits and sub-linear solution conduits. Concentrated flow along such features may shorten mean travel times from, say, 10,000 years to as little as 100 years. With rare exceptions such as WIPP-33, test wells and observation wells, being vertical, generally miss the major conduits. Since there was no hydrologic testing done in WIPP-33, the data-base does not reflect the presence nor character of channels. Tests conducted in wells accidentally near a channel may weakly reflect its presence. All of the tests miss the region of most likely solution features extending east of Livingston Ridge into the region of the western half of the LWA.

A scattering of head data-points in either continuous or discontinuous media can always be contoured because values decrease monotonously towards discharge regions. But that doesn't prove the existence of a smooth distribution. Measures in fractured formations often appear capricious rather than smoothly consistent, actually reflecting transients of very different response times in open faults to tight intervening blocks with only fine fractures. The ages of such waters may vary also. A karst channel imbedded in a formation may lie stagnant at different heads than its wall-rocks until suddenly recharged via a swallow hole. As pointed out in comments (Snow, March, 1997, p. 12) on karst hydrology, the technique of T-field modeling relied upon to fill the spaces of missing field data is invalid for discontinuous media. The conduit-size heterogeneity that invalidates T-field modeling increases from east to west due to increasing fracturization and dissolution of fillings and channels, thus the most important segments of potential flow paths from
the repository towards the discharge area in Nash Draw are ill-defined for modeling.

It was pointed out that explorations have not been conducted so as to define the variations of conduit type and their frequencies. Thus, even if T-field interpolation were valid, contaminant velocities would not be determinate because the variations of effective porosities are unknown. If DoE was aware of a line of sinkholes at the surface, including WIPP-33 (Response to Comments, p. 31), why was it not tested, and why was the obvious potential of more such features in or within the LWA not fully explored? Had the model of a simple confined porous aquifer been questioned objectively in response to observations of dissolution features, the truth would have emerged.

Because of its importance to transport, the description of conduit system geometry has received much attention by the community of hydrologists working elsewhere on nuclear waste repositories. Instead of seeking the appropriate geotechnical expertise to characterize conduit geometries, or developing their own innovative means of aquifer investigations for the purpose, DoE’s consultants have discounted, denied and avoided the issues. Instead, they have adopted the classical porous-media approach, treating the Culebra and other Rustler units as though they were sands instead of fractured, dissolved rocks. Likewise, lacking corresponding means of modeling transport through highly heterogeneous fractured media and karstic formations, DoE has made the damaging simplification that equivalent continuous media properties can be estimated, extended stochastically and modeled in conventional, 2-D, layer-cake stratigraphic style. Sensitivity studies of variable parameters and rudimentary 3-D infiltration effects (1 to 2 mm yr) on regional flows fail to incorporate the range of properties relevant to karst terrain. DoE’s model work does not approximate reality. Suppose that contaminated brine were to be displaced updip from the repository to the Rustler along hydrofractures. Might it not rest there in karst channels for a long period while the gradient remains flat? Then, when a 4 or 5-inch rainstorm suddenly recharges the karst via sinkholes, can it not respond to the transient gradient by transporting the waste across the environmental compliance boundary and to Nash Draw in a matter of weeks? Admitting observations of karstification, such as the sinkholes of WIPP-33, it is incumbent upon the applicant to prove that transport will not be rapid nor episodic, that larger effective porosities exist, as the tracer tests (in the wrong areas) suggest, not small effective porosities that would imply CCDF results exceeding EPA limits.

Comments 7-22. p. 28. 1st bullet

The notion of 1 to 2 mm recharge is intuitively questionable to anyone who has visited the Mescalero Plain, a channel-less surface pitted with depressions partially filled with eolian sand. Because sinkholes are known, and observations have been made at WIPP-33 of storm water infiltrating at high rates, it is deduced that many of the sand-filled depressions conceal sinkholes or dolines, conduits for rapid recharge that must aggregate inches over some areas, not millimeters. Such surface morphology and its hydrologic implications, as can be drawn from the Phillips thesis (1987) should merit intense study by DoE. The proponent’s consultants should pursue ground penetrating radar, backhoe excavations, shallow piezometry, surface flow gaging, and other techniques. The Peer Review Panel must not have been shown the field conditions, thus preventing development of their independent opinions.
The CCA uses the assumption that climate change may raise the water table to the surface, a condition impossible in karst terrain. A rise in the water table can multiply karst system discharges many-fold, because small rises saturate larger channel cross-sections and increase low gradients several-fold. The Mescalero Caliche implies a persistent water table below the caliche, even during glacial maxima. That horizon would be a good candidate for modeling the highest water table. Even for modern conditions of precipitation, the water table has remained undefined for lack of diligent field measurement.

Comment 20. last para., p. 30

DoE responded to CARD's concerns about potential cavernous zones in the Rustler. DoE counts upon the interpretation that soft sediments logged in boreholes across the WIPP site are not dissolution residues. That is based on Holt and Powers' investigation of exposures in shafts, where they noted intraformational conglomerates and graded bedding in fillings of erosion-bounded channels. Since these are features of open channels, they convinced everyone that they formed subareally, not in the subsurface as halite was eroded. They expressed the interpretation that a Rustler-age salt pan existed east of WIPP, that mudflats existed to the west and transitional regimes between. Conversely, Holt and Powers' description of features now obscured by shaft linings do not establish their subareal origin. The writer has had uniquely applicable experience in an environment of underground salt dissolution: In company of other geologists, he inspected, recorded, studied and interpreted processes of dissolution and sedimentation that occurred repeatedly in salt beds above a flooding potash mine. From 1988 to 1993, he made monthly inspections at the K2 Mine at Esterhazy, Saskatchewan, where successive inflows (up to 8000 gpm) from an overlying dolomite aquifer followed subsidence fractures that crossed a 30-ft redbed and downwards across 100 ft of bedded roof salt. In the course of weeks, a new leak would carve an elongate solution channel at the top of salt and along several bedding horizons in the salt. The channels were studied on hands and knees as successive new ones were formed and older ones closed by creep. Some were as much as 1000 ft long, downcut towards the mine in stair-step profile. Rounded cobbles were seen, transported from cave-ins of the overlying fractured dolomite, while eroded redbeds produced silt-chip conglomerates, sand, silt and clay which formed bedded deposits along the subterranean stream channels that meandered along the floors of sinuous solution passages walled by intact rock salt. Point bar deposits of the transported clastics contained imbricated cobbles recording flow direction. Graded bedding recorded the progressive diminution of rates as aquifer grouting stanchcd the flow. If one could revisit the closed passages, such cut-and-fill sedimentary features would be preserved. They would closely resemble those described by Holt and Powers at the WIPP shafts, yet the Saskatchewan channels formed not at the surface but at 3100 feet in depth. It is by no means evident that all Rustler conduits were initiated along fractures formed in response to Salado salt dissolution. Dissolution channels may also have been directly caused by dissolution of salt beds in the Rustler, or by fractures developed as a result of differential subsidence as Rustler or Salado salt was removed. The clay horizons in the Rustler were probably residuals from dissolution of those Rustler salt beds. The solution channels may extend eastward into the WIPP site, because they are related to Rustler, not
necessarily Salado salt dissolution.

The controversy between Rustler salt dissolution vs. salt non-deposition (e.g., Non-Salado Flow and Transport Position Paper, December 15, 1994, 3.1.1.4) has been conveniently decided (ibid., 3.1.1.4.2) with bias favoring WIPP. A more convincing determination is needed because PA would have a different outcome if Rustler salt intervals have been dissolved from the site. If the top-to-bottom progressive salt dissolution model (Snyder, 1985) is correct, then conduits must remain in the transition zone, and drilling and testing have not been adequate to define them at either the top of Salado, nor in the Unnamed Member, the Tamarisk nor Forty-Niner Members where salt beds once prevailed. In support of the Rustler dissolution concept, it is noted that the thinning of the Rustler interval, from east (about 500 ft) to west (about 300 ft) across the site is wholly attributable to differences of salt thickness. It is preferable to ascribe the thinning to dissolution because the alternative, non-deposition, would require about 200 ft more syn-depositional subsidence of the basin, an abrupt flexure at the site of the WIPP.

Two other observations in Culebra cores from on-site drill holes support late, and perhaps current dissolution. First, the percentage of fracture fillings of gypsum decreases from east to west across the site. Second, vugular porosity, probably by dissolution of fine-grained dolomite replacements of beds of fecal pellets, has developed on-site as well as at the Culebra Bluffs outcrop. Both of those features are clearly due to post-depositional dissolution, both contribute to westward-increasing transmissibility, and their occurrence would be consistent with dissolution channelization of salt beds in the same sequence of rocks. All such effects increase in severity towards the west. Since the Salado formation has not been thinned appreciably at the WIPP site, the presence of Culebra dissolution features there is more reasonably associated with Rustler salt dissolution than with subsidence fracturing by Salado dissolution. Nonetheless, vugular and fracture porosity attributable to dissolution of Culebra dolomite and gypsum fracture fillings on site may have important relationships to through-going conduits that provided the flux of water, such as enlarged fractures, faults or contact zones. It not prudent to dismiss such secondary porosity features in the belief that T-field modeling incorporates them. The extremes are never included in borehole sampling, since the probability of channel intersection is vanishingly small on an area basis. Such extremes dominate overall performance, because nearly all flow paths funnel through solution channels or other large conduits when present.

Comment 20, p. 32

CARD has not expressed concern that the dissolution front will propagate to the WIPP site during the (10,000 year) period of regulation, but rather, that there has been misrepresentation of the present-day distribution of dissolution conduits capable of fostering rapid transport from the repository footprint to the compliance boundary. The dissolution front has long since incorporated the WIPP site. With higher pluvial recharge rates, dissolution of highly soluble salt and gypsum may enhance conductivities within the regulatory period, displacing conditions eastward.

Comments 7 to 22. p. 33
The application of uniform recharge rates of 0.2 to 2.0 mm/yr over the entire region of Rustler modeling leads DoE to the conclusion that it "takes thousands of years for water to reach the Culebra in the WIPP site." The problem with that concept stems from the implications of non-uniform recharge. East of the LWA, where the limited explorations have revealed no exceptions to the intact, undissolved character of the Rustler or Salado, vertical conductivity is probably negligible, (e.g., 0.2 to 2.0 mm/year), unchanged from that of the original intact sequence of salt, siltstone, sandstone and anhydrite, perhaps with all fractures sealed by gypsum or halite. West of the LWA, but east of Livingston Ridge, there are known swallow holes that have to connect to solution channels. In the transition zone that includes at least the western half of the LWA, there are surface depressions without surface channels masked by eolian sand. These features are suggestive of unidentified swallow holes. Recharge through them has been observed to be brief and localized, so that the equivalent steady, uniform recharge might be as little as the assumed 2mm/yr, or as great as 20 mm/yr (Phillips, 1987). But travel times via solution channels, large and small, would be very much shorter, averaging a small multiple of the period between events, a few years instead of thousands. In effect, DoE's failure to fully describe all aspects of conduit system geometry has lead to indefensible CCDF curves based on idealized homogeneity. A few calculations of the implied travel times would illustrate the vulnerability of DoE's assumed conditions.

P. 33, para (i)

All DoE's flow modeling has been done upon the assumption of isotropic conductivity properties, the only assumption possible to a party that has not conducted tests in sufficient number to systematically evaluate the anisotropy of different areas, as should have been done. At a few of the test pads, anisotropy has been evident (Jones, et. al., 1992), but inconclusive of generality from site to site. These data cast doubt on the correctness of models that have assumed isotropy, and that therefore the direction of flow is parallel to the gradient. In the event that some areas between the repository and the discharge points for regional flow have well-defined, sub-parallel solution channels in the Rustler, then the major flow components are parallel to those channels, not the regional gradient. Because water in large solution channels lies nearly stagnant, perhaps for years between recharge events, the heads in them are controlled by the elevation of the discharge points. If such points are disposed from north to south along Nash Draw, each parallel channel trending easterly or northeasterly into the LWA would have a different head, diminishing from north to south. Without knowledge of the channels, random piezometers in the wall-rocks would be interpreted to record a southerly gradient. But during unobserved storm events, slight components of the gradient along the length of the channels would produce major transient flows in those directions. The true nature of karstic transport cannot be modeled in the steady-state, isotropic manner typically employed for stratified intergranular media. It would be necessary to acquire sufficient data to define the anisotropy and the conduit geometry to model the transients that account for the majority of the fluxes.

P. 34, para. (ii)

CARD does not insist that all Rustler groundwater must discharge at Nash Draw, but rather that a
larger fraction discharges there than would be allocated by DoE on the basis of its isotropic, non-channelized model. The important consideration is that brine from the repository, conveyed either along breached well or shaft seals or along hydrofractures, would arrive at the Rustler aquifer in a region tributary to Nash Draw, not Malaga Bend. In that region of prevalent solution channels, the velocity of westerly travel to a discharge area in Nash Draw is likely to be far greater, and travel times to the compliance boundary will be correspondingly shorter. In terms of fundamental properties that invalidate the CCA, it is the effective porosity and anisotropy that are different from those assumed by DoE, thus producing failing CCDF curves. Both properties are strongly influenced by the presence of preferentially-oriented solution channels, either at salt contacts or in fractures. Sorptive and diffusive retardation also deteriorate. Failure to seek knowledge of dissolution by appropriate explorations is the reason for serious doubt of the idealized model results presented in the CCA.

P. 39, 3rd. para.

As discussed above, the failure to characterize solution channels in and west of the LWA has led DoE to ascribe to those areas transmissibilities unconservatively minimized. It claims to have modified measures to account for pore and fracture dissolution features, but it is not evident that those modifications have been sufficient. Since data on hand were used to adjust recharge to the level of 0.2 mm/yr for replication of model head distribution, then T-field manipulations consistent with those magnitudes would not change values appreciably, lest gradients decrease too much while maintaining uniform recharge. Better models can be developed that incorporate more realistic geology than DoE has offered.

Let us suppose that one gives credence to the observations of Phillips (1987), that surface manifestations of karstic drainage persist east of WIPP-33 and northeast of the Nash Draw embayment, both penetrating the LWA. The system of dissolution channels must pervade the saturated interval to at least the depth of the Culebra where fracture fillings have been dissolved. The evaporation estimated for the area of Laguna Grande de Sal (Phillips, 1987) suggests greater effective recharge in that karstic area, since flows from occasional storms drain efficiently via swallow holes into the aquifer. Extending eastward from the eastern extremity of evident Culebra leaching, salt beds may remain in the Rustler, preventing all recharge through the unit. Recharge rate, variable over the region, should correlate best to vertical hydraulic conductivity. While rates on the order of 1 mm/year may correspond to the low values of laboratory conductivity associated with intact siltstones, anhydrites and salt, there is no ready method of measuring average conductivity of ground perforated by a few, widely-spaced swallow holes. The only evident means would entail opportunistic surface flow measurements at sinkholes on the rare occasions of storms during years of patient observation. For example, five feet of ponded water in the WIPP-33 sinkhole represents at least a minimum recharge rate over its watershed during some interval between storms. A rough correlation between vertical and horizontal conductivities also prevails in such a karst region, since the Salado limits the depth of flow and directs it laterally to the discharge area. Both vertical and horizontal conductivities far exceed values derived from a steady state model scaled to the evaporation-controlled discharge, because karst systems operate by transient events. Quantitative hydrology in karst terrains has evolved slowly, due to measurement
constraints, but has progressed by application of dye-tracing and surface flux measurements, tools neglected by DoE for comprehension of the WIPP site hydrology.

The importance of the admissibility of such alternative models, embodying non-uniform transient recharge, anisotropy and higher-than-measured T values in and west of the LWA, is that transient transport models so constructed would yield far shorter travel times to the environmental compliance boundary. The gradation of solution features, fewer but larger as one moves westward, connote westward decreasing effective porosities and consequently faster transport rates at the same gradient and conductivity. The field observations and demands of conservatism justify and necessitate such interpretative modeling, rather than acceptance of homogeneous-isotropic steady models with uniform recharge that happen to support licensing with acceptable CCDF distributions.

DoE has responded (p. 40) to the noted difficulties of representing local-scale transmissibility, espousing the stochastic tools of de Marsily and others. Such methods fail in karst terrain because their fundamental premise is that conductivity varies continuously. Fractured formations also are discontinuous. From matrix to fracture, conductivity jumps orders of magnitude; from unaltered to solution-channeled evaporites, conductivity jumps orders of magnitude. Measurements in wallrocks bear no relationship to the properties of the conductors. The spatially-variable T-fields DoE has applied cannot be defended if solution conduits prevail in the Rustler. The presence or absence of them is the first and foremost characterization required, an activity DoE has neglected.

The connectedness of transmissibilities noted in the first bullet (bottom p. 40) is particularly inappropriate for karstic aquifers. An equidimensional grid can represent intergranular porous media adequately (e.g., a sand), but not a solution-channeled carbonate or evaporite. If one were successful in finding and measuring T for a cell traversed by a channel, then cells upstream and downstream of it (wherever they are), are perfectly connected and highly correlated, while other cells nearby are uncorrelated to it. Such is the nature of the region, roughly west of the middle of the LWA, that remains ill-defined in properties attributable to dissolution. If the Rustler flow field from repository to Nash Draw were characterized as spatially linked in the direction of flow, the transport model for PA calculations would have produced adverse results.

In the last bullet (p. 41), DoE discounts the significance of all T-fields, on the grounds that retardation of radionuclides in transport through the Culebra is such as to ensure that no releases occur at the accessible environment. That transport model employs a single horizontal fracture in the Culebra, with matrix diffusion and sorption providing the retardation. In a karst conduit model (the same discharge concentrated at a one-dimensional conduit of tubular cross-section), specific surface would be so small that matrix diffusion and sorption would be negligible. Retardation has been demonstrated at tracer test pads south and southeast of the repository, data consistent with media dominated by a network of fine fractures, but not solution openings. Matrix diffusion is assumed, not proven, since a convective dispersion model can also explain the tracer breakthrough behavior from these tests. Whether retardation of conservative tracers is attributable to matrix diffusion or aperture distribution, or both, it is a property strongly dependent upon conduit-system geometry, whose variations along the flow path remain obscure for lack of exploration efforts by
DoE. Because karst channels exist within the compliance boundary, retardation properties deduced from ill-placed tracer tests cannot be applied in those regions. Hydrofracture from a pressurized repository, following partings in the Salado updip to the west that break to shallower strata and the Rustler would probably connect to dissolution channels of vanishing retardation capacity. It is the mis-representation of effective porosity and retardation that invalidates the DoE transport modeling, both arising from neglect of the true nature and implications of the fractured and dissolved conduit system.

Comment 8. p. 43

DoE responded to some aspects of the alleged inadequacy of fracture characterization. By neglecting work on the Culebra that is within the realm of currently available technology (e.g., slant-hole or horizontal-hole drilling and coring), it has shut off the possibilities of gaining insights into other features that consequently remain wholly obscure. What, for instance, is the nature of fracture system geometry and conductivity for other saturated rock units, such as the thick Rustler anhydrites? And what is the role of fracture-system dissolution, of vugular permeability, and most significantly, of dissolution channels in or on salt beds? What are the hydrological implications of the distribution of massive gypsum bodies altered from anhydrite beds? There are too many loose ends to the evaluation of transport in this complex medium, too much uncertainty to warrant a licence for radioactive waste disposal at WIPP.

While the fractured Culebra is the most persistent transmissive unit tested, it is only 6-7m thick. If the fracture conduit systems in the very thick anhydrites had been examined and were better understood, might not the site hydrology be found to be dominated by them? DoE assumes that anhydrite fractures are the result of the dissolution of Salado salt, not the dissolution of Rustler salt. Conversely, CARD cited evidence to the effect that abundant Rustler salt dissolution has thinned the unit over the east-west extent of the site. Thus, anhydrite fracturization is consistent with other dissolution features within site boundaries, and thus co-existent with them. Anhydrite fractures need not be numerous to be significant, especially for transport. Given that subsidence develops a certain magnitude of rock mass strain, producing apertures, the fracture conductivity increases with the square of spacing, as does contaminant velocity. So, if a thick monolith of anhydrite tends to have widely-spaced, obscure subsidence fractures, it may provide very short travel times in such units as the Tamarisk or Forty-Niner, even in absence of dissolution conduits. Such undetermined property variations in the aquifer leave corresponding uncertainties in the CCDF.

Whereas DoE claims to have acted conservatively in the PA modeling, to treat the Culebra as confined is obviously incorrect for transport. All Rustler strata participate in the flow field, since they are interconnected by steep fractures, faults and dissolution chimneys. Future mine subsidence will produce cross-cutting features, as may repository driven hydrofractures. One revealing long-term test has been the water level recovery after the Air Intake Shaft was lined and sealed. From 1989 to 1994, monitoring wells on and off the site registered water level rises, defining a consistently-varying cone centered on H-16 (with 71 ft of recovery), while sufficient contour control defined a figure elongate in plan, NW-SE. The direction of elongation coincides
with one of the known regional tectonic fracture orientations. The recovery cone reflects the whole saturated, fractured Rustler formation, not just the Culebra, though all monitoring wells are completed in that thin dolomite.

Comment 10, p. 43

With respect to the use of Darcy’s Law, CARD agrees with the assumption of linear friction for the sake of conservatism, even if turbulence may act briefly in transient channel flows following recharge events.

Comment 11, p. 44

It appears to be necessary to reiterate CARD’s objection to the WIPP site T-field construction technique, which is based on an assumed continuity of values. The mathematics is without merit because there are sharp discontinuities between conduit sizes of matrix, fractures and solution channels. Let us suppose that well tests have characterized the Culebra transmissibility at two points in the region separated by a mile, and it is desired to establish a rational value of T at a midpoint between them. In a fracture-dominated medium, it is correct to treat the nodal value to represent some volume around it, i.e., to assign an equivalent continuous-medium conductivity to the thickness and breadth of a defined volume circumscribing the node. The intermediate, undefined node lies within a similar volume. Field experience in karst terrain indicates that adjacent nodal values may bear no relationship to each other. Sudden inflows occur to tunnels in fractured igneous rocks when faults are intercepted, or in carbonate rocks when solution channels are intercepted. Likewise, when salt or potash mining intercepts trapped or connected brine-filled conduits, sudden inflows are experienced. At the WIPP site, the transition from a fully-cemented domain east of the LWA to a maturely-developed karst conduit domain astride Livingston Ridge, there are sub-domains at all scales that are so wildly capricious that a hydrologic test in one gives no clue to its neighbors. Each sub-domain differing by several orders of magnitude in transmissibility. The interference testing that has been done supports the contention of structural control. Certain well pairs are apparently connected efficiently, while most pairs are not. DoE has over-worked the data set, never questioning the validity of conclusions based upon smooth contouring or stochastic manipulation.

Comment 12, p. 44

DoE has failed to adopt vastly-improved technology of core recovery available for at least 20 years, or of directional drilling technology available for at least 10 years. Inspection of WIPP Project cores pre-dating 1995 (i.e., most of the data-base) reveals so much rubble and so many missing core intervals as to guarantee that fractured and dissolved features, if present, could not be described. Even the superior, latest cores from the vertical H-19 pad holes are incapable of disclosing the predominant near-vertical fractures of the Culebra. DoE has spent far more to justify poor simplifications of the conduit system than it would have cost to seek contemporaneous skills in the geotechnical and petroleum disciplines that could have, and still could rectify the lack of knowledge. Without such data, the underlying causes and variations of effective porosity and
retardation are unknown. Fracture data are needed to determine if other features, such as dissolution of fractures and development of channels plays a part at the pad scale. Without such explorations targeting fracture systems, there is little hope of discovering dissolution conduits.

As expressed before, the stochastic model is unconservative in the presence of dissolution features that occur in parts of the flow field: DoE's approach is not robust.

Comment 13. p. 44

In the domain of Rustler dissolution that extends eastward an uncertain distance from WIPP-33 and Nash Draw, the relevance and legitimacy of hydrostratigraphic units is lost due to cross-cutting fractures and solution openings. The assumption of confinement is inconsistent with the presence of such openings, whose distribution can be determined using improved field observations.

Comment 15. p. 45

CARD has reiterated concern for mis-representation of the current Rustler hydrology by models that discount the current effects of widely-separated solution channels in the carbonates and soft, erodible clastic sediments, as well as partial fracture fillings residual after evaporite dissolution. Insofar as the solubility of halite and gypsum facilitates rapid conduit enlargement, minor changes in velocity and chemistry due to increased recharge during the span of 10,000 years can speed the propagation of a dissolution front and enhance the hydraulic conductivity throughout the karst terrain.

While fractures that are short, arcuate and slickensided are typical of those that develop by shrink-and-swell processes in the near-surface, it is not credible to claim that no other types of fractures are present. An orthogonal pattern of regional tectonic fractures is evident elsewhere in the Delaware Basin. They can be observed at outcrops such as Culebra Bluffs, the Capitan Reef and in Carlsbad Caverns. These and any subsidence fractures tend to be missed by drill holes because they are steep and widely separated, especially in poorly-cemented units that deform somewhat plastically.

The argument that fluids apparently saturated in halite or gypsum cannot further dissolve the conduits that convey them is incorrect. The slightest shift towards dis-equilibrium, either by meteoric water dilution or temperature change can facilitate renewed dissolution of either species. The observed coexistence of open fractures and gypsum-filled fractures, open vugs and carbonate-filled vugs reflects the current geochemistry and active dissolution, thus supports current development and thus regional variations in degree. CARD warns against underestimation of the role of undisclosed solution features in controlling transport, especially in the western parts of the LWA.
POTENTIAL FLOW PATHS FROM THE WIPP SITE TO THE ACCESSIBLE ENVIRONMENT

by Richard H. Phillips, Ph.D.
and David T. Snow, Ph.D.

The Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico, is intended for the permanent disposal of radioactive waste from nuclear weapons production. The WIPP site was selected in 1974. It is now 1997, and the Department of Energy (DOE) still does not know the position of the water table, the flow paths of Rustler groundwater, or where the Rustler groundwater discharges. Without an understanding of such basic hydrologic parameters, "knowledge about the site is incomplete." (EEG-61, 1996). If completed early in the WIPP investigations, a study of near-surface hydrology would have revealed vital information.

The water table represents the top of the saturated zone. At the WIPP site, the water table "is believed to be in the Dewey Lake Redbeds" (EEG-61, 1996, p. 2-6). DOE has collected data on the hydraulic heads of Culebra groundwater from 35 test wells at the WIPP site and vicinity. According to DOE, contour maps of these water levels "suggest" that Culebra groundwater at WIPP flows to the south (SEIS, 1996, p. 4-20). DOE concludes that groundwater flow in Nash Draw "is unrelated to groundwater at WIPP," (SEIS, 1996, p. 4-18), and "that the Culebra probably discharges into the Pecos River" at Malaga Bend (EEG-61, 1996, p. 2-7). If the position of the water table is "believed," and the groundwater flow path is "suggested," and the groundwater discharge point is "probable," then little is known for certain, and all the risk assessments based upon modeling of radionuclide migration through an assumed groundwater flow path are without foundation.

Groundwater flows occur in a conduit, such as an aquifer, according to its hydraulic conductivity and the gradient of hydraulic potential (heads) acting in that conduit. Since heads in an aquifer can be measured readily by measuring the water surface in cased wells penetrating an aquifer, the gradient is commonly determined from the spacing of contours drawn to describe the potentiometric surface from a number of such piezometers. Such has been the work done for 30 years, in attempts to understand flow in the Culebra dolomite.

If the Culebra aquifer were isolated, above and below, by impervious aquicludes, and the water were supplied and discharged at its edges, the piezometric work might have been adequate for predicting flow paths. It has been recognized (Corbet and Knupp, 1996) that recharge occurs by infiltration through overlying strata, but flow models have assumed uniform areal recharge and smoothly-varying hydraulic conductivity for lateral flow in the aquifer. Had some work been done to assess local variation of
such recharge, more effective understanding of localized flow controls in the Culebra, as well as the Dewey Lake Redbeds, would have ensued. DOE chose to neglect warnings that the system does not vary smoothly. Because the Rustler and Dewey Lake are karstic, the flows are probably dominated by a small number of very conductive horizontal and vertical conduits.

One type of piezometric surface is the water table, depicted as the surface of uppermost saturated rock, having atmospheric pressure. If the piezometric surface for a buried aquifer, like the Culebra, lies below the water table for rocks above it, such as the Dewey Lake, a gradient exists across the strata tending to develop recharge. If they coincide, there is either no recharge since there is no gradient, or there may be great recharge if the interval has such high hydraulic conductivity in the vertical direction that vertical flows take place with a minimal vertical gradient. Such distinctions need to be made at the WIPP site, but because the hydrology of units overlying the Culebra has been neglected, there is no detailed knowledge of the shallow water table nor the heterogeneities of the Dewey Lake and other units.

At a sinkhole, such as WIPP-33, the water table (first water encountered in a drill hole) must coincide with the Culebra piezometric surface. At WIPP-33 a nested sequence of five caverns, one in Dewey Lake siltstone, two in Forty-Niner gypsum, and two in Magenta dolomite, was found during drilling. Rapid surface inflow during the rainstorm of September 18-19, 1985 proved the existence of a vertical conduit connecting these caverns, of such dimensions as to provide rapid, concentrated recharge to the Rustler aquifer. If adjacent Dewey Lake rocks are undissolved, a well located there might disclose a water table higher than the Culebra piezometric surface, the difference implying that a gradient is required to produce slow recharge because of low vertical conductivity. It is still important to the WIPP project that a comprehensive program be undertaken to study the shallow water table, the heterogeneities of vertical conductivity, and the implications for Rustler flow.

WIPP is a disturbed site. Previously existing exploratory boreholes for oil, gas and potash, and the WIPP boreholes and test wells themselves, all requiring casings through the Rustler, have affected hydraulic head distribution in the Rustler. WIPP monitoring wells have experienced sharp rises in water levels. Between 1988 and 1993, water levels in the Culebra dolomite generally rose from 4 to 30 feet (EEG-62, 1996). These water level rises "were strongly correlated with a nearby salt water disposal well operated by the oil and gas industry." (EEG-61, 1996). Subsequent measurements are unreliable, as graphically illustrated by DOE's annual mapping of the changing Culebra potentiometric surface (ASER, 1992-1995, Figure 7-3). For purposes of long-term prediction, what is needed is a record of the primitive conditions (Snow, 1994).
The best record we have of the Rustler potentiometric surface prior to disturbance by WIPP shafts and boreholes is given in Mercer and Orr (1977, Figure 23). This map shows a southwesterly gradient from Forty-Niner Ridge to the Salt Lake (Laguna Grande de la Sal) at the lower end of Nash Draw. Hunter (1985) also produced maps of the Rustler potentiometric surface. These maps also show a southwesterly gradient through Nash Draw to Laguna Grande de la Sal (Phillips, 1987, Figure 75).

One of the most compelling arguments for prevalent flow paths to Nash Draw, as opposed to Malaga Bend, is the water balance. The surface area of Laguna Grande de la Sal is so large (2,120 acres, or 9.23 x 10^7 ft^2 in natural extent), and net evaporation rates are so high (6.32 ft/yr), that the Rustler flow discharging to Laguna Grande and evaporated by the lake must be an order of magnitude greater (5.83 x 10^8 ft^3/year) than the incremental flow discharging to the Malaga Bend reach of the Pecos River (6.53 x 10^7 ft^3/yr) (Phillips, 1987, pp. 219-222, 232-235). Further, the Malaga Bend brine springs have geochemistry more consistent with the "brine aquifer" at the top the Salado, while Laguna Pequena, which flows into Laguna Grande, has geochemistry more consistent with the gypsum and dolomite aquifers of the Rustler (Phillips, 1987, pp. 242-248). Laguna Pequena is the single, most copious discharging point for the Rustler (Phillips, 1987, pp. 227-231), and most flow paths must be directed there from WIPP, as from elsewhere in the watershed.

The DOE assumes a southerly flow path from the WIPP site to the brine springs at Malaga Bend on the Pecos River, bypassing Laguna Grande. This flow path would have obvious advantages for the DOE: it is 20 miles from the WIPP site boundary to Malaga Bend along this path, compared to 12.5 miles as the crow flies; it runs through areas of low Culebra conductivity for up to 7.85 miles from the WIPP site boundary; and it bypasses Nash Draw.

### DATA FOR DOE FLOW PATH FROM WIPP SITE TO MALAGA BEND

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<th>head (ft)</th>
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<th>NaCl (mg/l)</th>
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The geochemistry of Culebra water is inconsistent with southerly flow from the WIPP site. Dissolved halite (sodium and chloride) decreases by a factor of 1300 along the assumed flow path, and the principal mineral constituents change to gypsum (calcium and
sulfate). More importantly, the geochemistry is inconsistent with the concept of the Culebra dolomite as a confined aquifer, bounded above and below by impermeable layers, and containing only fossil water left over from the Ice Ages. Siegel and Anderholm (1994) state that "no plausible geochemical process has been identified that would cause this transformation in a hydrologically confined unit." According to Chapman (1989), the only plausible mechanism is rainwater recharge. DOE has yet to present a flow path that is consistent with the geochemistry.

Dissolved sodium and chloride in Culebra groundwater are given in Table 1. When these levels are plotted on a map (Figure 1), and contour lines are drawn, it is shown that the concentration of dissolved halite in Culebra groundwater decreases steadily from east to west across the WIPP site. This should demonstrate that Rustler groundwater is not old, and that fresh water recharge is occurring. Water saturated with halite, incapable of dissolving significantly more halite, contains approximately 318,000 mg/l of dissolved sodium and chloride (EEG-31, 1985). Within one mile of the WIPP site, the highest reliable measurements of dissolved halite in Culebra groundwater, at test well H-5b, range from 124,100 to 139,000 mg/l, well below saturation.

In the Rustler Formation, there has been extensive dissolution of halite across the WIPP site. This interpretation is supported by Powers et al. (1978), Gibbons and Ferrall (1980), Barrows (1982), Borrs et al. (1983), Barrows et al. (1983), Mercer (1983), Lambert (1983), Chaturvedi and Rehfeldt (1984), Bachman (1984), Snyder (1985), Chaturvedi and Channell (1985), Lowenstein (1987), Chapman (1988), Brinster (1991), and Anderson (1994). An isopach map of the Rustler Formation (Borns et al., 1983, Figure 2-25) shows a westward thinning of the Rustler from 460 feet at P-18, 0.86 miles east of the WIPP site, to 277 feet at WIPP-33, 0.54 miles west of the WIPP site. Borehole data show a downward and westward drop in the position of uppermost halite remaining in the Rustler Formation. This is attributed to downward and eastward progression of dissolution in the Rustler (Barrows, 1982), first and most extensively from the Forty-Niner member, then from the Tamarisk member, and finally from the lower unnamed member only in the west. The Magenta and Culebra dolomite members are disrupted and fractured as halite is removed from beneath them; as a result they become more transmissive to groundwater, which in turn accelerates the process of dissolution. The process "feeds upon itself." (Snyder, 1985)

When the progression of halite dissolution is plotted on a map, along with the distribution of salinity in Culebra groundwater [Figure 2], it is shown that some test wells contain dissolved halite in Culebra groundwater where there is no halite in the Rustler. These wells (e.g. H-6, P-14, WIPP-25, WIPP-26) are located west of the Rustler "dissolution front." If groundwater is supposed to be flowing from north to south, as DOE contends,
<table>
<thead>
<tr>
<th>Well</th>
<th>TDS</th>
<th>NaCl</th>
<th>CaSO4</th>
</tr>
</thead>
<tbody>
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<td>8,180</td>
</tr>
<tr>
<td>H-2</td>
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<td>H-3</td>
<td>51,700</td>
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<td>5,960</td>
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<td>H-5</td>
<td>135,000</td>
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<td>1,170</td>
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<td>H-6</td>
<td>52,000</td>
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</tr>
<tr>
<td>H-7</td>
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<td>7,200</td>
</tr>
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<td>Engle</td>
<td>3,000</td>
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</tr>
</tbody>
</table>

Sources: Mercer, 1983 (USGS-WRI 83-4016, Table 8); Ramey, 1985 (EEG-31); Chapman, 1988 (EEG-39); Lappin et al., 1989 (SAND 89-0462, Table 3-12); DOE/CAO 1996-2184, Appendix USDW, Table USDW-2; Annual Site Environmental Reports, 1992-1995.
FIGURE 1: DISSOLVED HALITE IN CULEBRA (mg/l)

CONTOUR INTERVAL 20,000 mg/l

MILES

N

LIVINGSTON RIDGE

11,800

13,400

18,100

18,100

11,800

560

124,100

100,000

92,650

101,900

90,000

80,000

80,000

71,400

60,000

60,000

57,750

45,300

0

20,000

20,000

18,800

WIPP SITE BOUNDARY

CONTour INTERVAL 20,000 mg/l
FIGURE 2: TOP OF SALT IN RUSTLER

- 13,400 mg/l NaCl in Culebra
- 18,100 mg/l NaCl in Culebra
- 45,300 mg/l NaCl in Culebra
- H-3
- TRANSPORTED HALITE IN CULEBRA WATER
- ANOMALOUS BOREHOLE:
  - NO HALITE IN RUSTLER

WIPP SITE BOUNDARY
OLD WIPP SITE BOUNDARY
WIPP-14
WIPP-33
how then did dissolved halite appear in these test wells? It could not have come from the brine aquifer at the top of the Salado salt formation, because its hydraulic head is less than that of the Culebra at all four of these wells [Table 2]. There is no halite in the Rustler to the north and west of these wells. There is halite in the Rustler only to the east, which requires a westerly component to groundwater flow.

The actual groundwater flow paths from the WIPP site to the environment are governed by three processes: (1) Water follows the path of least resistance, consistent with the gradient. Because dissolution proceeds fastest where velocities are greatest and salinities are lowest, open channels have been observed to form near discharge areas of a groundwater flow system, connecting to sinkholes, and eroding upgradient to places of greatest recharge. (2) The flow path must be consistent with groundwater geochemistry, taking three-dimensional flow into account. (3) Water flows downgradient in isotropic (unfractured) regions of the Culebra, but may flow at an increasingly acute angle to the contours in anisotropic (fractured to channeled) regions. Only if the geometry of the fractures or solution channels is known, can the flow direction be deduced from the gradient.

In karst, the paths of least resistance are solution-enlarged fractures and underground caverns. At WIPP, such paths are suggested by multi-well pump tests which showed some test wells to be interconnected by networks of open fractures, and by caliper logs and lithological descriptions which showed unconsolidated or cavernous zones in the Rustler Formation.

The most useful indicators of groundwater flow direction are measurements of hydraulic head (the level to which water rises in a cased well). In porous isotropic rocks like sandstone, water flows uniformly or radially downgradient, from higher to lower hydraulic heads. In soluble anisotropic rocks like gypsum and dolomite, water flows preferentially through discrete underground channels, rather than through the surrounding undissolved rock. However, if karst groundwater flow paths can be identified, say by dye-tracing or morphology, then the hydraulic heads will confirm which direction the groundwater flows along these paths.

Groundwater geochemistry is an indicator of the sense of the flow direction but not the flow path. The flow path must be consistent with groundwater geochemistry. The changes in geochemistry along the flow path must be explainable.

At WIPP, hydraulic heads were measured for the Culebra dolomite at 32 test wells, and for the Magenta dolomite at 16 test wells. Hydraulic heads were measured for the brine aquifer at the top of the Salado Formation at 11 test wells, and for the Forty-Niner
### TABLE 2. COMPARISON OF FRESH WATER HYDRAULIC HEADS, MEASURED IN FEET ABOVE SEA LEVEL

<table>
<thead>
<tr>
<th>Well</th>
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<th>Culebra</th>
<th>Magenta</th>
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<td></td>
<td>3159</td>
<td></td>
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<td>&gt;3129</td>
<td>3031</td>
<td>3152</td>
<td></td>
</tr>
<tr>
<td>H-3</td>
<td>3008</td>
<td>3152 *</td>
<td>3126</td>
<td></td>
</tr>
<tr>
<td>H-4</td>
<td>2995</td>
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<td>3146</td>
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<td>3057</td>
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<tr>
<td>H-14</td>
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<td>3109</td>
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</tr>
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<tr>
<td>H-16</td>
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<td>3116 *</td>
<td>3106</td>
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</tr>
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<td>3054</td>
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<td>3067</td>
<td>3126</td>
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<td></td>
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<tr>
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<td>&lt;3162</td>
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</tr>
<tr>
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<tr>
<td>Cabin Baby</td>
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</table>

Source: Lappin et al., 1989 (SAND 89-0462), Tables 3-6, 3-8, 3-10, 3-11.

Notes: Magenta was dry at H-7, WIPP-26, WIPP-28; not present at WIPP-29 (Mercer, 1983, Table 7).

Note: Synoptic data is difficult to assemble from the various sources of data presented in the Application.
member of the Rustler Formation at 4 test wells; measurements for the other members of the Rustler are nonexistent [Table 2]. However, a partial data set is better than none.

The data show that, in most places, water from the Magenta dolomite is able to infiltrate downward into the Culebra dolomite. This is possible when the hydraulic head for the Magenta is higher than the hydraulic head for the Culebra. In some places (e.g. H-6, WIPP-25), water from the Culebra is able to rise into the Magenta, due to higher heads. [These instances are denoted with asterisks in Table 2]. The data also show that water from the Magenta is able to rise into the Forty-Niner everywhere that hydraulic head in the Forty-Niner was measured.

It has been known for years that the Magenta and the Culebra are hydraulically connected (equal heads) at test well H-6, in the northwest corner of the WIPP site, "and thus the water flowing into Laguna Grande de la Sal and the Pecos River may not be identified as belonging to a particular zone of the Rustler Formation." In the absence of data, it is not known where the Magenta and the Culebra lose their hydrologic isolation from each other (EEG-32, 1985; EEG-61, 1996).

At test wells H-1, H-2 and H-3, clustered near the center of the WIPP site, the Magenta and the Culebra are separate hydrologic units; the hydraulic heads indicate that rainwater is able to infiltrate downward from the Magenta to the Culebra. This is consistent with low total dissolved solids (TDS) at H-2, where Culebra water is potable (8890 mg/l TDS), and with washouts or loss of core in Tamarisk gypsum, between the Magenta and Culebra, at H-1, H-2, H-3 and ERDA-9. This is within the recharge area for the Dewey Lake Redbeds and the Rustler Formation.

### DATA FOR DEWEY LAKE AND RUSTLER RECHARGE AREA

<table>
<thead>
<tr>
<th>test well</th>
<th>conduct. (ft/day)</th>
<th>head Cul.</th>
<th>head Mag.</th>
<th>TDS (mg/l)</th>
<th>NaCl (mg/l)</th>
<th>CaSO4 (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-2</td>
<td>.032</td>
<td>3031</td>
<td>3152</td>
<td>8890</td>
<td>4835</td>
<td>3303</td>
</tr>
<tr>
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<tr>
<td>H-3</td>
<td>.86</td>
<td>3008</td>
<td>3152</td>
<td>51700</td>
<td>39700</td>
<td>5960</td>
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</tbody>
</table>

From H-3 there is a southeastward direction of superior hydraulic connection, through DOE-1 and H-11. These three test wells were shown by multi-well pump tests to be hydraulically connected, perhaps through a network of open fractures in the Culebra (Beauheim, 1989). These could be karst channels in the Rustler. It is a zone of anomalously high hydraulic conductivity in the Culebra (0.86 ft/day at H-3, 1.5 ft/day at DOE-1, 1.7 ft/day at H-11). As the first manifestation of dissolution in the Culebra...
is probably the removal of gypsum from the fractures, the areal distribution of transmissibility may be directly related to removal of such fillings. Directional properties may be due to preferential dissolution along one set of fractures versus another set of different orientation. Alternatively, the directional feature may be a karst channel, adjacent to which the fracture fillings are more fully removed. Suggestive of karst development, there were washouts and loss of core at H-3 and H-11 in the Forty-Niner and the lower unnamed members. The lithologic description for DOE-1 is unreliable, with the Culebra 100 feet out of place; however, at potash test hole P-4, located 880 feet west of DOE-1, water was encountered in the lower unnamed member, 48 feet below the Culebra. A flow path along this trend would be consistent with hydraulic heads in the Culebra, which drop steadily from H-3 (3008 ft) to DOE-1 (3001 ft) to H-11 (2995 ft).

West of H-11 there is a linear surface depression with sinkholes and disrupted drainage patterns, strikingly similar to those in Nash Draw. The depression is four miles long and up to 7000 feet wide, and is plainly visible in the WIPP site air photos. Its southern margin follows Livingston Ridge from the Gnome site turnoff to the WIPP site turnoff, extends alongside the James Ranch dune field, and reaches within 2000 feet of test well P-17, where water was encountered in the lower unnamed member, 17 feet below the Culebra. When this east-west trending depression first approaches Livingston Ridge, at a point 2.1 miles west of P-17, it connects to Nash Draw through a northeast-southwest karst trench, 0.5 miles long, walled by high dunes, that is plainly visible in the WIPP site air photos. Within Nash Draw, a north-south trench follows the base of Livingston Ridge for 0.8 miles. Here it joins an east-west trench, 1.2 miles long, that connects with test well H-7; drilled into a sink, H-7 encountered one cave in the Dewey Lake Redbeds and five caves in the Culebra dolomite. This karst trench is generally 100 to 300 feet wide. If such a surficial trench, having three segments of differing orientation, is indicative of one or more subsurface solution channels, it may connect, through courses unknown, to Laguna Grande de la Sal.

Until groundwater flow reaches H-7, it passes through an area where there is residual halite in the Rustler, at least in the lower unnamed member. This would account for the large amounts of sodium and chloride upgradient, especially at DOE-1 and H-11. Hydraulic conductivity at P-17 is not high (.074 ft/day), but this test well probably missed the active solution conduits; hydraulic conductivity at H-7 is very high (at least 31.0 ft/day), and represents karst conditions. At H-7 the Culebra sequence is 46.0 ft thick (24.3 ft of dolomite, 21.7 ft of caverns); the transmissivity is 1430 ft²/day, the highest of any WIPP test well. The hydraulic heads at H-11, P-17 and H-7 are equal (2995 ft), implying a region of such high transmissibility that a high gradient is not needed to drive groundwater flow.
Northward from the recharge area there may be a trend of preferential flow that extends through the ventilation shaft, thence to H-16, H-18, and WIPP-13. There were washouts and loss of core at all three test wells; in the ventilation shaft there were five washouts where steel liner plates were installed to prevent further caving of the shaft wall. At H-16, heads in the Culebra (3005 ft) and Magenta (3116 ft) are lower than in the recharge area. At H-18, head measurements are not available. A solution channel must underlie WIPP-13, where the hydraulic head in the Culebra is 3064 feet above sea level and the Culebra is hydraulically connected to the Magenta; (hydraulic heads in the Magenta should confirm this, but the data are not available).

A chain of topographic depressions suggestive of an underlying flow channel can be seen in the WIPP site air photos, snaking through the WIPP-14 sinkhole, where 71.4 feet of mud with gypsum and anhydrite fragments was found below the Culebra. This path may continue westward to WIPP-34 and DOE-2; there was loss of core in the Forty-Niner and lower unnamed members in both boreholes, and loss of circulation of drilling fluid in the Dewey Lake Redbeds at DOE-2. Here, at DOE-2, the path would intercept a network of open fractures which were shown by multi-well pump tests to be hydraulically connected to WIPP-13 and H-6 (Beauheim, 1986). These could be karst channels in the Rustler. This is a zone of high hydraulic conductivity (4.0 ft/day at DOE-2, 3.1 ft/day at WIPP-13, 3.2 ft/day at H-6). Both of these trends which may merge at WIPP-13 pass through areas where there is residual halite in the Rustler Formation; this is consistent with the elevated levels of dissolved halite at WIPP-13.

Multi-well pump testing revealed that WIPP-13 is hydraulically connected to H-6, where the hydraulic heads for the Magenta and the Culebra are equal. Thus, the Rustler aquifer may include both of these dolomites as one. From H-6 at the northwest corner of the WIPP site, it takes little imagination to see a connection to WIPP-33, 0.84 miles to the southwest. The most likely flow path lies beneath an east-west trend of three smaller sinkholes, two of which have swallowed surface water carried by arroyos (Phillips, 1987, pp. 82-86). At WIPP-33, five nested caverns, all filled with water, were found within a 110-foot section of Dewey Lake siltstone, Forty-Niner gypsum, and Magenta dolomite, indicating the thickness of the karst aquifer there. The flow may continue from WIPP-33 to the vicinity of WIPP-25, 2.0 miles west of WIPP-33 in Nash Draw, where gypsum spring deposits at the surface are evidence of groundwater discharge in the geologic past, when the water table was higher (Bachman, 1985). Water in this karst aquifer would continue to Laguna Grande de la Sal.

A flow path from WIPP-13 to WIPP-25 would be consistent with hydraulic heads in the Rustler, which drop steadily from WIPP-13 (3064 ft) to H-6 (3057 ft) to WIPP-25 (3054 ft). No hydrologic
data were taken at WIPP-33. Between WIPP-13 and H-6 the flow path enters the region where no halite remains in the Rustler; this is a possible explanation for the steadily decreasing levels of dissolved salt from WIPP-13 to WIPP-25. The evident recharge of fresh water through sinkholes is also sufficient explanation.

### DATA FOR POSSIBLE GROUNDWATER FLOW PATHS

<table>
<thead>
<tr>
<th>test well</th>
<th>conduct. (ft/day)</th>
<th>head (mg/l)</th>
<th>head (mg/l)</th>
<th>TDS (mg/l)</th>
<th>NaCl (mg/l)</th>
<th>CaSO4 (mg/l)</th>
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<tbody>
<tr>
<td>H-3</td>
<td>0.86</td>
<td>3008</td>
<td>3152</td>
<td>51700</td>
<td>39700</td>
<td>5960</td>
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<tr>
<td>DOE-1</td>
<td>1.5</td>
<td>3001</td>
<td>N.D.</td>
<td>111000</td>
<td>101900</td>
<td>7260</td>
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<tr>
<td>H-11</td>
<td>1.7</td>
<td>2995</td>
<td>N.D.</td>
<td>110000</td>
<td>92650</td>
<td>7620</td>
</tr>
<tr>
<td>P-17</td>
<td>0.074</td>
<td>2995</td>
<td>N.D.</td>
<td>81200</td>
<td>71400</td>
<td>6700</td>
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<td>H-7</td>
<td>3.1</td>
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<td>N.D.</td>
<td>3200</td>
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<td>2490</td>
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<td>DOE-2</td>
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<td>3067</td>
<td>3182</td>
<td>57800</td>
<td>50200</td>
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<td>WIPP-13</td>
<td>11.0</td>
<td>3054</td>
<td>3054</td>
<td>17000</td>
<td>13400</td>
<td>3320</td>
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</tbody>
</table>

In a semiarid karst such as Los Medanos (where the WIPP site is located), where 14 to 15 inches of annual precipitation may occur during a few large storms separated by many dry months, the groundwater hydraulics may be wildly transient. In Dalmatia, the classic karst region of Yugoslavia, rapid recharge is known to raise the water table as much as 200 feet, and tracer tests reveal velocities of kilometers per week. In New Mexico, lower episodic rainfall may also produce transients, during which most of the discharge occurs. During the longer periods between storm-flows, the gradients vanish in the major channels, while low-permeability rocks outside the channels drain into them. The task of interpretive non-synoptic piezometry from wells tapping domains of different transient behavior, none of which record the behavior of the major channels, may not be very rewarding, nor can it support realistic models of flow or transport.

In every hydrologic system, groundwater moves inexorably toward regional base level, the lowest point in the watershed. In Nash Draw, the lowest point is Salt Lake, or Laguna Grande de la Sal. Salt lakes are in closed drainage basins, with no outlet at the surface or underground. They lose water only by evaporation, which precipitates salt. At Laguna Grande, groundwater seeps upward into the lake (Robinson and Lang, 1938); this is confirmed at test well WIPP-29, near Laguna Grande, where water from the lower unnamed member is able to rise into the Culebra [Table 2]. Laguna Grande has no outlet, at the surface or underground.
A low, but discernible topographic divide exists between Laguna Grande and Malaga Bend of the Pecos River. This topographic divide is now partly breached by an irrigation canal at an elevation of 2960 feet above sea level. The evaporite crust of Laguna Grande has killed all vegetation up to the same elevation, indicating that 2960 feet above sea level is the high-water mark for Laguna Grande. In times of major flooding, Laguna Grande overflows to the Pecos River (Phillips, 1987, pp. 216-217)

The evidence supports a conclusion that flow paths from the WIPP site are predominantly directed to Nash Draw along karst channels or fracture system enlargements. These observations indicate that the Rustler is not a barrier to rapid transport from the WIPP site to the accessible environment.
CAVERNOUS ZONES AT THE WIPP SITE

by Richard Hayes Phillips, Ph.D.

The Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico, is intended for the permanent disposal of radioactive waste from nuclear weapons production. The project is the brainchild of the United States Department of Energy (DOE). The waste is to be buried in steel drums and plywood boxes in direct contact with salt beds of the Salado Formation. The project lacks engineered barriers; it is the rocks themselves -- the Salado Formation and the aquifers of the overlying Rustler Formation and Dewey Lake Redbeds (shown in cross-section in Figure 1) -- which are intended to be the effective barriers to radionuclide migration.

The Culebra dolomite member of the Rustler Formation has long been recognized as the most likely pathway for contaminated water to travel from the WIPP site to the accessible environment. The Culebra dolomite is not a porous, homogeneous medium; groundwater does not move uniformly and predictably through interconnected pore spaces in the rocks. The Culebra, in most places, is highly fractured, and the effective groundwater flow paths are through the largest fractures, the paths of least resistance.

Dolomite is a soluble rock; it slowly dissolves when exposed to fresh water. As fractures become enlarged by solution, they become even more effective groundwater flow paths. Over time, more and more groundwater flows through fewer and fewer solution-enlarged fractures. Ultimately, these solution conduits become underground caverns, capable of carrying groundwater quite rapidly with little resistance. This type of groundwater hydrology is known by geologists, world-wide, as karst.

The problem with karst as a waste-disposal environment is that some radionuclides may travel unretarded, at the speed of water. The larger the aperture, or diameter, of the solution conduits, the less contact the radionuclides will have with the surrounding rock, and the less the amount of radionuclide retardation. The ability of the Rustler Formation to retard significantly the migration of radionuclides depends upon the absence of karst conditions, of channelized flow, at the WIPP site.

Recent pumping tests at hydrologic test wells in Culebra dolomite at the WIPP site (Beauheim, 1986; Beauheim, 1989) have resulted in unexpectedly short response times between certain test wells. For example, when water was pumped from test well DOE-2, there was a drop in water level within two hours at test well WIPP-13, which is 4835 feet from DOE-2. Test well H-6, which is 10,150 feet from DOE-2, responded within one day. Other test wells, no farther away (e.g. WIPP-12, WIPP-18 and H-5), showed no response at all. This indicates that DOE-2, WIPP-13 and H-6, in the
FIGURE 1: GEOLOGIC CROSS-SECTION THROUGH THE WIPP SITE
northern part of the WIPP site, are hydraulically connected by channelized flow in the Culebra dolomite. Similar results indicate a hydraulic connection between test wells H-3, DOE-1 and H-11 in the southeastern part of the WIPP site, with measurable response at test wells H-15, H-17, P-17 and Cabin Baby, and little or no response at test wells H-4, H-12, H-14, P-15 and P-18 [Figure 2]. These hydraulic connections are not necessarily fracture networks, as interpreted by Beauheim (1986, 1989); the response was so rapid that they could be karst channels.

Hydraulic conductivity is the velocity at which water moves through an aquifer. Transmissivity is the rate at which water is transmitted by the aquifer; it is equal to hydraulic conductivity times the thickness of the aquifer. The highest measured values for transmissivity and hydraulic conductivity in the Culebra dolomite aquifer at WIPP test wells are given in Table 1.

It has long been recognized that, in the Culebra dolomite, transmissivity varies by five orders of magnitude in the vicinity of the WIPP site, from 0.002 ft²/day at test well P-18, located 4547.3 feet east of the WIPP site, to 233.0 ft²/day at test well P-14, located 4664.2 feet west of the WIPP site (Haug et al., 1987). It is often represented that transmissivity in the Culebra dolomite increases steadily from east to west, but this is not the case. When measurements of transmissivity in the Culebra dolomite are plotted on a map [Figure 3], contour lines cannot be drawn, not even on a logarithmic scale. Rather, it becomes apparent that, among test wells within one mile of the WIPP site, seven test wells show anomalously high transmissivity in the Culebra dolomite, one to three orders of magnitude higher than in any others. These test wells include, besides P-14, the very six test wells shown by pumping tests to be hydraulically connected (DOE-2, WIPP-13, H-6; H-3, DOE-1 and H-11).

Anomalously high transmissivity in some boreholes is exactly what one would expect in a karstland. A borehole which misses one of the active solution conduits should show values which are much less than the average. This applies to almost all boreholes in a karstland because the area of active solution conduits is only a small part of the total area. It is possible, indeed likely, that none of the measured transmissivities within one mile of the WIPP site are representative of karst conditions in the Culebra dolomite, because none of these test wells were reported to have encountered cavernous zones in the Culebra.

However, cavernous zones were encountered at WIPP-33, a borehole located 2753.4 feet west of the WIPP site. There were five caverns in all: four in the Rustler Formation (two in Magenta dolomite, two in Forty-Niner gypsum), and one in the Dewey Lake Redbeds. The caverns were inferred by: (1) a precipitous drop of the drilling equipment (zero minutes per vertical foot); (2) a loss of circulation of drilling fluid; and (3) no core recovery.
FIGURE 2: RESULTS OF MULTI-WELL PUMP TESTS
<table>
<thead>
<tr>
<th>test well</th>
<th>transmissivity</th>
<th>hydraulic conductivity</th>
<th>source of data</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-1</td>
<td>0.87</td>
<td>0.038</td>
<td>LaVenue et al. (1989)</td>
</tr>
<tr>
<td>* H-2</td>
<td>0.70</td>
<td>0.032</td>
<td>Beauheim (1989)</td>
</tr>
<tr>
<td>* H-3</td>
<td>19.0</td>
<td>0.86</td>
<td>Mercer (1983)</td>
</tr>
<tr>
<td>* H-4</td>
<td>1.1</td>
<td>0.046</td>
<td>Haug et al. (1987)</td>
</tr>
<tr>
<td>* H-5</td>
<td>0.2</td>
<td>0.009</td>
<td>Mercer (1983)</td>
</tr>
<tr>
<td>* H-6</td>
<td>74.0</td>
<td>3.2</td>
<td>LaVenue et al. (1988)</td>
</tr>
<tr>
<td>H-7</td>
<td>1430.0</td>
<td>31.0</td>
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</tr>
<tr>
<td>H-8</td>
<td>16.0</td>
<td>0.59</td>
<td>Mercer (1983)</td>
</tr>
<tr>
<td>H-9</td>
<td>231.0</td>
<td>7.7</td>
<td>Mercer (1983)</td>
</tr>
<tr>
<td>* H-10</td>
<td>0.07</td>
<td>0.002</td>
<td>Mercer (1983)</td>
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<tr>
<td>* H-11</td>
<td>43.0</td>
<td>1.7</td>
<td>Beauheim (1989)</td>
</tr>
<tr>
<td>* H-12</td>
<td>0.18</td>
<td>0.007</td>
<td>LaVenue et al. (1989)</td>
</tr>
<tr>
<td>* H-14</td>
<td>0.31</td>
<td>0.013</td>
<td>LaVenue et al. (1988)</td>
</tr>
<tr>
<td>* H-15</td>
<td>0.13</td>
<td>0.005</td>
<td>Beauheim (1987)</td>
</tr>
<tr>
<td>* H-16</td>
<td>0.80</td>
<td>0.037</td>
<td>Beauheim (1987)</td>
</tr>
<tr>
<td>* H-17</td>
<td>0.22</td>
<td>0.009</td>
<td>Beauheim (1987)</td>
</tr>
<tr>
<td>* H-18</td>
<td>2.0</td>
<td>0.08</td>
<td>Beauheim (1987)</td>
</tr>
<tr>
<td>P-14</td>
<td>233.0</td>
<td>10.6</td>
<td>Haug et al. (1987)</td>
</tr>
<tr>
<td>* P-15</td>
<td>0.09</td>
<td>0.004</td>
<td>LaVenue et al. (1988)</td>
</tr>
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<td>* P-17</td>
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<td>0.074</td>
<td>Haug et al. (1987)</td>
</tr>
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<td>0.00007</td>
<td>Haug et al. (1987)</td>
</tr>
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<td>* WIPP-12</td>
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<td>Beauheim (1987)</td>
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<td>69.0</td>
<td>3.1</td>
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<td>0.014</td>
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<td>0.026</td>
<td>LaVenue et al. (1988)</td>
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<tr>
<td>* WIPP-21</td>
<td>0.25</td>
<td>0.010</td>
<td>LaVenue et al. (1988)</td>
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<td>* WIPP-22</td>
<td>0.37</td>
<td>0.017</td>
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<td>WIPP-25</td>
<td>270.0</td>
<td>11.0</td>
<td>Mercer (1983)</td>
</tr>
<tr>
<td>WIPP-26</td>
<td>1250.0</td>
<td>54.3</td>
<td>Mercer (1983)</td>
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<td>WIPP-27</td>
<td>650.0</td>
<td>25.0</td>
<td>Mercer (1983)</td>
</tr>
<tr>
<td>WIPP-28</td>
<td>18.0</td>
<td>0.69</td>
<td>Mercer (1983)</td>
</tr>
<tr>
<td>WIPP-29</td>
<td>1000.0</td>
<td>33.3</td>
<td>Mercer (1983)</td>
</tr>
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<td>WIPP-30</td>
<td>0.3</td>
<td>0.013</td>
<td>Mercer (1983)</td>
</tr>
<tr>
<td>AEC-7</td>
<td>0.26</td>
<td>0.010</td>
<td>LaVenue et al. (1989)</td>
</tr>
<tr>
<td>* DOE-1</td>
<td>33.0</td>
<td>1.5</td>
<td>Haug et al. (1987)</td>
</tr>
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<td>* DOE-2</td>
<td>89.0</td>
<td>4.0</td>
<td>LaVenue et al. (1988)</td>
</tr>
<tr>
<td>* ERDA-9</td>
<td>0.47</td>
<td>0.020</td>
<td>LaVenue et al. (1988)</td>
</tr>
<tr>
<td>D-268</td>
<td>1.9</td>
<td>0.020</td>
<td>LaVenue et al. (1988)</td>
</tr>
<tr>
<td>* Cabin Baby</td>
<td>0.28</td>
<td></td>
<td>LaVenue et al. (1988)</td>
</tr>
<tr>
<td>Engle</td>
<td>43.0</td>
<td>0.04</td>
<td>LaVenue et al. (1988)</td>
</tr>
<tr>
<td>USGS-1</td>
<td>515.0</td>
<td>11.0</td>
<td>LaVenue et al. (1988)</td>
</tr>
</tbody>
</table>

* Test wells located at or within one mile of the WIPP site.
FIGURE 3: CULEBRA TRANSMISSIVITY, ft$^2$/day

- ANOMALOUS BOREHOLES
- KARST SINK HOLES

Legend:
- Circle with number: Transmissivity value in ft$^2$/day
- WIPP Site Boundary

Scale:
- 0 - 2 miles

Locations:
- LIVINGSTON RIDGE
- O 270
- O 233
- O 19
- O 1250
- O 1430
A camera was then lowered into the borehole, which confirmed the presence of underground caverns. If cavernous zones are present in other WIPP boreholes, the same three criteria should apply. Unfortunately, an examination of the geophysical logs and lithologic descriptions for other WIPP boreholes reveals that the first two criteria -- drilling time and lost circulation -- are rarely noted. Nor can cavernous zones in the Culebra and Magenta dolomite members of the Rustler Formation be detected by a lack of core recovery alone, because the Culebra and Magenta are typically fractured, which makes core recovery difficult. However, a correlation of geophysical logs and lithologic descriptions does reveal a consistent lack of core recovery at two other stratigraphic horizons in the Rustler Formation:

(1) A zone of solution residue characterized by soft reddish-brown siltstone or mudstone with gypsum-filled voids and clasts of brecciated gypsum and anhydrite. This zone grades downward into a greenish claystone separated from the Magenta dolomite by 13.9 to 18.7 feet of anhydrite or gypsum. In the WIPP ventilation shaft this zone is 6.7 feet thick; it washed out 2.5 feet deep into the shaft wall; water seeps into the shaft at this level; and a ten-foot steel liner plate was installed to prevent further caving of the shaft wall.

(2) A zone of solution residue consisting of claystone or mudstone, gray to dark reddish-brown, with brecciated anhydrite clasts, gypsum crystals, and gypsum-filled fractures; poorly consolidated, and readily crumbled. The claystone grades upward into a layer of soft shale, black to dark gray, immediately beneath the Culebra dolomite. In the WIPP ventilation shaft this zone is 7.1 feet thick; it washed out into the shaft wall; water seeps into the shaft at this level; and a ten-foot steel liner plate was installed to prevent further caving of the shaft wall.

Note that the first zone is in the Forty-Niner member of the Rustler Formation; the second zone is in the lower unnamed member of the Rustler Formation; and both zones produce water, at least in the WIPP ventilation shaft. This is direct evidence that no member of the Rustler Formation is impermeable, that the Magenta dolomite and Culebra dolomite are not confined aquifers. This substantiates the findings of Ferrall and Gibbons (1980), who examined available cores of the Rustler Formation and observed high-angle to near-vertical fractures in each member.

If these zones appeared only in the WIPP ventilation shaft, or elsewhere but rarely, it might be reasonable to regard them as "washed out zones" attributable to drilling fluid. However, both of these zones can be correlated across the WIPP site, with a consistent lack of core recovery. Both zones are poorly consolidated, probably transmissive, and possibly cavernous.
In the zone above the Magenta dolomite there was loss of core, washout, and/or loss of circulation at H-17, H-11b3, H-3b3, H-1, WIPP-19, WIPP-12, DOE-2, WIPP-34, H-16, H-18, and WIPP-33. In the zone below the Culebra dolomite there was loss of core or cuttings at H-11b3, H-3b3, P-1, H-14, H-15, H-18, P-12, WIPP-13, WIPP-11, DOE-2, WIPP-34, and WIPP-14. Detailed summaries of these cavernous encounters, compiled almost entirely from geophysical logs and lithologic descriptions, with occasional reliance on Chaturvedi and Channell (EEG-32, 1985), are given in Tables 2 and 3. The boreholes are mapped in Figure 4.

Dissolution residue was reported in the Forty-Niner member, within 15 to 18 feet of the Magenta, but with no loss of core, at ERDA-9, WIPP-18, WIPP-19, WIPP-21, WIPP-22, and WIPP-13. Dissolution residue was reported in the lower unnamed member, within 2 to 4 feet of the Culebra, but with no loss of core, at ERDA-9, WIPP-18, WIPP-21, WIPP-22, H-6, and WIPP-33.

All the boreholes listed above are located at the WIPP site or within one mile of the WIPP site. In addition, at borehole H-7c, located 2.9 miles southwest of the WIPP site in Nash Draw, there was loss of core at 273.5 to 280.0 feet below the land surface, immediately below the Culebra dolomite. At borehole WIPP-25, located 2.5 miles west of the WIPP site in Nash Draw, there was lost circulation of drilling fluid at 522 to 526 feet below the land surface, within a 20.6-foot section of mud in the lower unnamed member of the Rustler Formation.

There is another dissolution zone in the Tamarisk member of the Rustler Formation. Four boreholes clustered near the center of the WIPP site have encountered washouts or loss of core in Tamarisk anhydrite: at H-1 (650.0-653.5 feet below land surface, 22.5 feet above Culebra); at H-2a (593.0-606.0 feet below land surface, 17.0 feet above Culebra); at H-3b3 (645.5-652.5 feet below land surface, 19.5 feet above Culebra); and at ERDA-9 (690.0-698.0 feet below land surface, 6.0 feet above Culebra). At the same horizon in the Tamarisk member, dissolution residue was encountered in the WIPP ventilation shaft and along two paths leading away from ERDA-9: northward at WIPP-21, WIPP-22, WIPP-19 and WIPP-18, and northwestward at H-18, WIPP-13 and H-6.

Caverns are known to occur in the Dewey Lake Redbeds as well. The lithologic log for borehole H-7c reports "boulders caving in" at 59 feet below the land surface. Lost circulation of drilling fluid in the Dewey Lake Redbeds has been reported at H-7c (24 feet above the Rustler), at WIPP-33 (37 feet above the Rustler), at WIPP-25 (124 to 154 feet above the Rustler), at P-1 (180 feet above the Rustler), and at DOE-2 (400 feet above the Rustler).

This correlation of cavernous zones raises two questions: (1) are karst conditions expressed at the land surface; and (2) if so, is WIPP hydrologic data representative of karst conditions?
TABLE 2: CORRELATED EVIDENCE OF CAVERNOUS ZONE, FORTY-NINER MEMBER, RUSTLER FORMATION

H-17:
"no recovery," 7.2 ft, claystone, 542.9-550.1 ft below surface, 13.9 ft above Magenta

H-11b3:
"no recovery," 6.2 ft, claystone, 595.7-601.9 ft below surface, 21.0 ft above Magenta

H-3b3:
"washed out zone," 2.5 ft, mudstone, on caliper log, 536.5-539.0 ft below surface, 20.0 ft above Magenta

H-1:
"washed out zone," 8.5 ft, mudstone, on caliper log, 538.5-547.0 ft below surface, 16.0 ft above Magenta; loss of circulation of drilling fluid

VENTILATION SHAFT:
"deep washout," 6.7 ft, mudstone, first liner plate, 569.2-575.9 ft below surface, 20.2 ft above Magenta

WIPP-19:
"no core," 2.1 ft, mudstone, 620.2-622.3 ft below surface, 25.5 ft above Magenta

WIPP-12:
"no core," 6.0 ft, clay, 678.7-684.7 ft below surface, 19.2 ft above Magenta

DOE-2:
"no core," 2.5 ft of 10.2 ft interval, mudstone/siltstone, 669.8-680.0 ft below surface, 18.6 ft above Magenta

WIPP-34:
"no core," 2.7 ft, mudstone, 691.0-693.7 ft below surface, 22.1 ft above Magenta

H-16:
"no recovery," 2.5 ft, clay, 566.8-569.3 ft below surface, 20.9 ft above Magenta

H-18:
"no recovery," 7.1 ft, clay, 542.2-549.3 ft below surface, 21.9 ft above Magenta

WIPP-33:
"cavity; determined by drop of drill string during drilling and through interpretation of caliper log," 9.5 ft, gypsum, 416.5-426.0 ft below surface, 23.0 ft above Magenta

"cavity; no core (drill string dropped), possible cavernous formation," 6.0 ft, gypsum, 430.0-436.0 ft below surface, 13.0 ft above Magenta

ALSO AT WIPP-33:
cavity, 7.0 ft, siltstone, in Dewey Lake Redbeds, (no core, 0.0 min/ft drilling time, lost circulation), 357.0-364.0 ft below surface

"cavity; no core (cavernous)," 2.0 ft, in Magenta dolomite, no circulation for 24 hours, 0.0 min/ft drilling time, 452.0-454.0 ft below surface

"cavity (drill string dropped)" 5.0 ft, in Magenta dolomite, no core, no circulation for 24 hour period, 462.0-467.0 ft below surface
### TABLE 3: CORRELATED EVIDENCE OF CAVERNOUS ZONE, LOWER UNNAMED MEMBER, RUSTLER FORMATION

<table>
<thead>
<tr>
<th>Well</th>
<th>Description</th>
<th>Depth</th>
<th>Below Culebra</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-17</td>
<td>&quot;some rock washed away,&quot; core recovered, 0.8 ft, claystone</td>
<td>733.2-734.0 ft</td>
<td>1.8 ft</td>
</tr>
<tr>
<td>H-11b3</td>
<td>&quot;no recovery (estimated zone of core loss),&quot; 2.6 ft, clay</td>
<td>765.9-768.3 ft</td>
<td>0.4 ft</td>
</tr>
<tr>
<td>H-3b3</td>
<td>&quot;only 20% of the core was recovered,&quot; 5.5 ft, black shale and siltstone, appears on caliper log</td>
<td>691.5-697.0 ft</td>
<td>directly below Culebra</td>
</tr>
<tr>
<td>P-1</td>
<td>&quot;friable&quot; (brittle, readily crumbled), 10.0 ft, mudstone</td>
<td>580.0-590.0 ft</td>
<td>1.0 ft</td>
</tr>
<tr>
<td>H-14</td>
<td>&quot;no recovery,&quot; 4.6 ft, claystone (?)</td>
<td>569.4-574.0 ft</td>
<td>directly below Culebra</td>
</tr>
<tr>
<td>H-15</td>
<td>&quot;no recovery,&quot; 9.2 ft, mudstone</td>
<td>890.8-900.0 ft</td>
<td>5.1 ft</td>
</tr>
<tr>
<td>VENTILATION SHAFT</td>
<td>&quot;washed out zone,&quot; 7.1 ft, mudstone/claystone, third liner plate</td>
<td>727.2-734.3 ft</td>
<td>0.3 ft</td>
</tr>
<tr>
<td>H-16</td>
<td>&quot;washed out core,&quot; 4.0 ft, claystone</td>
<td>725.1-729.1 ft</td>
<td>0.7 ft</td>
</tr>
<tr>
<td>H-18</td>
<td>&quot;no recovery,&quot; 3.6 ft, clay and claystone</td>
<td>713.8-717.4 ft</td>
<td>1.9 ft</td>
</tr>
<tr>
<td>P-12</td>
<td>&quot;no sample,&quot; 5.0 ft, siltstone</td>
<td>660.0-665.0 ft</td>
<td>4.0 ft</td>
</tr>
<tr>
<td>WIPP-13</td>
<td>&quot;no core,&quot; 2.0 ft, mudstone</td>
<td>727.0-729.0 ft</td>
<td>0.1 ft</td>
</tr>
<tr>
<td>WIPP-11</td>
<td>&quot;no core,&quot; 4.5 ft, mudstone</td>
<td>888.0-892.5 ft</td>
<td>8.0 ft</td>
</tr>
<tr>
<td>DOE-2</td>
<td>&quot;no core,&quot; 1.4 ft, mudstone</td>
<td>847.6-849.0 ft</td>
<td>1.6 ft</td>
</tr>
<tr>
<td>WIPP-34</td>
<td>&quot;no core,&quot; 3.5 ft, mudstone</td>
<td>860.8-864.3 ft</td>
<td>directly below Culebra</td>
</tr>
<tr>
<td>WIPP-14</td>
<td>&quot;no core,&quot; 81.4 ft, mud with gypsum and anhydrite fragments (upper 71.4 ft), mud and siltstone (lower 10.0 ft), entire 23.5 ft of Forty-Niner Member; entire 87.2 ft of Tamarisk Member, siltstone, sandstone, anhydrite, clay, gypsum; entire 19.0 ft of Culebra dolomite; 676.3-836.2 ft below surface</td>
<td>836.2-917.6 ft</td>
<td>directly below Culebra</td>
</tr>
</tbody>
</table>

ALSO AT WIPP-14:
"no core," 159.9 ft: siltstone and mudstone (10.7 ft) and gypsum (19.5 ft), lower 30.2 ft of Forty-Niner Member; entire 23.5 ft of Magenta dolomite; entire 87.2 ft of Tamarisk Member, siltstone, sandstone, anhydrite, clay, gypsum; entire 19.0 ft of Culebra dolomite; 676.3-836.2 ft below surface
FIGURE 4: WASHOUTS AND LOSS OF CORE IN RUSTLFR
Every karstland has sinkholes in the land surface. Two types of sinkholes are recognized: (1) collapse sinks, formed when surface rocks collapse abruptly into underground caverns, allowing surface runoff to be swallowed rapidly; and (2) alluvial dolines, or solution-subsidence dolines, formed when surface rocks subside slowly due to solution of underlying rocks; these are flooded after major rainstorms and become filled with alluvial sediments. Collapse sinks are more common where soluble rocks are exposed at the land surface; alluvial dolines are more common where soluble rocks are overlain by sandstones, as at the WIPP site.

West of the WIPP site is Nash Draw, one of the largest karst features with surface expression in the world. Nash Draw is a huge depression, 18 miles long and 10 miles wide, formed by the coalescence of thousands of sink holes. The H-7 test wells were drilled into one of the sinks in Nash Draw; it is located near the western end of an obvious karst valley, walled on both sides by high dunes, and plainly visible in the WIPP site air photos. There are ephemeral watercourses draining into the valley from the sides, but upon entering the valley these watercourses disappear underground. At borehole H-7c a cavern was encountered in the Dewey Lake Redbeds, with lost circulation of drilling fluid and "boulders caving in." The Culebra dolomite was broken into six sections totalling 24.3 feet, separated by five cavities totalling 21.7 feet; this was underlain by 6.2 feet of mud, beneath which there was no core for 80.8 feet. Transmissivity in the Culebra dolomite is 1430 ft²/day, the highest measurement at any of the forty-one WIPP test wells.

The most obvious sinkhole in the WIPP site vicinity is WIPP-33, located in sec 13, T 22 S, R 30 E. It is a closed topographic depression about 700 feet in diameter and 30 feet deep. It is prominent on the WIPP site air photos, and is shown on the USGS topographic maps. One of the few small arroyos in the WIPP site vicinity drains into this depression. It is floored with matted leaves, organic matter and desiccated clay, indicating occasional flooding of the depression. Evidence of surface collapse can be seen in the caliche escarpment at its southeastern rim. Evidence of subsurface collapse was seen in backhoe trenches, where caliche breaks off abruptly, with near-vertical drops of four feet to the sandstone bedrock surface. Joint-controlled solution features were found in carbonate-cemented sandstone beneath the caliche. In the WIPP site gravity survey, a negative gravity anomaly of high amplitude was measured, originating no deeper than the Magenta dolomite. Borehole WIPP-33, drilled into this depression, encountered 44 feet of alluvial fill, and five underground caverns filled with water -- one in Dewey Lake siltstone, two in Forty-Niner gypsum, two in Magenta dolomite. In the Rustler Formation, all anhydrite has been converted to gypsum, and all halite has been dissolved and removed; salt dissolution has also affected the top of the Salado Formation.
Three other sinkholes form a chain trending west-southwestward, directly to WIPP-33, implying an underground flow path beneath them. All are visible in the WIPP site air photos, and all are underlain by structural depressions in the caliche surface. The westernmost sinkhole is 400 feet long, 200 feet wide, 2 to 4 feet deep, is floored by organic debris and desiccated clay, is saturated after rainstorms, contains at least 24 feet of alluvial fill, and swallows some of the water from the WIPP-33 arroyo. The second sinkhole is 300 feet long, 200 feet wide, 8 to 10 feet deep, and is not as well developed, being floored by sand with a weak clay pan and only partly filled with alluvial sediments, although non-incised watercourses are present on its slopes. The easternmost sinkhole is 300 feet long, 150 feet wide, 2 feet deep, is floored by organic debris and desiccated clay, is saturated after rainstorms, contains up to 20 feet of alluvial fill, and has an arroyo disappearing into it. This arroyo formed suddenly during the heavy rains of September 18-19, 1985, only to be swallowed by the sinkhole; this is direct evidence of active karst processes. This same rainstorm filled the WIPP-33 sinkhole with 5.0 feet of standing water, which infiltrated within days.

Another sinkhole in the WIPP site vicinity is WIPP-14, located in sec 9, T 22 S, R 31 E. It is 600 to 700 feet in diameter, 9 feet deep, and is shown on the USGS topographic maps. Draining into the WIPP-14 depression from the east are at least five ephemeral water courses. It is floored by windblown sand, organic debris, and desiccated clay. No collapse is evident at the surface, but such evidence could be obscured by 8 to 15 feet of dune sands that have accumulated on the crests of the depression. It is underlain by a structural depression in the caliche surface, 400 to 650 feet in diameter and 6 feet deep. Gleyed sediments were observed in trench exposures, indicating past ponding, when perched water accumulated in the depression and caliche became extremely leached and degraded, leaving only remnants pockmarked with solution features. Carbonate-filled fractures in Santa Rosa sandstone beneath the caliche are direct evidence of rainwater infiltration. The depression is underlain by a high-amplitude negative gravity anomaly. Borehole WIPP-14, drilled into this depression, encountered 15.4 feet of alluvial fill; there was 243.1 feet of lost core, including 71.4 feet of mud with gypsum and anhydrite fragments directly below the Culebra; halitic mudstone was found in the lower 3.7 feet of the Rustler Formation; all other halite has been dissolved and removed.

There are now 27 hydrologic test wells within one mile of the WIPP site. Six of them (DOE-2, WIPP-13, H-6, H-3, DOE-1, H-11) may be representative of fracture flow in the Culebra, but none are known to be representative of karst conditions. WIPP-33 is located one-half mile from the WIPP site, and WIPP-14 is located within 100 feet of the WIPP site. There is no excuse for not converting these existing boreholes into hydrologic test wells. The simplest explanation is that DOE is not interested in karst.
CONCEPTUAL ERRORS IN THE DOE MODEL
OF GROUNDWATER FLOW IN THE RUSTLER FORMATION

by Richard Hayes Phillips, Ph.D.

Konikow (1996) identified the three most common sources of error in modeling of groundwater flow: (1) conceptual errors; (2) uncertainties in the model; and (3) uncertainties in the data.

These are conceptual errors in DOE's model of groundwater flow in the Rustler Formation at the WIPP site and vicinity:

(1) Darcy's Law should not be applied to a karstland, because groundwater velocity is not proportional to the potentiometric gradient (Barrows, 1982):

In permeable rocks other than those giving rise to karst, the water table parallels the land surface, with somewhat less relief. The potentiometric surface is the level to which groundwater will rise in a cased well. These water levels can be mapped, relative to sea level; and contour lines can be drawn, in accordance with the slope of the water table. Groundwater will flow across the contour lines, generally perpendicular to them; and the more closely spaced the contour lines, the faster the groundwater flows. Velocity is proportional to the permeability times the potentiometric gradient. This is expressed as Darcy's Law, the general hydrogeologic equation (Jennings, 1971).

A water table such as occurs in porous rocks like sandstone does not exist in karst. Wells close together often reach water at very different levels (Sweeting, 1973; Jennings, 1971). Trying to map contour lines is futile. Potentiometric contour lines are not a reliable indicator of groundwater velocity or direction.

(2) The Culebra should not be modeled as a porous homogeneous medium with continuously varying properties (Snow, 1995).

Karstified rocks are not porous homogeneous media (Milanovic, 1976). Primary permeability, which depends on the size and degree of interconnection of the original pore spaces in the rock matrix, is uncommon in karst; secondary permeability, consisting of flow through joints, fractures, solution conduits, caverns, and cave sediments, is much more representative (LeGrand, 1983; Milanovic, 1981). DOE admits that "flow velocities are usually orders of magnitude higher in the fractures than in the matrix" (SEIS, 1996, p. H-24). That is precisely the point. According to Rehfeldt (EEG-27, 1984): "The groundwater travel time in open fractures is very short in comparison to travel time in porous media. Open fractures exist in Nash Draw, at H-6, and are likely present elsewhere at and near the WIPP site." Konikow (1995) regards open fractures in the Culebra as "the most likely fatal flaw in site integrity."
The fracture model should not assume "continuous, isotropic, radial flow in cubically fractured medium." (Lovejoy, 1995)

This is an attempt to model a fractured medium as a homogeneous medium. Fractures are an extreme example of heterogeneity. Fractures are preferential flow paths for water (Konikow, 1996).

Flow in the Culebra is highly anisotropic (varies with direction, has preferred orientation). In the northwest corner of the WIPP site is the H-6 hydro pad, which consists of three wells forming an equilateral triangle, 100 feet on a side. The wells are labeled H6a, H6b, and H6c; a line connecting H6a and H6c is oriented east-west. A convergent tracer test was performed in the Culebra by pumping well H6c and simultaneously introducing tracers into wells H6a and H6b. As reported by Rehfeldt (EEG-27, 1984), "the peak concentration of the H6b tracers arrived 30 times faster and at a concentration 10 times greater than the H6a tracers. Flow in the H6b-H6c direction (150° or 330°) is probably through discrete channels whereas flow in the H6a-H6c direction (90° or 270°) was through the dolomite matrix or through a very tortuous system of fractures."

Dissolution of gypsum filling has opened some fractures in the Rustler Formation, creating "anisotropic fracture permeabilities at least an order of magnitude greater than matrix permeability. ... Throughout the site, flows are concentrated in any such fractures ... Large-aperture solution channels may transect regions of fracture-dominated dolomite (and perhaps anhydrite) devoid of mineral fillings." (Snow, 1995).

The Magenta and Culebra dolomites have been fractured since shortly after their deposition. The impact of this fracture pattern on WIPP geohydrology depends upon the size, angle, length, orientation, spacing and extent of the fractures, the degree and type of fracture filling by groundwater, and the amount of fracture enlargement by solution. The most reliable means of evaluating the fracture pattern would be to collect core samples from a slant drilling program. If angled 45° with respect to the horizontal, and oriented perpendicular to the predicted trends of dominant fracture sets, a three-dimensional record could be obtained (Gibbons and Ferrall, 1980).

DOE should not use "a two-dimensional model where significant flow or transport occurs in the third dimension." (Konikow, 1996)

Traditional "layer-cake" hydrogeology represents aquifers as continuous porous media separated by continuous aquitards or aquicludes (Snow, 1995). "There has been too little accounting for the three-dimensional nature of ground-water flow and consequent leakage through confining layers." The Culebra is one part of a three-dimensional flow system (Konikow, 1996). The Rustler is best characterized as one aquifer with five members.
(5) Borehole data should not be assumed to be representative of hydraulic conditions beyond the immediate vicinity.

In karst, the hydraulic conductivity along solution-enlarged fractures may be three orders of magnitude greater than that of the adjacent unaltered rock (Fetter, 1980). Because the active solution conduits comprise a small part of the total area of the watershed, most boreholes will miss them, and will show values for hydraulic conductivity which are not representative of karst conditions (Bloom, 1978; Barrows, 1982). Borehole measurements may reflect aquifer properties only within the immediate vicinity of the borehole (Konikow, 1995). The technique of interpolation between data points, although useful in porous, homogenous media, should not be applied to a karstland (LeGrand, 1973).

(6) Matrix diffusion in the Culebra dolomite is not a reliable mechanism for the retardation of radionuclide migration.

In rocks with dual porosity, groundwater flows mainly through open fractures in the rock, while some groundwater is diffused through smaller fractures into the rock matrix. This process, known as matrix diffusion, is capable of retarding the migration of radionuclides in groundwater (SEIS, 1996). In karst, however, water flowing through fractures in soluble rocks will enlarge the fractures as it does so. The more permeable the groundwater pathways, the more rapidly they will become enlarged (Barrows, 1982). More and more groundwater flows through fewer and fewer solution conduits (Fetter, 1980), with less and less diffusion of groundwater into the rock matrix. The end result is a regional network of primary solution channels and stagnant secondary pathways (Barrows, 1982), with little or no matrix diffusion.

(7) Distribution coefficients used for the Culebra dolomite are not representative of field conditions.

The distribution coefficient (Kd), or sorption coefficient, is a measurement of the proportion of radionuclides that are retarded during migration of groundwater. The magnitude of retardation is proportional to the surface area in the host rock encountered by flowing water and therefore available for sorption. The higher the Kd value, the greater the retardation of radionuclide migration. The Kd values used in WIPP performance assessment were determined in the laboratory from single measurements upon Culebra dolomite samples which were crushed to a powder, thus providing much greater surface area per volume of rock than actually occurs in the field. The results, preferred by DOE, give a Kd value as high as 7300 for Culebra dolomite, compared to a Kd value of 19 for tablets of solid rock, which is more representative of fracture flow in the Culebra dolomite. The greater the aperture (diameter) of the groundwater channels, the lower the Kd value. Under karst conditions, the conservative assumption is that Kd equals zero, that some radionuclides will
travel at the speed of water. The only way to obtain reliable
distribution coefficients is to perform sorbing tracer tests in
the field (GCR, 1978; EEG-61, 1996; SEIS, 1996).

(8) There is no evidence that clay linings on fractures in the
Culebra dolomite will affect radionuclide migration.

The WIPP performance assessment takes credit for radionuclide
retardation due to clay linings on fractures in the Culebra
dolomite. The claim is based on experiments that were performed
not upon fractures in the Culebra, which contain only small
amounts of clay, but upon corrensite clay taken from a black
shale layer in the lower unnamed member of the Rustler. Clay
fillings are most likely to exist in secondary pathways, where
groundwater movement is infrequent enough to allow the clay to
settle out of the water; here the clay could block the movement
of water into the rock matrix, thus preventing matrix diffusion.
The WIPP performance assessment takes "double credit" for a
mechanism that may not exist, by claiming significant
radionuclide retardation in primary pathways in the Culebra,
while denying that clay fillings in secondary pathways would

One of the problems with analyzing DOE's Compliance Certification
Application (DOE/CA0-1996-2184) is its incompleteness. Materials
are continually being added to the docket, and to criticize the
Application now is like shooting at a moving target. By the time
the EPA certifies that the Application is complete, the public
comment period will be over, and DOE will be at liberty to assail
its critics without fear of response, using materials which were
unavailable during the public comment period. Therefore, instead
of analyzing the WIPP performance assessment as it now stands, it
is more reasonable to analyze a completed report, trusting that
the public will be given another chance to analyze the Compliance
Certification Application when EPA deems it complete.

One recent addition to the docket is a Sandia Report by Corbet
and Knupp (SAND 96-2133), received by the New Mexico Attorney
General on January 15, 1997, midway through the public comment
period. The report, which models regional groundwater flow in
the Rustler Formation, is said to have bounded the hydrologic
effects of karst, potash mining, and climatic change, simply by
analyzing the effects of a three order of magnitude increase in
hydraulic conductivity in the Culebra dolomite. Unfortunately,
the report begins with conceptual errors and misrepresentative
data, and the difference is always favorable to DOE.

The use of "geologic data to infer hydraulic conductivity values
for areas in which conductivity measurements were not available"
is inexcusable. DOE has had 20 years to collect the necessary
data. There is no substitute for field work. The interpretation
should be drawn from the data, not the other way around.
These values for rock hydraulic properties, said to be inferred from geologic observations, are not always consistent with borehole data in the vicinity. Examples are given below.

Figure 2-6: The "eastern limit of Salado dissolution" is placed at Livingston Ridge, which is not correct. Seven boreholes east of Livingston Ridge (P-6, P-12, P-13, P-14, H-3, H-6 and WIPP-33) encountered dissolution residue at the top of the Salado.

Figure 2-7: In Zone I, the fracturing and disruption of Rustler strata in Nash Draw is attributed to dissolution of the upper Salado, rather than to karst processes in the Rustler. This zone includes borehole WIPP-25, where the Tamarisk and lower unnamed members consist almost entirely of mudstone breccia and gypsum.

Figure 2-7: In Zone II, Rustler strata is said to be fractured but not disrupted. This zone includes borehole H-7, where 24.3 feet of Culebra dolomite was broken into six sections separated by five cavities totalling 21.7 feet; this was underlain by 6.2 feet of mud, beneath which there was no core for 80.8 feet.

Figure 2-9: The zone assumed to have hydraulic conductivity of $1 \times 10^{-11}$ m/sec (2.8 x 10^{-4} ft/day) in Rustler anhydrite includes borehole WIPP-33, where all of the anhydrite has been converted to gypsum, some of the gypsum has been removed by dissolution, and two gypsum caves were encountered in the Forty-Niner member.

Figure 2-10: The zone assumed to have hydraulic conductivity of $1 \times 10^{-7}$ m/sec (2.8 x 10^{-4} ft/day) in Rustler mudstone includes borehole WIPP-14, where 71.4 feet of mud, with anhydrite and gypsum fragments, was encountered beneath the Culebra dolomite.

Figure 2-11: The Dewey Lake Redbeds are assumed to have hydraulic conductivity of $2 \times 10^{-7}$ m/sec (.028 ft/day) everywhere east of Livingston Ridge. This is a wild guess. I am unaware of any measurements of hydraulic conductivity in the Dewey Lake Redbeds. However, at test wells H-11 and WQSP-6, inflow from the Dewey Lake Redbeds was measured at 25 to 30 gallons per minute.

The "assumed values for hydraulic conductivity" in the Culebra dolomite are at variance with measured data. In Figure 2-8, the zone assumed to have hydraulic conductivity of $1 \times 10^{-7.5}$ m/sec (.009 ft/day) includes test wells H-3, DOE-1 and H-11, where hydraulic conductivity is 0.86 ft/day, 1.5 ft/day, and 1.7 ft/day, respectively. The zone assumed to have hydraulic conductivity of $1 \times 10^{-6}$ m/sec (0.28 ft/day) includes test wells DOE-2, WIPP-13, H-6 and P-14, where hydraulic conductivity is 4.0 ft/day, 3.0 ft/day, 3.2 ft/day, and 10.6 ft/day, respectively. The zone assumed to have hydraulic conductivity of $1 \times 10^{-5}$ m/sec (2.8 ft/day) includes test well H-7, where hydraulic conductivity is at least 31.0 ft/day. Hydraulic conductivity (in ft/day) is here calculated as transmissivity (in ft$^2$/day) divided by the
thickness of the aquifer (in feet). It is true that hydraulic conductivity at these eight test wells is anomalously high, but that is exactly the point. To disregard the highest measurements of hydraulic conductivity is to throw out the evidence for karst.

Potential recharge, defined as "the maximum amount of moisture available to recharge the saturated zone," is assumed to be 0.2 to 2.0 mm/yr. These values are claimed by Corbet and Knupp to be "certainly reasonable." In fact, precipitation for the last ten years at the Carlsbad airport has averaged slightly over 15 inches per year, or 40 cm/yr. Corbet and Knupp are saying that annual recharge equals 0.05% to 0.5% of annual precipitation, which is to say that evapotranspiration equals 99.5% to 99.95% of precipitation. From this they conclude that the travel time for vertical leakage to reach the Culebra is "probably thousands or tens of thousands of years." These estimates of recharge are too low. Geohydrology Associates (1978) and Barrows (1982) estimated 96% evapotranspiration and 4% recharge. Phillips (1987) estimated 94% evapotranspiration and 6% recharge.

"Vertical leakage may contribute as little as 5% or more than 50% of the total inflow" to the Culebra at WIPP. This statement is an open admission that DOE does not even know the order of magnitude of rainwater recharge to the Culebra. The truth is that vertical leakage contributes nearly 100% of recharge to the Culebra; the alternative explanation, that the Culebra contains "fossil water" left over from the Ice Ages, is not supported by geochemical data showing Culebra water to be far from saturated.

The conclusion that the Culebra is "poorly connected to the source of recharge" is entirely unsubstantiated. DOE does not even claim to know where the recharge area is located. It is said not to be "feasible" to measure, in the field, the vertical conductivity of the "confining layers" because it would take longer than "several months" to do so. This is a poor excuse. DOE has already had 20 years to study rainwater recharge.

Regarding the hydrologic effects of climatic change, the computer simulations employed by Corbet and Knupp "covered the time period from late in the Pleistocene (14,000 years ago) to 10,000 years in the future." The full-glacial maximum (generally considered to have been 23,000 to 17,000 years ago), and the climate and hydrology associated with it, were not considered. Indeed, Corbet and Knupp assume that the climate over the next 10,000 years will be no different than the last 8,000 years. As for potential recharge, Corbet and Knupp assume that 2.0 mm/yr was realized during the late Pleistocene (14,000 years ago), and that maximum recharge during the Holocene was 0.6 mm/yr. Recharge at 8,000 years ago is assumed to have been zero, although Corbet and Knupp do admit that this value is "somewhat arbitrary."
Glacial advances are cyclical. The Holocene is properly viewed not as an epoch distinct from the Pleistocene, but as the latest interglacial interval. Due primarily to a decrease in obliquity (the tilt of the earth’s axis), the amount of incoming solar radiation received during the summer at the Arctic Circle (and throughout most of the northern hemisphere) will decrease during the next 9000 years. The polar ice cap will not be able to melt back during the summer, and a glacial advance is predictable.

During the last full-glacial maximum, summers were at least 10°C (18°F) colder in south-central New Mexico, and the evaporation rate was 40% to 50% of the present rate. The combined amount of precipitation and runoff into the local lake basins of the Texas panhandle was about 50% greater than at present; this would be sufficient to cause Laguna Grande de la Sal (the discharge point for contaminated water from the WIPP site) to overflow into the Pecos River. Climatic transitions can be rapid; temperature drops of up to 5°C (9°F) have been identified. For a fuller discussion of climatic change, see Phillips (1987, Chapter 9).

All the studies cited by Corbet and Knupp relate to groundwater flow through porous, homogeneous media. Not a single report on karst hydrology is referenced. Corbet and Knupp acknowledge that they are using equations for flow in porous media, based on Darcy’s law. The idealized cross-sections of groundwater basins (Figure 2-1) are representative of porous, homogeneous media. They bear no resemblance to karst hydrology at the WIPP site.

"Differences in the elevation of the water table" are said to "provide the driving force for groundwater flow." This is not necessarily true. In karst, the driving force for groundwater flow is the flushing of underground caverns by fresh water recharge after major rainstorms. Groundwater will flow through preferential pathways, through channels of high transmissivity, even if the flow path is not directly downgradient.

"All of the outflow" from the Culebra at WIPP is attributed to "lateral flow. Therefore, contaminants introduced into the Culebra will travel toward the accessible environment along the Culebra rather than by migrating upward or downward into other units." This statement is in direct conflict with measured data. DOE’s data set for hydraulic heads, incomplete though it is, shows that water in the Culebra can and does flow upward to the Magenta at test wells H-6 and WIPP-25. The Culebra is not a confined aquifer, and DOE’s attempt to model it as such is a misrepresentation of reality. If it is simply too difficult, for purposes of performance assessment, to model the Rustler as one complex artesian aquifer with five units, with water flowing up, down, and sideways, as it does in the real world, then the proper response is not to oversimplify the actual conditions of Rustler groundwater flow to the point of science fiction, but to abandon the attempt to obtain EPA certification to open WIPP.
Comments on DoE's Compliance Certification Application, 1996
For the Waste Isolation Pilot Plant, New Mexico

David T. Snow, Ph.D., P.E.

Introduction

Disposal of radioactive waste is a virgin industry, the product of 50 years' labor to conceive safe
resting places for the legacy of bombs and power plants. Not one prototype has been built
anywhere on earth to test the many solutions proposed by the thousands of involved technologists
of many persuasions and countries. The nuclear waste disposal industry is in about the same state
that dam-building occupied when (in the 1930's) we suffered in America the failures of the St.
Francis Dam, the Fort Peck Dam, the Hales Bar Dam and others. Failures are predictable for
prototypes dependent upon geology, an inexact science replete with surprises, usually because
exploration provides only a fraction of the necessary data. Since WIPP is the guinea pig, we must
treat the ground with the respect experience should have taught us. The wishful thinking, the false
confidence detectable in a thousand topics the DoE proposal entails is cause for uncommon
conservatism, remembering that the proponent, all its contractors and even reviewers have a
positive bias. There is a comfortable interdependency among a diversity of "experts", none of
whom have built a successful repository, nor put their names to their findings. Who are the
professional engineers the public has licenced, who can be trusted with this complex paper edifice?

I wish to express a healthy skepticism about some untested expectations of repository
containment, and upon the best-case assumptions used to predict transport in groundwater. I
submit my qualifications (see website www.mallmerchant.com/dr-snow) to express views drawn
from abundant hydro-geotechnical experience, much of it with repository siting.

Apropos of responsibility, the EPA has imposed the common-sense restriction, based on RCRA
prohibitions on land disposal of toxic waste (present in some TRU containers) that the waste must
be retrievable. EPA only requires that the retrieval be possible, not that it be easy or economic
(CCA 7.6.1). It is clear that future generations will find it infeasible, practically precluding retrieval
from this site. That effectively leaves no slack for inevitable mistakes in concept, data validity or
interpretation, or the design of the many vital parts such as those intended to minimize the mobility
of dissolvable actinides, to isolate the repository contents from shallow strata or to limit
radioactive transport in aquifers carrying water to the accessible environment. DoE claims (CCA
7.6) that waste retrieval is possible and it has been demonstrated. Were the simulated waste
containers in place in time to be crushed by a roof collapse, then retrieved? Assuming that actual
retrieval would be attempted after repository performance proves unsatisfactory, the real
conditions would entail crushed drums and wooden boxes under tons of fallen salt, part of whose
radioactivity has escaped in liquid form and dispersed throughout cracks of the disturbed rock zone
(DRZ) beneath the heaved floor, or as salt backfill impregnations. The total contaminated volume
might be five to ten times the original volume, a mechanically-heterogeneous mix of salt, metal and
plastic, poorly suited for machine excavation, diluted but radiologically as variable as its source. The problems of safe handling, as well as of packaging, transport and of disposal would be more monumental and uncertain than the present, near-impossible task of safe siting. The economic burdens would be so great that stop-gap options of surface protection or land abandonment would be far more feasible and likely. A present mistaken decision to store the waste is not permissible because creep closure and its consequences make waste retrieval impractical. If any miner says it can be done, it is because he expects never to be so required.

DoE has been eager to solve the national problem of too many inadequate TRU waste storage facilities around the country, by concentrating it all at WIPP. It has lead to a premature solution. The proposal is elaborate and seemingly conceived carefully, yet it retains unsolved some fundamental problems. Neglect of these has produced a project the public should view as irresponsible, thus not allowable.

At the outset, there were established some wise geological criteria for site selection (CCA 2.1, p.2-6). Some of these have not been satisfied for the WIPP site. Contrary to DoE’s claims, 1) the plastic nature of the salt host-rock does not have the ability to encapsulate the waste under all conditions, since fractures of the DRZ around the rooms developed in the stiff anhydrite interbeds provide egress of fluid waste components and collected brines through hydrofractures, and 2) the consequences of karstic dissolution of the Rustler and Dewey Lake Red Beds are unknown in character, though some features of karst exist at and near the site. 3) future exploitation of known resources is neither predictable nor necessarily minimal.

Containment

It is clear that radionuclide releases from WIPP to the accessible environment in excess of the limitations of 40 CFR 191 can occur only if three factors are met:
1. A sufficient fraction of the actinide inventory must be mobilized in dissolved or colloidal form.
2. The engineered containment within and adjacent to the repository must be breached and capable of discharging brine, and
3. The intervening geologic environment and man-made features within it facilitate effective transport to the compliance boundary.
As long as poor definition characterizes the nature of the waste (such as the amount, size distribution and solubility of plutonium particles) and other parameters are ill-defined, such as the amount of reacting brine and numerous other components still being investigated in the actinide source term (AST) project, DoE cannot eliminate the first factor unequivocally. The CCA relies heavily on elimination of factors 2. and 3. Among the various claims being disputed by interveners to this application, the writer addresses some limited but vital subjects related to failure of seals and engineered barriers, discharge from the undisturbed and disturbed repository via paths to the surface or to Rustler aquifers caused by hydrofracturing around borehole seals or shafts or through the overburden strata. Secondly, groundwater flow and transport incident to concentrated discharge in fractures and dissolution conduits of the Rustler and younger formations is discussed, suggesting that those barriers are compromised.
Shaft Seals

The intended hydraulic function of shaft seals (CCA 3.3.1.2) is to "restrict groundwater flow" and "limit radionuclides", not to eliminate them. There is neither a proven, field-tested technology of sealing (especially in salt), nor an irrefutable conceptual design to assure us that those objectives will be met. Shaft seals in mining applications have histories of such frequent failures as to make a prudent engineer treat the proposed seals with cautious skepticism, even if their design is apparently good, innovative, well-studied and reviewed.

I examine, first, the mechanical behavior of some seal components in relation to each other, during the period of shaft closure before significant repository air pressures are imposed. I examine, second, the propensity for seal failure by pneumatic hydrofracture, a potential mechanism for development of a conduit for concentrated, rapid egress of air and brine, contaminated or otherwise, from the repository to the Rustler aquifers or the surface. It is evident that the seal designers may have given insufficient credence to the hydrofracture mechanism along the seals, or into the strata above the repository, competing avenues for release of the pressures that will build upon compression of the air and gasses that will develop in the repository.

Concrete plugs with asphalt water-stops have recently been redesigned. Such "chemical" seals in mine-shaft use have a checkered history of failure by displacement. Asphalt is a viscous liquid, so when subjected to shear, it is more readily deformed than is salt. The intended function of the asphalt, filling not only a shaft segment, but also filling a tapered kerf (slot) excavated all-around one radius into the shaft wall, is to intercept the DRZ, believed to be the most likely path for fluid bypassing the impermeable seal materials that will fill the shaft. The radial extension of the DRZ around the tip of the kerf has been modeled (CCA 7.6.1) to conceptualize its development and subsequent crack closure when the asphalt and adjoining concrete plugs take on load from the convergence of salt. One cannot tell from the text whether or not the modeling is realistic in conceptualizing the closure consequences.

The asphalt will shrink slightly during cooling (days), after the upper concrete plug has set (hours). Presumably, the concrete plug will support itself in shear without salt damage as the concrete gains strength (months). Ensuing creep deformation of the walls (years) will load the asphalt and concrete. According to reported structural calculations (SEAL 7.4.4.2), the radial stresses for upper, middle and lower seals in asphalt will be only 1.8, 2.5 and 3.2 MPa at 100 years, and in concrete (SEAL 7.4.1.2), only 2.5, 4.5 and 5.5 MPa at 50 years. They claim that such modest backpressures will heal the DRZ, even while creep continues to close the shaft. The geometry of the kerf will speed its closure, relative to the radial closure around cylindrical concrete elements, thus modeling should show vertical components of salt movement towards the kerf. As stated (CCA 7.6.1, Para 2), after 20 years the DRZ is localized, 2 m deep, at the asphalt/concrete contact, where such shear of salt against concrete must be maximum.

The designer's concern should be that more rapid closure of the kerf will raise the asphalt pressure more rapidly than the salt/concrete contact pressure, so that asphalt may prise and penetrate upwards along that contact. Whenever a fluid of density less than the surrounding rock rises to higher levels, the propagation of the hydrofracture is unstable. There is nothing to prevent...
the extrusion of the asphalt until the water-stop is replaced (centuries) by salt, and the asphalt is displaced along the contact of the overlying clay seal segment. Apparently we cannot count on the interception of potential seepage paths along the shaft DRZ by placement of asphalt water-stops, because they may not be permanent.

The asphalt column at the top of the Salado (element 6 of Fig. 3-4) is to be composed of asphaltic aggregate. It will be lightly loaded and will have some shear strength, so will have limited or no mobility past its upper plug of concrete placed against anhydrite of the Unnamed member of the Rustler.

Other parts of the seal system should compact without discharge or distortion.

Repository Pressure and Discharge

Waste emplacement design includes a backfill of sacks of MgO placed to buffer acidity as CO₂ evolves from decomposing organics in the waste. Hydration to Mg(OH)₂ will sequester water beneficially, but release it as CO₂ combines with the hydroxide. Besides maintaining low actinide solubility, it is evident that the MgO will reduce the rate of gas pressure build-up and diminish the liquid filling repository voids.

Castile brine occurrences pressurized by biogenic H₂S (such as ERDA-6, 1981) are analogues for the evolution of repository contents, wherein decomposition of cellulose, plastics, rubber and steel will generate CO₂ and H₂. DoE's concepts of the nature of these Castile brine reservoirs is found in CCA 6.4.8, but there is no recognition that primitive pressures must be lithostatic as a limit, that the extent, interconnectedness and discharge processes must be tied to the stress state of salt. The Castile fluids are stored in rather stiff fractures in the anhydrite. The pressure has developed by microbial reduction made possible by methane or petroleum in the presence of anhydrite. Its threshold for dissipation by hydrofracture along weak contact partings is the lithostatic pressure of salt adjoining such fractures, not the steep fractures interior to the anhydrite beds. Upon tapping such a reservoir with a drill hole, its head is initially thousands of feet above land surface, but as it flows, friction drops the pressure rapidly. It would flow freely until anhydrite fracture closure attains hydrostatic pressure for the brine.

How much of the H₂S is dissolved or gaseous in the Castile is unknown, but it is probably dissolved because none of the drill intersections have produced gas only, followed by brine. In addition to elastic closure of fractures and expansion of brine, evolving gas in the column drives the well discharge. Remote parts of a reservoir become isolated as diminishing pressure causes closure of hydraulic fractures at salt contacts.

In the repository, compaction begins with air only, and ends with air, decomposition gasses and brine from inflows, all at lithostatic pressure. The greatest factor of uncertainty is the amount of brine that will enter during the long room closure period while pressure is below lithostatic. The National Academy review (NAS, 1996, App. C) summarized the competing theories, indicating cumulative inflows in the range of 500 to 800 l/m of drift. It appears that none of those computations were coupled to backpressure computations. Like the Castile anhydrite beds, some
areas of which contain abundant brine, there is probably a variation of brine content in fractures of Salado interbeds, and variations in size and continuity between reservoir areas. Hydrofractures may or may not join various steep-fracture reservoirs, depending upon their pressure histories. So the calculated cumulative brine flows may err by large amounts, and a conservative inflow may total more than 1000 l/m.

The choice of backfilling materials in the rooms provides the only control over final void volumes, since the waste can sustain only so much residual void space when compacted to lithostatic total stress. Ideally, since waste voids will probably become saturated, residual porosity should be maximized, to limit the amount that can otherwise be expelled from the repository after the gas has escaped. The MgO backfill will absorb water into the hydroxide, then yield it as the carbonate is formed. The amount of MgO is said to exceed the gas expected to evolve, so a net water absorption will function to inhibit corrosion, just as will pH control. But unlike salt backfill, MgO will not sequester air; the Mg(OH)₂ will saturate and consolidate as it continues to take load. Compressed air in fractures and contacts and within the collapsed drums will all communicate to hydrofractures that can form as pressure attains lithostatic in the repository. It doesn't seem conservative to assume that the backfill and residual voids will retain all the remaining brine, since gas will continue to evolve. I am unaware of any DoE claim that brine will be unavailable for transport of radionuclide contaminants away from the repository, nor would it be prudent to so assume.

A possible safety measure rejected by DoE is the option of completing the backfilling around the waste and MgO packages with dry compressed or adobe bricks of clay. It is well-known that clays of the montmorillonite family have extremely high cation exchange capacities and can exert high swelling pressures. Reduction of the initial air volume and prompt backpressure would shorten the time to cessation of closure. Diminished inflow and enhanced absorption of brine would ameliorate corrosion. Perhaps an absence of free brine could be guaranteed, limiting the actinide source to the fluids already in the waste, less the actinides which can be absorbed by the clay. In absence of incontrovertible geologic containment and retardation, such engineered barriers may be the only way to get certified.

It is safe to say that a diminished rate of decomposition of the waste does not eliminate the prospect of continued pressure build-up to hydrostatic. As proposed, the large initial voids ratio of the repository (as seen in Fig. 3-8) probably implies that the air cannot be contained at less than lithostatic pressure in the residual voids of the waste containers, some of which will be brine-filled. Continued gas generation, at any rate, will ultimately raise pneumatic pressure to lithostatic in spaces communicating with the DRZ in the marker beds. The compressed air and gasses are available to form and drive hydrofracture either along the seals or through the overburden rocks. The energy available for propagation and friction is in excess of 2.5 X 10¹⁲ joules, if the original void volume of about 460,000 m³ (SEAL 8.3.2), plus any generated gas is compressed to about 1/146 th of that volume.

Seal Failure. In shafts and boreholes, the pre-existing contacts between wall rocks and seal materials are likely paths of hydrofracture, and the vertical aspect enhances instability (runaway propagation to up-hole regions of decreasing rock stress). There is nothing to stop it except
whatever tensile strength may exist in the least-healed discontinuity, such as dust coatings on original walls. It may propagate readily between air-filled voids of the compacted salt fill, and certainly along fluid films in the clay seals. Asphalt deforms to pass air at contacts, and salt will yield to form a parting against concrete. Likewise, boreholes sealed with concrete will not sustain much beyond lithostatic fluid pressures before parting at contacts. The DRZ fractures, even healed ones in salt, are candidates for hydrofracture. One might design end-constraints for a salt column to exceed lithostatic radial pressure, but it would not be permanent. It is easy enough to design effective seals for fluid pressures below lithostatic, but not above.

The computations in SEAL 8., the hydrologic evaluation of seal performance, are perhaps valid, but the assumptions of homogeneous, intergranular or continuous fractured-media properties do not apply under all conditions, such as at high pressures. Seals and DRZ rocks behave as continuous media during early phases of repository closure, but under lithostatic or higher pressures, fluids will travel along singular pathways not envisioned by the modelers. During compaction of clay and perhaps of salt, air can be expelled along contacts of the seals. During any subsequent consolidation phase, water can be expelled along those same pathways. Either fluid will take the path of least resistance, usually by forming a conduit at the rock/seal contact, persistently maintaining that opening as flow occurs or preserving a path susceptible to re-opening and concentrated flow when pressure is raised. Seals can be breached to the Rustler aquifers or to the surface via the unsaturated zone. If engineered barriers in the repository preclude free brine, it would be harmless air and gas discharge. Otherwise, the undisturbed scenario has a potential for radionuclide releases to Rustler aquifers by way of shafts or boreholes.

Hydrofracture through the Salado. If the shaft seals are as good as they can be made, then hydrofracture will occur elsewhere instead. In essence, no fluid phase can be long contained by seals or geologic media when the fluids exceed lithostatic pressure; the best that can be done is to assess the relative weaknesses of competing paths of egress. Mindful that roof slabbng (even presently occurring in the experimental rooms) exposes one or more weak partings, at anhydrites "a", "b" or the clay at the base of MB 138, subsequent closure will cause those members to bend and decline towards the center of the room. Air will remain in the anhydrite fractures even as rock stress attains lithostatic over rooms as well as pillars (the unmined salt between rooms). During roof deformation, shear displacements produce microscopic openings along several such stacked partings that extend towards the centerline of the pillar. Coalescence of the DRZ from room to room can occur by hydrofracture across the pillar regions, completing the continuity of the entire repository, even if there are room or panel seals in place. DoE has chosen to neglect the NAS recommendation (1996, p. 145) for generous, long room entry seals, that would diminish the continuity of the repository. All rooms should dead-end in salt for isolation. Canadian potash mines safely excavate 2000 ft rooms with only one entry. The concrete seals to be emplaced for RCRA compliance (CCA 3.3.2) are not being relied upon for compartmentation to isolate nuclear waste products. Therefore, the energy of air compression and gas generation stored in the entire repository is available to drive a single hydrofracture to great distances.
I anticipate a counter-argument that lithostatic pressure cannot build because the slightly-permeable anhydrite beds would continually bleed air from the repository, especially from the updip extremities, while brine continues to drain into the down-dip extremities. The fallacy of that argument is the erroneous belief that brine in the marker beds is at no more than 12.5 MPa (Beauheim, et al., 1993), when measurement itself disturbs the pressure. Virgin pressure must be lithostatic to prevent salt closure of the fractures. Therefore, it is doubtful that appreciable air losses can occur through the marker beds until that formation pore pressure is exceeded at the repository end, even if it takes centuries to attain it.

In the far-field, remote from any stress perturbations the excavations may impose, it is safe to assume that creep of salt maintains lithostatic, all-around rock pressure equal to the overburden load. In such circumstances, the presence of structural weaknesses will govern the nature of a hydrofracture forming in response to fluids exceeding lithostatic. Clay partings along contacts between salt and marker beds, and some clay lamina within salt beds are candidate horizons. These may be interrupted at infrequent local breaks in stratigraphy formed during Permian deposition by channels that crossed the shallow salt-flats. They have been observed in the experimental area of the repository (D. Borns and R. Patchett, personal communication, 1995). The effect of such an interruption of a bedding-plane hydrofracture is to force the opening to propagate elsewhere. It is known also that hydrofractures tend to jump up to higher levels in the strata, where load is less. In homogeneous rock, hydrofractures become dish-shaped. Such behavior in the Delaware Basin has been demonstrated. In 1991, the Bates #2 Well encountered brine with 1000 psi shut-in pressure while drilling at 2240 feet. It flowed about 840 gpm for 5.5 days. Responsible for the brine was a Texaco Co. well injecting (oil-field waterflood operations) at 3000 ft depth, about 760 ft lower than the Bates well intersection and about two miles away. It is consistent with that incident to predict that when pneumatic pressure in the repository approaches the fracture gradient of 0.966 psi/ft depth, it will either hydrofrac a seal or produce a single, elongated hydrofracture along a succession of overlying partings of the Salado, ultimately breaching the Rustler aquifers. As EEG (1996, p. 2-4) point out, the Rustler/Salado contact is also a potential pathway. Alternatively, an extensive hydrofracture may intersect a borehole inadequately sealed to sustain the pressures from deeper horizons.

The importance of borehole sealing, at sites both on and off the land withdrawal area, is evident from the Bates #2 Well experience, and from other water-flood hydrofractures encountered in recent years. DoE has chosen to accept the condition of numerous abandoned wells in the region, presuming them to be well sealed in accordance with state regulations. But the imperfection of casing cement jobs and the corrosion that destroys casings in evaporite environments point to predictable vertical paths open to the surface now or in the foreseeable future via the many abandoned and active oil wells. The possibility that waterflood operations in the neighborhood may propagate hydrofracture to the repository, saturate and pressurize it, then hydrofrac an outlet to the surface is very real.

Discharge of air and gasses is innocuous, insofar as TRU waste is not expected to generate appreciable radioactive gas to contaminate the repository air. The significance of pneumatic hydrofracture is that it prepares and maintains an open path for escape of liquids to follow after the available vapor-phase has discharged from the repository. The energy of any remaining room
closure is available to expel fluids of density below that of salt. Only if engineered barriers have been emplaced in the rooms can sufficient brine sequestration be envisioned to preclude eventual brine discharge along hydrofracture conduits, and DoE has not maximized use of such barriers.

Disturbed-case scenarios. Whereas the above considerations leading to pneumatic hydrofracture apply to the undisturbed repository, they should also be applied to the single borehole E1 or E2 case or the E1E2 case that would, at least, discharge accumulated gasses and air from the repository. After hydrofracture, repository pressure may not normally attain lithostatic again without a connection to the Castile brines or waterflood brines. If the drilling occurs subsequent to undisturbed hydrofracturing, pressures may become elevated when a Castile brine reservoir is intercepted, the E1 scenario (CCA, 6.3.2.2.2).

In the event of potash mining in the McNutt member of the Solado overlying the repository, the consequences would be far more extensive than merely the enhancement of Culebra transmissibility (Corbet and Knupp, 1996). In addition to shaft penetrations, the overburden between the mine and the surface would be disrupted by numerous steep subsidence fractures. Many traversing salt may reheat while mining proceeds, but typically, potash mines flood via fractures carrying water from overlying aquifers, as occur in the Rustler. Thus, a mine overlying the WIPP repository can provide different connections to the accessible environment, depending upon the time of repository breaching relative to the time of mining. The mining level, about 75m above the repository, would retain lateral continuity for centuries before it seals itself. Thus, it would provide continuity from the repository to the surface, via the shafts, boreholes old and new, and especially via hydrofractures, the mine and Rustler aquifers. Several of these are potentially more likely than the simple M scenario envisioned by DoE.

The E2 scenario (CCA 6.3.2.2.1), a drill hole inadvertently penetrating the repository would discharge any accumulated air and gas, but if it occurs after venting by undisturbed hydrofracture, the rooms may have closed to a state of near-saturation, facilitating brine discharge to the borehole, driven by expansion of the remaining gas and elastic expansions. The repercussions would depend upon the state of the repository, thus the timing of events. Diversion to the Culebra aquifer would result from successful blowout prevention at the collar of the hole.

A drill hole through a partially vented repository room, a closed access drift or the DRZ of any part of the system could conceivably be drilled deeper for resource exploration, whereupon a pressurized brine reservoir in the Castile could be encountered (E1 scenario, CCA 6.3.2.2.2), producing brine flow. Because no mechanically effective backfill or room seals are to be employed, direct circulation to a point of hydrofracture egress is likely to sweep any mobile contents out of a panel or perhaps two panels, but the panel closures would protect other panels from direct flushing. However, any blowout preventer restraining direct brine discharge up the hole would result in hydrofracture from room to room, to any shaft, borehole or hydrofracture to the Rustler, since the Castile brine is generally at lithostatic pressure for its deep level, thus much higher than lithostatic for shallower levels. The path depicted in Fig. 6-11 represents only one of those possible, and probably not the worst.
Many potential paths are possible with the E1E2 scenario, as described in CCA 6.3.2.2.3, conceivably sweeping as many as two panels of their mobile wastes. It seems unlikely that the DRZ would have greater conductivity than would paths through rooms, but in the event that panel closures function effectively, brine flowing through any salt-bounded fracture could readily enlarge it to concentrate flow, bypassing much of the waste. It is not convincing to say that the E1E2 scenario is the worst case, that it is to be minimized because the compound probability of two such penetrations is low. The E1 drill hole in combination with prior breaching paths seems more likely and dangerous. The event of exploration well penetration of the repository seems unlikely to contaminate the Culebra because such wells would be new and cased through the Culebra. Thus the claimed retardation due to Culebra transport processes might not provide a barrier when needed most.

Rustler Hydrology

It has long been DoE’s position that flow through the Culebra dolomite provides a final barrier to excessive releases to the accessible environment. While shorter, more concentrated discharges, in place and time, to the immediate surface are likely to result from exploration boreholes or sealed boreholes, shafts, subsidence fractures or hydrofractures, it is worthwhile to evaluate the conceptual hydrogeology of the Culebra, implemented in so many studies contributing to Performance Assessment (PA).

The case for obtaining a comprehensive set of data to characterize the structure of the Culebra has been made before (Ferrall and Gibbons, 1978; Snow, 1995; NAS, 1996 and others), so that modeling for transport calculations can more correctly represent the true conditions. The reasons have to be reiterated here.

Fractures and stratigraphic features would become secondary in importance if it were realized that the Rustler contains significant solution conduits within the WIPP site and within the range of potential hydrofractures and boreholes that may communicate with the repository. Then, fractures would no longer be the key elements in governing transport. Upon demonstrating karst features within the model domain, it may be so evident that travel times are brief (say, 5 to 250 years) that the Rustler must be discounted as a barrier to transport to the accessible environment.

Fracture System in the Culebra

DoE’s hydrologists are among the world’s foremost modelers, but the data DoE has collected to facilitate appropriate conceptual aspects and the details of the models themselves do not reflect the state of the art of geotechnical engineering, in view of the hydrostratigraphy, the fracture system geometry or the suspect dissolution features of the rocks overlying the Salado. Consider, first, the lack of fracture data and its adverse influences.

It was one of the Carlsbad area potash mining companies that convinced ERDA to examine that area; to store TRU waste seemed a great end-use for a spent mine, and when that was rejected, the government got some help in drilling to prove the resource of space could be found beneath the mining horizon. The coring of drill holes has been with the same equipment and of the quality
appropriate to the potash industry, probably by the same "experienced" drillers. For potash exploration, only the chemistry of the ore matters; the quality of core recovery is unimportant. Consequently, any attempt to learn much from the cores in storage, such as structural details, is a frustrating exercise because the core looks like crushed road aggregate, for the most part. Frequently, recoveries are less than 50% of the length of hole, and the weakest parts, such as seams, solution zones and fractured intervals are missing from the hundreds of boxes representing millions of dollars worth of drilling. One hole of the H-11 pad site reflects superior care in obtaining good recovery, though it would still be considered abysmal by engineering geologists trained for damsite exploration work. Instead of the traditional single-tube core barrel used in potash programs, it is reported that the H-19 pad holes of 1995 were drilled, at last, with a triple-tube core barrel, obtaining about 98% recovery. In my view, 30 years of exploration effort before 1995 were squandered in inept technology. Even the 1995 core misses the objective of fracture system characterization because DoE has continued to refuse (DoE letter to EEG, August 17, 1995) to execute slant-hole coring, without which near-vertical fractures cannot be intercepted with sufficient frequency. Outcrop evidence and common knowledge would tell them that flat-lying sediments abound in vertical fractures, as must be the case in the Culebra. A reasonably-representative data-set can and still must be obtained at WIPP by applying well-established directional drilling technology perfected in the last decade by oil companies for the task of intercepting steep producing fractures. It is reported that directional drilling costs about 15% more than vertical drilling, so economics are no impediment.

The need for fracture system data to model the flow and transport of contaminants in the Culebra has been detailed recently (Snow, 1995) and reinforced by reviewers (NAS, 1995), such as Dr. Konikow. The role of matrix diffusion, hydrodynamic dispersion and sorption depend upon parameters that can only be estimated crudely by in-situ tracer tests. The interpretation of tests depends upon models that cannot be well-conceived in absence of data on the fracture system geometry and stratigraphic details.

Indirect inferences of fracture system geometry at the site have to depend upon remote observations, such as the outcrops at Culebra Bluffs along the Pecos River, SW of Nash Draw. According to personal observations preserved in photographs, there are two steep orthogonal sets of fractures, NE and NW in strike, with long traces seen on bedding surfaces and spacings about 1-2m. These are consistent with regionally-pervasive tectonic patterns visible in the Capitan Reef and elsewhere in the Basin (Swift, 1992). Superimposed on the orthogonal tectonic joint pattern are more numerous, randomly-oriented fractures, sometimes abutting in polygons.

Judging by a similar distinction between joints above versus below a dissolved evaporite sequence in Manitoba, I believe that the random set at Culebra Bluffs results from dissolution of underlying evaporites, which occurs differentially over space and time to impose strains in various directions. Horizontal partings at clay lamina in the Culebra probably shear and open by the same differential subsidence mechanism.

At the WIPP site, there has been variable removal of salt from the uppermost Salado rocks and the Unnamed Anhydrite unit of the Rustler, perhaps increasing in magnitude of removal from east to west across the site. Since the demarcation is not abrupt, neither is the distribution of Culebra
fracture types predictable. Only a well-conceived and executed slant-hole drill-coring program could resolve the changes of pattern to be expected across the site. The nature, apertures and spacings of each type are needed, augmented by length parameters from outcrop studies. Core data should facilitate interpretation of fracture system anisotropy and the effective porosity, all in the interests of better PA modeling than is possible with currently oversimplified geometry (such as horizontal fractures only) and the absence of data.

Further objectives should be to include fracture system distinctions across the dissolution-transition zone coincident with the WIPP site, and especially to characterize dissolution channeling effects evident by erosion of fracture fillings and the opening of vugular strata. Fracture conduits traversing the Dewey Lake Red Beds and the several Rustler members are needed, since the assumption made by DoE that the Culebra is confined by impermeable beds is clearly unjustified (see below).

It is appropriate to caution against exploration expenditures for fracture system characterization to the exclusion of dissolution-feature characterization.

Karst Hydrology

If DoE cannot be induced by the reasoning of many to evaluate and employ knowledge of fracture hydrology, preferring to labor handicapped without such knowledge, then what is the efficacy of recommending explorations to obtain knowledge of karst hydrology at WIPP, data even more vital to establishment of transport properties of the Rustler? Fear of failure, having spent $2 billion on studies already seems to have driven completion-oriented managers to deny the existence of karst features (CCA 2.1.3.5.2). Ultimate failure, still a very real possibility, would be to have a repository filled with TRU waste that has to be retrieved later at astronomical costs when our progeny, perhaps ten generations from now, discover shafts, drill holes or springs discharging radioactive brine to the Pecos River. It has been an unspoken hope that slant-hole coring for fractures could accidentally disclose solution cavities in the Dewey Lake and Rustler formations, features already obvious to a field-oriented geologist, re-iterated as evidence of karst by a procession of competent but largely discounted scientists (Olive, 1957; Vine, 1963; Bachman, 1974; Anderson, 1978 and 1994; Barrows, 1982; Chaturvedi and Channel, 1985; Phillips, 1987; Snow, 1995; EEG, 1996).

Claiming reliance on retardation during actinide transport through the idealized Culebra towards the accessible environment (5 km distant), the E1E2 scenario is by no means the worst case, but even it cannot approach 40 CFR 191 standards if short travel times implied by karst hydrology are correct in magnitude. The field evidence presented in Phillips' (1987) dissertation on WIPP site geomorphology is so potentially damaging to the project that DoE has suppressed it, not even listing it in the CCA bibliography. That is inexcusable, when the work constitutes the most exhaustive exploration of surface features, including 1000 auger holes and many backhoe trenches investigating sinkholes and solution trenches on the Mescalero Plain. His evidence is clear that there are local windows through the Mescalero caliche horizon and that there are many aligned sinkholes with alluvial infillings. These are evident, even though dune sands mantle much of the plain, free of surface drainage channels. He recorded observations of storm runoff disappearing
down one such sinkhole, the WIPP-33 drill site where five nested caverns were drilled to the depth of the Culebra. Water-balance methods, based on reasonable evaporation rates from Laguna Grande de la Sal, versus stream-gaging data from Malaga Bend seem to indicate that Nash Draw is the discharge point for nine-tenths of the recharge. This implies shorter paths from WIPP via cavernous channel features reasonably deduced from the geomorphology and geochemistry.

In current comments to the CCA, Phillips (1997) has summarized surface and near-surface hydrological evidence to conclude that the karst solution features on and near the WIPP site are subject to modern infiltration events. The Dewey Lake Red Beds have several regions of sufficient transmissibility and potable water that it constitutes a subsurface drinking water supply. He further documents the occurrence of karst features in the Rustler units: the Forty-Niner, Magenta, Tamarisk and Culebra, including sites within the WIPP boundaries. There are places of apparently continuous dissolution extending from Dewey Lake downwards to the Culebra. Salinities in Culebra water samples decrease along the preferred path, to Malaga Bend, according to DoE, as well as along other potential paths to Nash Draw. Their finding is inconsistent with confined flow in the Culebra, but is consistent with fresh-water recharge through sinks, especially west and southwest of WIPP. Portions of the Culebra carry potable water, making it a candidate for drinking water supplies, rather than a "brine unsuitable even for stock-watering".

The importance of these findings is that the WIPP site is established as a recharge area for a dissolution-enhanced aquifer on and west of WIPP that spans the Dewey Lake and most of the Rustler to at least the Culebra. That is contrary to DoE's modeling of the thin dolomite as a confined aquifer. DoE has modeled the Culebra with transmissibilities computed on the faulty assumption of continuously-varying values. The T-field computations are invalid for fractured media, much less for karstic channels traversing tighter rocks. Typically, exploration drilling on a random pattern cannot be expected to intercept nor measure the high-conductivity solution channels as must exist to carry storm runoff such as flowed into the WIPP-33 sinkhole on September 18-19, 1985, or as observed in other karst regions of the world. Travel time from the site to Nash Draw is speculative, but if it accords with experience in other karst regions, it may be less than 100 years.

The current regional groundwater model (MASS 14.2) errs significantly by neglect of concentrated, intermittent recharge across strata via sinkholes, at least in large parts of the domain. The continuity of Darcy's Law models with properties averaged over large regions cannot represent the transient, channelized flows that occur rarely in karst, giving the medium effective porosities that are orders of magnitude smaller than intergranular media would suggest. Recharge estimates of 0.2 to 2.0mm per year were based on small transmissibilities (seemingly neglecting some of the extreme-averaged tests) in the Culebra, none that represent vertical flows. This range is at odds with Phillips' estimated recharge of 0.75 inch/year (1987, p. 224), a more reasonable figure for 15 inches of rainfall that form no surface drainage channels. Phillips' estimate was based on evaporation from the original surface area of Laguna de la Sal before mine process water was ever discharged there. Sinkholes must connect to highly-conductive channels in the subsurface, features that are believed to develop by headward extension, probably from the discharge points in Nash Draw. The surface morphology suggests that channels must extend onto the WIPP site itself, since sinkholes are present there. As reason to believe that Nash Draw is the terminus of the
shortest, fastest paths from WIPP via the Rustler, there is the significant excess of computed net evaporation at Laguna Grande over the gain of streamflow at Malaga Bend. Flow paths to Nash Draw are shorter than DoE’s expected paths to Malaga Bend. Whereas pluvial-period groundwater flow may have been most responsible for karst development, the established paths during today’s dry climatic conditions are probably also southwestward into Nash Draw.

Average transport properties would be very different for a Rustler aquifer dominated by even occasional periods of rapid, karstic channel flow. The speed with which organic contamination shows up in karst terrain is suggestive of the behavior to expect of actinide transport. Little specific surface can be active for sorption or matrix diffusion. If efforts to characterize the formations are to continue, then testing of rare solution conduits has to be done. Usually, dye-tracing is employed to establish travel times. The location of drill holes seeking direct evidence of conduits can be guided by the negative gravity anomalies (Barrows, et al, 1983), by surface morphology, by the distribution of salinities and fracture fillings in the Culebra (Beauheim and Holt, 1990), and by following apparent trends of high transmissibilities deduced from interference testing.

It should be as transparent as the emperor’s new clothes that the Culebra and overlying strata are inadequate to the belabored task of providing a barrier to excessive cumulative releases at the compliance boundaries. But if proof must be obtained that transport would be swift and conservative in the Rustler, then perhaps explorations must proceed step-wise, in order to be wholly convincing. Regulatory agencies should require completion of a geophysical and subsurface drilling program to obtain statistically relevant data characterizing fracture system geometry and karst-conduit geometry. Regional efforts in the realm of conventional surface hydrology are needed to confirm suspected partitioning of the recharge between the Malaga bend and Nash Draw discharge areas.

Summary Statement

Two of the three major barriers have been shown to be unreliable: neither repository containment nor transport processes guarantee satisfaction of the cumulative release limits of 40 CFR 191. DoE should rely solely on a favorable actinide source term that is brought about by incorporating optimum engineered barriers within the repository (but not in transport) to show compliance. Furthermore, retrieval of the waste after decades of loading is infeasible. Establishment of an alternative site and method of disposal may be necessary. The expense and delay, though burdensome, would serve the public interests better than failed emplacement at WIPP. A monitored retrievable storage facility, safely above the water table in stable rock openings is suggested. There are well-drained candidate sites in fractured tuffs or carbonates in other desert mountain ranges within government nuclear reservations.
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Abstract of

Comments on doe's Compliance Certification Application, 1996
For the Waste Isolation Pilot Plant, New Mexico

David T. Snow, Ph.D., P.E.

The complex but untested design of a proposed permanent underground storage facility for the nation's low-to-intermediate military nuclear waste deserves, but is not getting, the highly conservative treatment the public should expect. Flawed from the outset by brine in the salt beds and by the mechanical squeeze the plastic salt will inevitably impose on the waste drums, it is a certainty that any mobile radioactivity, such as brine may obtain by dissolving some of the plutonium, will ultimately be extruded upwards into shallow aquifers or to the surface. No conceivable seal design can withstand the extrusion, since fluid at pressures equal or more than the pressure of the rocks will fracture upwards along the boundaries of the seals, or along abandoned boreholes to the repository level. Otherwise, if defects in the salt strata prove weaker, fractures will break upwards to the aquifers. Similarly, hydraulic fracturing could occur to and drive brine through the repository in the event that oil-field pressure stimulation is continued in the vicinity, or if our progeny inadvertently sink exploration drill holes through the repository, intercepting highly-pressured brines that predictably underlie the repository.

Doc has relied upon the apparent properties of the Culebra dolomite, a likely path for travel from the repository to the accessible environment (distant about 5 km) in calculating total radionuclide releases that do not exceed the limits of 40CFR191 in the first 10,000 years. While tests in 30-odd boreholes span four orders of magnitude of hydraulic conductivity (on which speed of travel depends), none of the tests reveal the worst that is likely to exist. Evidence gathered at the surface (such as sinkholes into which storm-waters disappear, and more), as well as subsurface drill data largely obscured by low-technology coring techniques used in the past 30 years, support conservative opinions shared by many geologists that large solution conduits exist at shallow depths. Unlike the slow paths envisioned by DoE, the evident dissolution pathways typical of cavernous regions imply rapid groundwater movements from the region of the WIPP site to nearby Nash Draw. Consequently, the Culebra is not reliably characterized as a barrier to rapid flow or excessive radionuclide releases.

Failing to demonstrate in its application either that the underground repository can retain the radwaste by effective sealing, or by reason of the integrity of overlying strata to contain or delay it, DoE must rely wholly upon engineered barriers in the repository. While one chemical component has been proposed (MgO) as a partial backfill that will minimize plutonium solubility, Doc has not proposed other barriers that could absorb the brines to immobilize the potential effluent. In view of the above, the application should be rejected.
Conceptual Errors in the DOE Model of Groundwater Flow in the Rustler Formation
Richard Hayes Phillips, Ph.D.

The DOE model of groundwater flow in the Rustler Formation is a misrepresentation of reality. The Rustler is a fractured, karstic, anisotropic, artesian aquifer with three-dimensional flow. It should not be modeled as a porous, homogeneous, isotropic, confined aquifer with horizontal flow. The processes of matrix diffusion and clay sorption have not been demonstrated in the field; the values assumed for rock hydraulic properties are at variance with observed lithology and measured transmissivity; and the values assumed for rainwater recharge are unreasonable.

Cavernous Zones at the WIPP Site
Richard Hayes Phillips, Ph.D.

Evidence of karst at the WIPP site is gathered and presented. Zones of unconsolidated or cavernous rock in Rustler mudstone, in both the Forty-Niner and the lower unnamed members, are correlated stratigraphically across the WIPP site; a zone of dissolution in Tamarisk gypsum is identified; encounters of caverns in the Dewey Lake Redbeds are reported; and karst sinkholes at H-7, WIPP-33 and WIPP-14 are described in detail.

Rainwater Recharge at the WIPP Site
Richard Hayes Phillips, Ph.D.

Evidence of rainwater recharge at the WIPP site is gathered and presented. Mescalero caliche, Gatuná sandstone, and the Dewey Lake Redbeds are shown to be transmissive to rainwater recharge. Water in the Dewey Lake Redbeds is commonplace and potable; recharge tends to occur where the Santa Rosa Sandstone is not present. Groundwater and karst features are found in all members of the Rustler Formation. Water in the Culebra Dolomite is everywhere unsaturated, in places potable, and freshest where recharge is greatest.

Potential Flow Paths From the WIPP Site to the Accessible Environment
Richard H. Phillips, Ph.D.
and David T. Snow, Ph.D.

Flow paths from the WIPP site are primarily directed along karst channels and fracture system enlargements, allowing rapid transport to the accessible environment. Potential flow paths from the WIPP site to Nash Draw are identified, consistent with geophysical logs, lithologic descriptions, washouts during drilling, loss of core, loss of circulation of drilling fluid, caverns identified by drilling, multi-well pump tests, high transmissivity, hydraulic heads, groundwater geochemistry, dissolution of halite, distribution of salinity, karst geomorphology, air photo interpretation, sinkholes identified by augering, field observations of rainwater recharge at WIPP-33, field observations of groundwater discharge at Laguna Grande de la Sal, and the regional water balance.
RAINWATER RECHARGE AT THE WIPP SITE

by Richard Hayes Phillips, Ph.D.

The Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico, is intended for the permanent disposal of radioactive waste from nuclear weapons production. The WIPP site was selected in 1974. It is now 1997, and the Department of Energy (DOE) still does not know where the groundwater aquifers are recharged. This, at a minimum, must be understood, or DOE’s site characterization has no credibility (EEG-32, 1985; Anderson, 1994; Konikow, 1995; EEG-61, 1996; SEIS, 1996, Appendix H).

DOE’s failure to grasp the fundamentals of WIPP site hydrology stems not from a lack of evidence, but from an unwillingness to face the truth: (1) the WIPP site is in karst; (2) the Dewey Lake Redbeds and the Rustler Formation are recharged by rainwater; and (3) groundwater flow at WIPP is three-dimensional.

The controversy over karst at the WIPP site dates to a paper by Larry Barrows entitled: "WIPP Geohydrology -- The Implications of Karst" (Barrows, 1982; reprinted in EEG-32, 1985, Appendix A). Barrows cites as evidence of karst geomorphology: (1) ample precipitation; (2) lack of surf: ace runoff; (3) disappearing arroyos; (4) sink holes; and (5) underground caverns.

The WIPP site is located in one of the largest karstlands in the world. The Pecos River valley is famous for Santa Rosa Sinks, Bottomless Lakes, and Carlsbad Caverns. Within one mile of the northwest corner of the WIPP site is Nash Draw, a huge depression in the land surface, up to 18 miles long and 10 miles wide. Nash Draw was formed by the coalescence of thousands of sink holes caused by the abrupt collapse or gradual subsidence of overlying rocks into underground caverns beneath them.

Nash Draw is bounded on the east by Livingston Ridge, which is actually a rim, a 100-foot escarpment capped by Mescalero caliche. Livingston Ridge is not a geomorphic divide; it does not represent the eastern extent of karst conditions. It is the eastern extent of widespread collapse of surficial rocks into the voids caused by dissolution of evaporite rocks in the subsurface. Karst exists east of Livingston Ridge, but the karst landforms are not as widespread or as well developed as in Nash Draw.

The WIPP site has almost no surface runoff. This is not due to inadequate precipitation. Rainfall averages 14 inches per year, and 20 inches per year is not uncommon. Rather, the WIPP site is covered with windblown sand in the form of deflation basins and partially stabilized dunes. These sands are transmissive enough to allow infiltration of even the largest storms. "Instead of
running off, the precipitation collects in the small topographic depressions and rapidly soaks into the ground. The absence of surface runoff is characteristic of a karstland." (Barrows, 1982)

Most of the depressions are windblown. But some of the larger ones are sink holes, exemplified by WIPP-33 and WIPP-14, located 1.1 mile and 3.4 miles east of Nash Draw, respectively. WIPP-33 is a collapse sink with a disappearing arroyo, underlain by five caverns: one in Dewey Lake siltstone, two in Forty-Niner gypsum, and two in Magenta dolomite. WIPP-14 is a solution-subsidence doline which has held water in the geologic past; now the Culebra dolomite is underlain by 70 feet of mud with gypsum and anhydrite fragments, here interpreted as cave sediments. The cavernous zones at WIPP-33 and WIPP-14 are direct evidence of karst. These zones can be correlated stratigraphically with washouts and loss of core in seventeen other WIPP boreholes and in the WIPP ventilation shaft. The question is not whether karst exists at the WIPP site, but whether karst hydrology is active today.

The Rustler Formation is the most transmissive aquifer and the principal karst horizon at the WIPP site. If karst hydrology is active today, then the Rustler Formation must be recharged by rainwater. A likely process, according to Barrows (1982), is downward infiltration of fresh water through feeders in the overlying Dewey Lake Redbeds to karst channels in the Rustler Formation. Conversely, if karst hydrology is not active today, then the Rustler Formation must not be recharged by rainwater. This would require a continuous impermeable layer, acting as a barrier to rainwater infiltration, somewhere in the stratigraphic column above the Rustler Formation. Bachman (1985) argued that Mescalero caliche forms such a barrier, preventing infiltration and recharge of the Dewey Lake Redbeds and the Rustler Formation.

Caliche is a layer of calcium carbonate that forms in desert soils at the depth of soil water penetration. Where soil cover is thin, the caliche horizon may become plugged and indurated, forming a "hardpan" resistant to erosion and impervious to rainwater. But where soil cover is thick, infiltrating soil water may migrate along the caliche surface until it finds a fracture that allows downward drainage, or a hole where a plant root has penetrated the caliche; or it may collect in a small depression in the caliche surface and begin to dissolve a new hole in the caliche. In the southwestern part of the WIPP site (SW/4 sec 30, T 22 S, R 31 E), where Mescalero caliche is in direct contact with the Dewey Lake Redbeds, trench exposures revealed fifteen solution pipes, 1 to 14 feet in diameter, right through the caliche. Here the Dewey Lake Redbeds are recharged directly by rainwater. These trenches were located in a karst valley, a broad swale one mile long, ten feet deep, trending east-west, and narrowing from 900 feet in the east to 200 feet in the west, where thick groves of mesquite bushes are impenetrable.
Other smaller topographic depressions, visible in the WIPP site air photos, shown on USGS topographic maps, lead directly to the deepest fluvial incisions in Livingston Ridge. The air photos reveal ephemeral or near-surface drainage courses expressed at the land surface as vegetation in dendritic patterns.

The Gatuna Formation, consisting of light reddish-brown, poorly consolidated sandstone, is alluvial fill material deposited in ancient sinks and topographic lows by westward-flowing streams. It was exposed in trenches on the slopes of WIPP-33, below the caliche escarpment. The Gatuna sandstone is commonly fractured, jointed, and broken into blocks. As soil water dissolves the carbonate cement, these openings become enlarged by solution, forming solution pans or tinajitas, and solution grooves or slots. The Gatuna is not a barrier to rainwater infiltration.

The Santa Rosa Formation consists of pale orange, coarse-grained sandstone, cemented by dolomite, interbedded with conglomerate lenses containing dolomite, chert, and quartz pebbles. The Santa Rosa has been eroded from the western part of the WIPP site; to the east, where it remains, it protects the underlying Dewey Lake Redbeds from erosion. At WIPP-14, the Santa Rosa was exposed in trenches beneath a leached and degraded caliche profile. The Santa Rosa exhibited carbonate-filled fractures, direct evidence of rainwater infiltration. The Santa Rosa retards, but does not prevent, rainwater recharge to the underlying Dewey Lake Redbeds.

Water has been encountered in the Dewey Lake Redbeds in eleven test wells within one mile of the WIPP site. All are listed in Table 1. According to the neutron log for H3-b4, a down-hole camera recorded "water streaming from fracture." The water level was 466.85 feet below the surface. Water was also observed in the Dewey Lake Redbeds in the air intake shaft near the center of the WIPP site (EEG-61, 1996, p. 2-6), at WIPP-33 (SAND 80-2011, p. 11), and in three private wells within 2.5 miles of the WIPP site (Ranch, Barn, and Unger). All are shown in Figure 1.

Table 1 reveals a strong correlation between encounters of water in the Dewey Lake Redbeds and absence of the overlying Santa Rosa sandstone. At least nine of the thirteen test wells where the Santa Rosa is not present produced water in the Dewey Lake Redbeds. It is not certain that the other four (H-6, P-14, WQSP-5, and Cabin Baby) did not produce water in the Dewey Lake Redbeds, because the actual neutron logs for these test wells are unavailable. However, the "abridged drill-hole histories" for P-13 (located 224 feet from the H-6 hydopad) and P-14 do not report water in the Dewey Lake Redbeds. Only two of the twenty test wells where the Santa Rosa is present produced water in the Dewey Lake Redbeds. At these test wells (H-11 and H-16) the Santa Rosa is only 54 feet and 15 feet thick, respectively. This is further evidence that the Santa Rosa retards, but does not prevent, rainwater recharge to the underlying Dewey Lake Redbeds.
FIGURE 1: TOTAL DISSOLVED SOLIDS mg/l, CULEBRA DOLOMITE

CONTOUR INTERVAL 50,000 mg/l

© WATER IN DEWEY LAKE REDBEDS

WIPP SITE BOUNDARY

MILES

0 1 2
<table>
<thead>
<tr>
<th>Test well</th>
<th>Santa Rosa thickness</th>
<th>Water in Dewey Lake</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-1</td>
<td>N.P.</td>
<td>*</td>
</tr>
<tr>
<td>H-2</td>
<td>N.P.</td>
<td>*</td>
</tr>
<tr>
<td>H-3</td>
<td>N.P.</td>
<td>*</td>
</tr>
<tr>
<td>H-4</td>
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<tr>
<td>H-5</td>
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<tr>
<td>H-6</td>
<td>N.P.</td>
<td>?</td>
</tr>
<tr>
<td>H-11</td>
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<td>*</td>
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<tr>
<td>H-14</td>
<td>N.P.</td>
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<tr>
<td>H-15</td>
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<tr>
<td>H-16</td>
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<tr>
<td>H-17</td>
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<tr>
<td>H-18</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>P-14</td>
<td>N.P.</td>
<td>?</td>
</tr>
<tr>
<td>P-15</td>
<td>N.P.</td>
<td>*</td>
</tr>
<tr>
<td>P-17</td>
<td>N.P.</td>
<td>*</td>
</tr>
<tr>
<td>P-18</td>
<td>78</td>
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<td>Cabin Baby</td>
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<tr>
<td>WQSP-1</td>
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<tr>
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<tr>
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<td>WQSP-5</td>
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<td>WQSP-6</td>
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</tr>
<tr>
<td>WQSP-6a</td>
<td>N.P.</td>
<td>*</td>
</tr>
</tbody>
</table>

Note: WQSP-6 and WQSP-6a are shown as one well in Figures 5 and 6.

Sources: DOE/CAO 1996-2184, pp. 2-131, USDW-25; SAND 88-0157, p. 81; SAND 80-2011, pp. 8, 11, 15, C-3; and EEG-61, p. 2-6.
Figure 2 graphically displays the relationship between the western edge of the Santa Rosa sandstone and the locations of wells that produce water in the Dewey Lake Redbeds. Simply stated, the recharge area for the Dewey Lake Redbeds is everywhere that the Santa Rosa Formation is not present.

The water in the Dewey Lake Redbeds is potable. Environmental Protection Agency (EPA) criteria for drinking water are twofold: (1) less than 10,000 milligrams per liter (mg/l) total dissolved solids (TDS); and (2) more than 5 gallons per minute (gpm) of water produced by the well. Water quality data for the Dewey Lake Redbeds are given in Table 2. Five private wells within eight miles of the WIPP site produce water of potable quality in the Dewey Lake Redbeds, but the quantity has never been measured. Three WIPP test wells produce water in sufficient quantity from the Dewey Lake Redbeds, but the quality has never been tested. At seven WIPP test wells, (and also at WIPP-33), water produced by the Dewey Lake Redbeds has never been tested for quality or quantity. At only one test well, WQSP-6a, has both the quality and quantity of water from the Dewey Lake Redbeds been tested, and it was found to meet both criteria for drinking water (3,920 to 4,238 mg/l TDS, 12 gpm). DOE claims (DOE/CAO 1996-2184, Appendix USDW, Table USDW-4) that test well WQSP-6a is not subject to EPA standards (40 CFR 191, Subpart C) because WQSP-6a is located on-site -- one mile southwest of the center of the WIPP site, 0.3 miles southwest of the waste emplacement panels (DOE/CAO 1996-2184, Figure 3-9). DOE says it is "possible" that other test wells are subject to EPA standards (DOE/CAO 1996-2184, Appendix USDW, Table USDW-4). DOE does not know because DOE has not done the necessary testing. P-17 is 3908 feet outside the WIPP site. WIPP-33 is 2854 feet outside the WIPP site. P-18 is 446 feet outside the WIPP site. All the private wells are outside the WIPP site. Until these wells are properly tested, it cannot be claimed that the Dewey Lake aquifer does not qualify as an underground source of drinking water under 40 CFR 191, Subpart C. Absence of evidence is not evidence of absence.

Directly underlying the Dewey Lake Redbeds is the Rustler Formation. In WIPP boreholes, outside of Nash Draw, the Rustler ranges in thickness from 276 feet at WIPP-33, a collapse sink, to 462 feet at P-18, considered to be a complete Rustler section. The Rustler is divided into five members, here described in descending order: (1) the Forty-Niner member consists of 48 to 78 feet of broken and slumped gypsum with a bed of massive siltstone near the base; (2) the Magenta dolomite, 19 to 28 feet thick, is a highly fractured aquifer; (3) the Tamarisk member consists of 80 to 179 feet of anhydrite or gypsum with clay seams; (4) the Culebra dolomite, 21 to 31 feet thick, also highly fractured, is the most transmissive of the Rustler aquifers; and (5) the lower unnamed member consists of 72 to 150 feet of siltstone and very fine-grained sandstone, with interbedded gypsum or anhydrite.
FIGURE 2: RECHARGE AREA AT WIPP SITE
TABLE 2: WATER IN THE DEWEY LAKE REDBEDS, GALLONS PER MINUTE, TOTAL DISSOLVED SOLIDS

<table>
<thead>
<tr>
<th>well</th>
<th>gpm</th>
<th>TDS (mg/l)</th>
<th>date</th>
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<tbody>
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<td></td>
</tr>
<tr>
<td>H-2</td>
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<td></td>
</tr>
<tr>
<td>H-3</td>
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</tr>
<tr>
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<tr>
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<tr>
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Notes: WIPP-33 encountered 7.0-foot cavity in Dewey Lake Redbeds; fluid level during logging was 274 feet below land surface.

Criteria for drinking water: < 10,000 mg/l TDS and ≥ 5 gpm.

The Culebra and Magenta dolomite members are persistent marker beds and reliable aquifers. In forty-one WIPP test wells, the Culebra was always saturated; the Magenta was dry at H-7 and WIPP-26, and is absent at WIPP-29, all in Nash Draw (Mercer, 1983, Table 8). But water is sometimes found in the other members of the Rustler, even near the center of the WIPP site. Water was observed seeping into the WIPP ventilation shaft from a zone of solution residue in the Forty-Niner member, 17.7 to 30.2 feet above the Magenta; test well H-1 yielded as much water in the Tamarisk member as in the Culebra or Magenta; and test well H-3 yielded as much water in the lower unnamed member as in the Culebra or Magenta (EEG-32, 1985, pp. 37, 39). Potash test holes P-4, P-12, P-13 and P-17 hit water in the lower unnamed member.

Karst features have been observed in Dewey Lake siltstone, Forty-Niner gypsum, Magenta dolomite, Tamarisk anhydrite, and Culebra dolomite. Lost circulation of drilling fluid has been reported in the Dewey Lake Redbeds at H-7c, P-1, DOE-2, WIPP-25 and WIPP-33; in Forty-Niner gypsum at H-1 and WIPP-33; and in Magenta dolomite at WIPP-33. Four boreholes clustered near the center of the WIPP site have encountered washouts or loss of core in Tamarisk anhydrite (H-1, H-2, H-3 and ERDA-9). Five cavernous zones were encountered in Culebra dolomite at H-7c. Just three miles from the WIPP site in Nash Draw, at the Gnome Site turnoff, a surface exposure of Forty-Niner gypsum features a striking display of grikes, tunnels, caves, and collapse sinks; at least one of the caves is large enough to enter. These caves supply fresh water to deeper Rustler aquifers (EEG-39, 1988).

Thus it is shown that rainwater recharge to the Rustler Formation is possible, that no impermeable barrier exists above the Culebra dolomite. The question is whether or not rainwater recharge is actually occurring. This question can be answered by looking at the geochemistry of groundwater in the Culebra dolomite.

Total dissolved solids (TDS) in Culebra groundwater has been measured in 38 WIPP test wells [Table 3]. In some cases there have been multiple samplings at the same test well; in these cases the lowest measured values are presented in Table 3, as they are the most likely to represent mixing of groundwater with fresh water, and the least likely to represent contamination by brine from nearby injection wells. Table 3 reveals that TDS in Culebra groundwater in WIPP test wells vary by nearly two orders of magnitude, from 239,000 mg/l at WIPP-29 to 2,710 mg/l at H-8. When the wells are plotted on a map [Figure 1], it is shown that even within the WIPP site, TDS in Culebra groundwater vary by a factor of 25 -- from 230,000 mg/l at H-15 to 8,890 mg/l at H-2b. These two test wells are less than 8,750 feet (1.66 miles) apart.

Figure 1 shows contour lines of TDS at a contour interval of 50,000 mg/l. The contour lines display a zone of high TDS in the northeastern part of the WIPP site, where the Santa Rosa
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Sources: Mercer, 1983 (USGS-WRI 83-4016, Table 8); Ramey, 1985 (EEG-31); Chapman, 1988 (EEG-39); Lappin et al., 1989 (SAND 89-0462, Table 3-12); DOE/CAO 1996-2184, Appendix USDW, Table USDW-2; Annual Site Environmental Reports, 1992-1995.
sandstone is present, with TDS steadily decreasing to the southwest, where the Santa Rosa is absent. This is consistent with the interpretation that Culebra groundwater becomes mixed with increasing amounts of fresh water as it approaches Nash Draw, because the hydrologic regime is increasingly karstic.

A similar observation was made by Chapman (EEG-39, 1988). She concluded (p. 35) that "the only plausible mechanism" for an order of magnitude decrease in TDS as Culebra groundwater moves along its flow path "is the influx of a large quantity of low TDS water. As no fresh-water aquifers are located in the WIPP area, the source of the fresh water must be surface water recharge."

Test wells known to have produced water in the Dewey Lake Redbeds are depicted as bull's eyes in Figure 1. At ten of these wells, TDS in the Culebra dolomite were measured; and in seven of these, the lowest measurement was 36,000 mg/l or less (H-16 was measured only once). According to Ramey (EEG-31, 1985): "Waters with greater than 35,000 mg/l of total dissolved solids are classified as brines." Thus, Culebra water in the recharge area, where the Santa Rosa is absent, is fresh enough not to be classified as brine. In fact, Culebra water at H-2b is potable (8,890 mg/l TDS). H-2b is on-site. DOE has tested the quality, but not the quantity, of Culebra water at H-2b. Five private wells within ten miles of the WIPP site produce water of potable quality in the Culebra dolomite, but the quantity has never been measured. Three test wells outside the WIPP site -- H-7bl, H-8b and H-9b -- produce water of sufficient quality and quantity (less than 10,000 mg/l TDS and more than 5 gpm) to meet EPA criteria and establish the Culebra as an underground source of drinking water under 40 CFR 191, Subpart C. Test well H-7bl is located only 2.9 miles from the WIPP site, in Nash Draw, along a potential groundwater flow path from WIPP to the accessible environment. Water quality data for the Culebra dolomite are given in Table 4. Thirteen wells which produced potable water are shown in Figure 3.

Conclusions: (1) karst landforms exist at the WIPP site, and karst hydrology is active at the WIPP site today; (2) rainwater infiltrates through solution pipes in Mescalero caliche, solution features in Gatuna sandstone, and fractures in the Dewey Lake Redbeds; (3) cavernous zones have been found, in WIPP boreholes, in Dewey Lake siltstone and in every member of the Rustler Formation -- in Forty-Niner gypsum, Magenta dolomite, Tamarisk anhydrite, Culebra dolomite, and mudstone of the lower unnamed member; (4) water has been found at the WIPP site in the Dewey Lake Redbeds and in every member of the Rustler Formation: (5) the Dewey Lake Redbeds and the Culebra dolomite contain potable water at and near the WIPP site, which can only be explained by rainwater recharge; (6) the recharge area for the Dewey Lake Redbeds and the Rustler Formation is at and near the WIPP site, everywhere that the Santa Rosa sandstone is not present; and (7) groundwater flow in the Rustler Formation is three-dimensional.
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Criteria for drinking water: < 10,000 mg/l TDS and > 5 gpm.
FIGURE 3: POTABLE WATER NEAR WIPP SITE
(less than 10,000 mg/L TDS)
TO: U.S. Environmental Protection Agency (EPA)  
Office of Radiation and Indoor Air  
401 M Street SW  
Washington, DC 20460

FROM: Richard Hayes Phillips, Ph.D.  
Citizens for Alternatives to Radioactive Dumping (CARD)  
144 Harvard SE  
Albuquerque, NM 87106

RE: DOE Response to Comments made to EPA by CARD on the DOE's CCA

Rebuttal to DOE Response to “CARD Comments 7 to 22,” pages 26-46

On March 17, 1997, CARD mailed to the EPA, in duplicate, nine scientific papers by five authors, in response to the Compliance Certification Application (CCA) by the Department of Energy (DOE) regarding the Waste Isolation Pilot Plant (WIPP), which DOE seeks permission to open. CARD also resubmitted Richard Hayes Phillips’ doctoral dissertation entitled: “Prospects for Regional Groundwater Contamination due to Karst Landforms in Mescalero Caliche at the WIPP Site near Carlsbad, New Mexico.” On May 16, 1997, without waiting for a response to CARD from DOE, the EPA Administrator informed DOE that EPA had deemed the CCA complete. On July 3, 1997, DOE submitted to EPA an anonymous 75-page response to CARD’s “comments.” Neither DOE nor EPA informed CARD of DOE’s response, and no copy was ever sent to CARD. Nor was CARD informed that the public comment period on the CCA had been extended to August 7, 1997, which could have given CARD an opportunity to rebut the DOE. On September 30, 1997, shortly after receiving a copy of DOE’s response from other sources, Dr. Phillips mailed to EPA a notarized letter stating his intention to write a rebuttal to DOE’s response, and asking for sufficient time to do so. On October 16, 1997, Lawrence G. Weinstock of EPA sent to Dr. Phillips a letter refusing to accept any further submissions until after the issuance of a proposed decision by EPA. On October 27, 1997, EPA published in the Federal Register its proposed decision to open WIPP, denying CARD the opportunity to rebut the DOE.

Five of the scientific papers submitted by CARD on March 17, 1997 concerned karst hydrology in the Rustler Formation. These papers were written by Drs. Richard H. Phillips and David T. Snow. The DOE, in its response, made no reference to Phillips’ doctoral dissertation, and reprinted verbatim some, but not all, of the other works of Phillips and Snow. DOE may not have wanted the EPA to read the parts of CARD’s work that deal with karst hydrology, rainwater recharge, groundwater flow paths, or conceptual errors and misrepresentative data used by DOE. Dr. Phillips, along with his notarized letter of September 30, 1997, resubmitted to EPA the parts of CARD’s work which DOE chose not to reprint, but rather to “summarize.” Phillips wrote: “Our work speaks for itself. We have a right to be judged according to what we actually said, not according to what the DOE says we said.”

The following is CARD’s rebuttal to DOE’s response to “CARD Comments 7 to 22,” the parts which DOE may not have wanted EPA to read. Our rebuttal begins by reexamining CARD’s original reports, identifying the passages which stand uncontested, and restating our original findings together with additional evidence to support them. We then present a point-by-point rebuttal to DOE’s response. As a convenience to the reader, CARD has numbered the arguments made by the DOE, and has numbered the paragraphs of CARD’s rebuttal correspondingly.
CARD urges all readers not to begin with DOE’s response, as EPA appears to have done. A more objective procedure is to begin with the original works submitted by CARD on March 17, 1997, then to read DOE’s response to CARD, and finally to read CARD’s rebuttal to DOE.

CAVERNOUS ZONES AT THE WIPP SITE

Most of CARD’s original paper by the above title stands uncontested. DOE has long held that the Culebra dolomite member of the Rustler Formation is the most likely pathway for contaminated water to travel from the WIPP site to the accessible environment. The Culebra is highly fractured, and the effective groundwater flow paths are through the largest fractures. Dolomite is a soluble rock; it slowly dissolves when exposed to water. As fractures become enlarged by solution, they become even more effective groundwater flow paths. The larger the diameter of the solution conduits, the less contact the radionuclides will have with the surrounding rock and the less the retardation of radionuclides.

Recent pumping tests in the Culebra dolomite have shown certain WIPP test wells to be hydraulically connected. These include DOE-2, WIPP-13 and H-6 in the northwestern part of the WIPP site, and H-3, DOE-1 and H-11 in the southeastern part of the WIPP site. DOE interprets these hydraulic connections as fracture networks, and takes issue with CARD’s contention that they could be karst channels in or near the Culebra.

CARD’s original report was based on the multiwell pump tests centered in the Culebra at test wells H-3 and DOE-2. CARD has since become aware of the multiwell pump test centered in the Culebra at test well WIPP-13. Response times were even more rapid; DOE-2, which is 4835 feet (0.92 miles) from WIPP-13, “responded within one hour to the beginning of pumping,” and H-6, which is 7137 feet (1.35 miles) from WIPP-13, “responded within 8 hours.” (CCA, Appendix SUM, p. 110) The delay in maximum drawdown at H-6, relative to the time at which the pump at WIPP-13 was turned off, was only 5 hours (CCA, Appendix SUM, Table 4.7). The apparent transmissivity between WIPP-13 and DOE-2 is 57 ft²/day; between WIPP-13 and H-6 it is 69 ft²/day (CCA, Appendix SUM, p. 114).

The WIPP-13 pump test also showed efficient hydraulic connections to test wells P-14 and WIPP-25. At P-14, which is 13,897 feet (2.63 miles) from WIPP-13, the first drawdown was in 71 hours, and the delay in maximum drawdown was 56 hours (CCA, Appendix SUM, Table 4.7). The apparent transmissivity between WIPP-13 and P-14 is 260 ft²/day (CCA, Appendix SUM, p. 114). P-14, which is located 4664 feet west of the current WIPP site boundary, is the only test well between the WIPP site and Nash Draw; its transmissivity was previously measured (in single-well tests) at 324 ft²/day (LaVenue et al., 1988, SAND 88-7002, Table C.1), the highest measured transmissivity east of Nash Draw. At WIPP-25, which is located in Nash Draw, 20,421 feet (3.87 miles) from WIPP-13, the first drawdown was in 76 hours, and the delay in maximum drawdown was only 26 hours (CCA, Appendix SUM, Table 4.7). The apparent transmissivity between WIPP-13 and WIPP-25 is extremely high, 650 ft²/day (CCA, Appendix SUM, p. 114). Figure 2 of CARD’s original paper should be altered accordingly, with test wells P-14 and WIPP-25 depicted as bull’s eyes.

The demonstrated hydraulic connection between test wells WIPP-13 and WIPP-25 is proof of karst hydrology at the WIPP site. Here is why:
WIPP-13 is located within the WIPP site, 2714.3 feet (0.51 miles) inside the northern boundary, and 7010.6 feet (1.33 miles) inside the western boundary. WIPP-25 is located in Nash Draw, about one-half mile from Livingston Ridge. Located almost exactly midway between WIPP-13 and WIPP-25 is borehole WIPP-33 (1.87 miles west of WIPP-13, and 2.02 miles east of WIPP-25). DOE, in its response to CARD, agrees that “Nash Draw and WIPP-33 are karstic features.” (EPA Docket, A-93-02, Item # II-H-46, p. 27). DOE, in its response to the Peer Review Panel, admits that open fractures have been observed in the Magenta dolomite at WIPP-13 (CCA, p. 9-29). The lithological log for WIPP-13 describes the Magenta dolomite as “broken and shattered by numerous fractures dipping 60°-80° and displacing bedding planes 0.5-1.0 cm;” it describes the Tamarisk member as having a zone of mudstone/gypsum breccia and steeply dipping fractures throughout, one of them filled only with silt; and it describes the Culebra dolomite as being “highly fractured,” with “numerous solution pits,” and underlain by 8 feet of soft, fissile mudstone with poor core recovery. The Culebra and Magenta hydraulic heads are believed to be equal at WIPP-13 and are known to be equal at WIPP-25, where Magenta transmissivity had been measured (in single-well tests) at 375 ft²/day. At WIPP-33 no hydrologic data were taken, but five water-filled caverns were found - two in Magenta dolomite, two in Forty-Niner gypsum, and one in Dewey Lake siltstone. WIPP-33 is the westernmost of a chain of four sinkholes, all of which DOE now concedes to be karst features (EPA Docket, A-93-02, Item # II-H-46, p. 31); they are almost perfectly aligned with WIPP-13. The response time between WIPP-13 and WIPP-25 was extraordinarily rapid - a delay in maximum drawdown of only 26 hours between test wells nearly four miles apart. There was also a measurable response at the WIPP exhaust shaft, 1.50 miles southeast of WIPP-13 (CCA, Appendix SUM, Table 4.7), which suggests an existent flow path from the WIPP repository all the way to Nash Draw. Beauheim (1987, SAND87-2456, pp. 45, 47) and LaVenue et al. (1988, SAND 88-7002, p. 6-3) state that a higher transmissivity zone between WIPP-13 and the WIPP shafts is necessary to explain the response; this is borne out by a recently reported Culebra transmissivity of 31.0 ft²/day at WQSP-1, located 0.51 miles south of WIPP-13 (CCA, Appendix TFIELD, Table TFIELD-2). DOE still insists that groundwater flow associated with Nash Draw is unrelated to groundwater flow at WIPP (SEIS-II, p. 4-21). This claim has never been substantiated; now it is disproven.

CARD’s original paper correlates and presents borehole data showing washouts and consistent loss of core in two distinct horizons of Rustler mudstone: in the Forty-Niner member about 20 feet above the Magenta, and in the lower unnamed member immediately beneath the Culebra. These are not occasional occurrences. CARD, in Tables 2 and 3, succinctly summarizes 12 such encounters above the Magenta and 14 beneath the Culebra, all of them at or near the WIPP site. CARD describes a similar horizon in the Tamarisk member, with washouts or loss of core in 5 locations and reports of dissolution residue in 7 others. DOE denies that these are evidence for caverns, citing DOE’s own poor coring techniques, and DOE denies that these are dissolution residues, thereby challenging the validity of DOE’s own lithologic logs (EPA Docket, A-93-02, Item # II-H-46, p. 30). CARD has since discovered the caliper log for the WIPP exploratory shaft, which records washouts in nearly the same stratigraphic horizons: in the Forty-Niner member, 574-583 feet below the surface, 18 feet above the Magenta dolomite; in the Tamarisk member, 686-694 feet below the surface, 5 feet above the Culebra dolomite; and in the lower unnamed member, 732-742 feet below the surface, 15 feet below the Culebra dolomite (TME 3178, Figure 3, Sheet 2). The washout in the Tamarisk member would correlate with the dissolution residue of siltstone and gypsum breccia found immediately above the Culebra at WIPP-19, interpreted by some as cave filling (Ferrall and Gibbons, 1980, SAND 79-7110).
CARD’s original paper describes in detail six karst sinkholes in the vicinity of WIPP: one at H-7, four at WIPP-33, and one at WIPP-14. DOE concedes that H-7 is a sinkhole, being located in Nash Draw, where the occurrence of karst and collapse features is to be expected (EPA Docket, A-93-02, Item # II-H-46, p. 31). DOE concedes that WIPP-33 is a sinkhole and, for the first time, concedes that three other depressions, east of WIPP-33, closer to the current WIPP site boundary, first identified by Phillips (1987, Chapter IV), are sinkholes as well (EPA Docket A-93-02, Item # II-H-46, p. 31). DOE appears to deny that WIPP-14 is a sinkhole (EPA Docket A-93-02, Item # II-H-46, p. 32), perhaps because this one straddles the current WIPP site boundary; but upon closer examination, what DOE has written is a classic “non-denial denial,” reminiscent of Watergate press conferences. CARD never stated that WIPP-14 is a collapse sink; the WIPP-14 depression is an alluvial doline (solution-subsidence doline) 600 feet in diameter, 9 feet deep, with 15 feet of alluvial fill, but there is no evidence of collapse. For this reason DOE can claim that the WIPP-14 borehole exhibited a “normal stratigraphic sequence,” even though the Culebra is immediately underlain by 71.4 feet of mud (not mudstone – mud) with gypsum and anhydrite fragments, an occurrence reported nowhere else east of Nash Draw. CARD interprets this material as cave sediments, and DOE has offered no alternative explanation. DOE truncates the words of Barrows et al. (1983, p. 57), who stated that WIPP-14 is an alluvial doline and attributed the high-amplitude negative gravity anomaly measured at WIPP-14 to conversion of anhydrite to gypsum “in the vicinity of karst conduits.” The observation by CARD that all halite has been removed from the Rustler at WIPP-14 is indeed “not consistent with the interpretation of Holt and Powers,” who claim that there has been no dissolution in the Rustler, that halite was never deposited where today it is absent; however, CARD is unaware of anyone outside of DOE, Sandia Labs and EPA who agrees with Holt and Powers. Not only does DOE fall short of denying that WIPP-14 is a sinkhole; the CCA confirms it. CARD has since discovered this passage in Appendix DEF (p. DEF-30): “Only a few small clusters of shallow dolines on the Mescalero caliche have been identified on the Los Medanos plateau east of Livingstone (sic) Ridge.” DOE refers the reader to Figure DEF-7, where the karst features are depicted with three black dots; at WIPP-33, WIPP-13, and WIPP-14.

RAINWATER RECHARGE AT THE WIPP SITE

DOE still does not know where the groundwater aquifers are recharged. In the CCA (Appendix HYDRO, p. 51) it is “suggested” that the Rustler Formation is recharged at Bear Grass Draw, some 25 miles north of the WIPP site; this was pure speculation, dating to a report by Robinson and Lang (1938). In the Draft SEIS-II (1996, p. 4-18) it is stated that recharge “probably” occurs 10 to 20 miles northwest of WIPP, where the Rustler Formation reaches the surface; this would be in Clayton Basin, which Hunter (1985) has shown to be hydraulically separated from the WIPP site (Phillips, 1987, Figure 75). In the Final SEIS-II (1997, p. 4-21), DOE changed its mind again and “suggested” that recharge originates “in areas that are north and northeast of the WIPP site.” DOE’s latest suggestion is not based on field observation or measured data; it is, in the words of EPA, “assumed” and “theorized” by DOE; it is a “new conceptualization” designed to explain the long-standing inconsistency between observed geochemistry and groundwater flow paths (EPA Docket, A-93-02, Item # III-B-3, pp. 77-78).

CARD, in Figures 1 and 2 of its original paper by the above title, has identified and mapped the recharge area for the Dewey Lake Redbeds and the Rustler Formation. Simply stated, the
recharge area is in the south-central and southwestern part of the WIPP site and south of the site, everywhere that the Santa Rosa sandstone is not present. At least 9 of 13 test wells in this area produced water in the Dewey Lake Redbeds. In 7 of 10 Culebra test wells in this area, total dissolved solids (TDS) were measured at 36,000 mg/l or less, fresh enough to be classified as brackish. This is consistent with the interpretation that Culebra groundwater becomes mixed with increasing amounts of fresh water as it approaches Nash Draw, because the regime becomes increasingly karstic, recharged through sinks or swallows.

DOE cannot and does not deny any of this. DOE admits in the CCA and in SEIS-II that the Dewey Lake “contains a productive zone of saturation, probably under water-table conditions, in the southwestern to south-central portion of the WIPP site and south of the site.” The saturated zone is typically found in the middle of the Dewey Lake, 180 to 265 feet below the surface, “and appears to derive much of its transmissivity from open fractures.” The saturated zone “may be perched or simply underlain by less transmissive rock.” Fractures below the saturated zone “tend to be completely filled with gypsum” (CCA, p. 2-131; SEIS-II, 1997, p. 4-29). DOE described the Dewey Lake Redbeds in this area as “relatively transmissive” (SEIS-II, 1997, p. 4-21), but DOE refuses to acknowledge rainwater recharge in the area.

EPA noted that these fracture fillings may be caused by infiltration of rainwater, and that the CCA did not adequately describe the fracture characteristics, the fracture density, the percentage of fractures filled and partially filled, or what caused the fractures in the first place (EPA Docket, A-93-02, Item # III-B-3, pp. 39-40). DOE alleviated EPA’s concerns by stating that the Dewey Lake Redbeds have “not produced water within the WIPP shafts, or in boreholes in the immediate vicinity of the waste panels” (EPA Docket, A-93-02, Item # III-B-3, p. 84; see also CCA, pp. 2-98, 2-131), and that the Dewey Lake “exhibits no flow at the WIPP site” (EPA Docket, A-93-02, Item # III-B-3, p.65). These statements are false, for the following reasons: (1) The Dewey Lake Redbeds have produced water in the WIPP exhaust shaft at approximately 100 feet below the surface, which EEG says “can be traced to recharge” (EPA Docket, A-93-02, Item # II-E-36, p. 3). The Dewey Lake produced water in the air intake shaft as well (EEG-61, 1996, p. 2-6). (2) The Dewey Lake Redbeds have produced water in four test wells in the immediate vicinity of the waste panels (H-1, H-2, H-3 and WQSP-6) (EEG-61, 1996, p. 2-6). One of these wells, H-1, is located directly above the waste panels (CCA, Appendix DEF, Figure DEF-8). (3) The Dewey Lake Redbeds exhibit flow at the WIPP site. Test well P-9 (the H-11 hydropad) produced 25 gallons per minute, and WQSP-6 produced 28 gallons per minute (EEG-61, 1996, p. 2-6). According to the neutron log for H3-b4, a down-hole camera recorded “water streaming from fracture” at 466.85 feet below the surface, 200 feet below the so-called “saturated zone,” in a horizon where, according to DOE, “fractures tend to be completely filled with gypsum.” (CCA, p. 2-131; SEIS-II, 1997, p. 4-29). This open, water-filled fracture is only 35 feet above the Rustler Formation, which leads to the inescapable conclusion that, in the immediate vicinity of the waste panels, the Dewey Lake Redbeds contain feeder channels which readily transmit water from the surface to the Rustler Formation.

DOE’s original fallback position was that the Rustler anhydrites, siltstones and claystones are confining layers (CCA, pp. 2-127, 2-128), barriers to rainwater infiltration. In performance assessment, the Forty-Niner, Tamarisk, and lower unnamed members are assigned a permeability of zero (CCA, pp. 6-123, 6-147, 6-148). This is consistent with testing of unaltered anhydrite core samples in the laboratory. It is not consistent with occasional reports of Rustler claystones producing water at rates equivalent to the Culebra or Magenta (Mercer and Orr, 1979; Mercer, 1983; Chaturvedi and Channell, 1985, pp. 37, 39; Beauheim, 1986; LaVenue et al., 1988, p. 2-5;
Lappin, 1989, Table 4-3, reprinted as CCA, Appendix SUM; Jones et al., 1992, p. 2-12). Clearly, DOE's assumption that rainwater recharge never reaches the Rustler Formation was unwarranted. Under pressure from EPA, "DOE concluded that the presence of anhydrite within Rustler units does not preclude slow downward infiltration, as had been previously argued by DOE." (EPA Docket, A-93-02, Item # III-B-3, p. 78)

Based on an assumption of "extremely slow vertical leakage" (CCA, Appendix MASS, p. MASS-72), DOE concluded that the travel time for infiltrating rainwater to reach the Culebra is "probably thousands or tens of thousands of years." (CCA, Appendix MASS p. MASS-75) According to DOE, this equates to an infiltration rate of 0.2 to 2.0 mm/yr (EPA Docket, A-93-02, Item # II-H-46, p. 37), which amounts to only 0.05% to 0.5% of annual precipitation (40 cm/yr). This would require a continuous, impermeable layer, acting as a barrier to rainwater infiltration, somewhere in the stratigraphic column above the Rustler Formation. If it is not the Dewey Lake Redbeds, then it would have to be the dune sands or the Mescalero caliche, because the Santa Rosa and Gatuna formations are not continuous at the WIPP site.

The lack of surface runoff at the WIPP site indicates that the surface sands are transmissive enough to allow infiltration of even the largest storms. EPA states that about 75% of total annual precipitation results from intense thunderstorms between April and September (EPA Docket, A-93-02, Item # III-B-3, p. 88). Phillips (1987, Chapter IV) stood in one of these thunderstorms and observed one of the few small arroyos at the WIPP site, draining into the WIPP-33 depression; five feet of standing water sank into the sand within days.

As evidence for a continuous barrier to rainwater recharge and karst hydrology at the WIPP site, EPA cites the Mescalero caliche. "DOE indicated that the Mescalero caliche is typically present beneath the sand." (EPA Docket, A-93-02, Item # III-B-3, pp. 58-59) DOE stated that the Mescalero "covers the WIPP area as a hard, caliche crust," and DOE indicated that the caliche is up to 10 feet thick (EPA Docket, A-93-02, Item # III-B-3, p. 43), which led EPA to conclude that karst development is not a threat to waste containment at WIPP (EPA Docket, A-93-02, Item # III-B-3, p. 52). DOE also said, in the CCA, that the Mescalero caliche "is expected to be continuous over large areas," but that "WIPP data are limited mainly to boreholes." (CCA, p. 2-60). EPA did complain that "a site-specific detailed map of the Mescalero caliche distribution was not provided in the CCA" (EPA Docket, A-93-02, Item # III-B-3, p. 43).

EPA is referred once again to Richard Hayes Phillips' doctoral dissertation, the only extensive work on the surficial geology of the WIPP site and vicinity. EPA has three copies, including one with color photographs submitted at public hearings in Albuquerque in 1990. There is no confirmation that anyone in EPA has read it, or factored into deliberations the relevance of its findings.

Phillips' dissertation contains 16 site-specific detailed maps of the Mescalero caliche surface, based on 1000 augur holes and 10 backhoe trenches, including WIPP-14 and the chain of four sinkholes at WIPP-33. Four of these trenches, described in Chapter V, were located in the eastern end of a karst valley, within the WIPP site (SW ¼ sec 30, T 22 S, R 31 E), within the rainwater recharge area, where Mescalero caliche is in direct contact with the Dewey Lake Redbeds. The karst valley, one mile long, plainly visible in the WIPP site air photos (a valuable tool neglected in DOE geological investigations), is also described in CARD's original paper. DOE, in its response to CARD, does not deny that this is a karst valley.
Trench exposures in the karst valley revealed 15 solution pipes, 1 to 14 feet in diameter, most of them passing entirely through the caliche, the largest of them displaying surface collapse in the Dewey Lake Redbeds. Some of the solution pipes formed where taproots had penetrated the caliche; others formed where rainwater collected in depressions on the caliche surface. Altogether, 15.3% of the caliche surface was absent, with surficial sand in direct contact with Dewey Lake Redbeds. A smooth, continuous caliche surface cannot be expected; the effect is more like Swiss cheese. After heavy rainstorms, water runs along the caliche surface until it disappears into the solution pipes and infiltrates into the Dewey Lake Redbeds.

DOE videotaped the trenches. Larry Barrows, Al Lappin, Steve Lambert and George Bachman all viewed the trenches, as did a number of other scientists affiliated with New Mexico Tech, Texas Tech, EEG, and EPA. The trench exposures were consistent with Mescalero caliche morphology described by Bachman (1973) and Bachman (1974), excerpted in the CCA (Appendix XRE, pp. XRE2-20, XRE2-22). DOE, in its response to CARD, is forced to admit that Mescalero caliche has “some permeability,” and that “recharge to the water table can occur over the entire land surface” (EPA Docket, A-93-02, Item # II-H-46, p. 27). At the WIPP site, there is no barrier to rainwater infiltration at any level above the Culebra.

**POTENTIAL FLOW PATHS FROM THE WIPP SITE TO THE ACCESSIBLE ENVIRONMENT**

Most of CARD’s original paper by the above title stands uncontested. DOE disagrees that: (1) there has been extensive dissolution of halite in the Rustler Formation; (2) the Culebra dolomite is recharged by modern rainwater; (3) DOE’s proposed flow path is inconsistent with groundwater geochemistry; and (4) Laguna Grande de la Sal is the principal discharge point for Rustler groundwater, including the Culebra dolomite. These issues are dealt with in CARD’s point-by-point rebuttal to DOE.

CARD, in its original paper, identified three potential karstic groundwater flow paths from the WIPP site to the accessible environment. Anderson (1996, p. 4) has visualized these flow paths also; he describes them as resembling a “pincer,” leaving the southwestern pan of the WIPP site “as an outlier of the main dissolution front.” From the recharge area in the central part of the WIPP site there is a southeasterly flow path to H-3, DOE-1 and H-11, proceeding between H-17 and P-17, thence westward to H-7 in Nash Draw. From the recharge area there is a northwesterly flow path between H-18 and WIPP-18 to WIPP-13 and H-6, thence westerly to the WIPP-33 chain of sinkholes and WIPP-25 in Nash Draw. There is a westerly flow path from the WIPP-14 sinkhole to DOE-2 and WIPP-13, where two flow paths merge and the Rustler becomes one unconfined aquifer with five members. These flow paths remain unchallenged, and CARD has further evidence to support them. They include and extend in a logical way the flow paths recognized by DOE.

Jones et al. (1992, SAND92-1579, p. 2-21) have observed that Culebra fracture fillings are absent or have been dissolved at H-3, DOE-1 and H-11 in the southeastern part of the WIPP site, and at DOE-2, WIPP-13 and H-6 in the northwestern part of the WIPP site. As these six test wells are located within two zones of high transmissivity identified by multi-well pumping tests (Beauheim, 1986; Beauheim, 1989). Jones et al. conclude that open fractures “significantly enhance groundwater flow and solute transport.”
Since the submission of its original paper, CARD has discovered a more complete transmissivity database for the Culebra dolomite (LaVenue et al., 1988, SAND 88-7002, Table C.1; Beauheim, 1989, SAND89-0536, Table 6-1). Accordingly, CARD has updated its own database, which is given in Table 1 of this paper. Hydraulic conductivity is computed as transmissivity divided by the thickness of the Culebra aquifer, though the transmissive interval is probably thicker.

The rainwater recharge area identified by CARD includes test wells H-1, H-2, H-3, ERDA-9, and all four of the WIPP shafts. Two of the flow paths originate here. When CARD submitted its original paper, the Culebra transmissivity at H-3 (19 ft²/day) was thought to be anomalously high. Now we know that Culebra transmissivities elsewhere in the recharge area are comparable (20.0 ft²/day at H-1; 16.0 ft²/day at H-2; 22.0 ft²/day at ERDA-9; and 28.0 ft²/day at the WIPP exhaust shaft). These transmissivities are more than an order of magnitude (more than ten times) greater than previously believed, implying a faster rate of recharge and lateral flow. Hydraulic continuity throughout the recharge area is indicated by the drawdown at well locations H-1, H-2 and H-3 caused by drainage into the WIPP shafts during the spring of 1983 (LaVenue et al., 1988, SAND88-7002, p. G-6; see also Figures E.1, E.2 and E.3), and by drawdown and recovery at well locations H-1, H-2, H-3, H-16 and ERDA-9 following drilling and grouting of the WIPP air intake shaft between 1988 and 1994 (Silva, EEG-62, 1996, pp. 49-52).

CARD and DOE have identified a zone of high transmissivity through the southeastern part of the WIPP site, indicating a flow path from H-3 to DOE-1 to H-11. CARD noted at the public hearings in February 1997 that lithologic descriptions for H-1, H-2 and H-3 were never published. CARD has since discovered drawings and brief descriptions of Culebra core samples at H-2b, H-3b2 and H-3b3 (Jones et al., 1992, SAND92-1579, Figures 6-2, 6-3, 7-2 and 7-3). At H-2b and H-2b2 the cores were massive or vesicular with some fractures, most of them filled with gypsum. But at H-3b2 the Culebra is "totally fragmented." Only three core samples totaling 4.0 feet were recovered; 18 feet of Culebra core was lost, and another 5.0 feet of core was lost in black clay (not claystone - clay) immediately beneath the Culebra. At H-3b3 the whole Culebra interval was "broken into pieces" less than 1 foot in length; where pieces were preserved, the core was very porous; some fractures were open, some were filled with gypsum; 14.5 feet of Culebra core was lost, and another 4.0 feet of core was lost in the black clay beneath the Culebra. This is entirely consistent with a cavernous groundwater flow path through the Culebra dolomite and the claystone of the lower unnamed member.

Jones et al. (1992, SAND92-1579) also present drawings and brief descriptions of Culebra core at H-11b1, H-11b2, H-11b3 and H-11b4 (Figures 10-2, 10-3, 10-4 and 10-5). Here the Culebra is sometimes "highly fragmented," sometimes "massive with subvertical fractures;" core recovery was about 80%. The Culebra is underlain by black clay with subvertical fractures, some of them open, some of them filled with gypsum.

DOE has concluded from tracer-injection testing at H-1, H-2, H-3, P-14, H-14 and H-19 that most or all of the flow in the Culebra dolomite comes from the lower 10 feet (CCA, Appendix MASS, Attachment 15-6, p. 6) to 21 feet (Lappin, 1988, SAND88-0157, p. 77) of the Culebra. This is consistent with the interpretation that fracturing is more extensive in the lower Culebra due to caving in the mudstone and claystone immediately beneath the Culebra. There is direct evidence that the lower unnamed member is involved in groundwater flow along this path; at H-3, the dissolution residue in the lower unnamed member yielded as much water as the Culebra or Magenta (EEG-32, 1985, p. 39).
Table 1: Highest Measured Transmissivity (ft$^2$/day) and Hydraulic Conductivity (ft/day)

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<th>Test well</th>
<th>Transmissivity</th>
<th>Hydraulic Conductivity</th>
<th>Source of data</th>
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<td>0.73</td>
<td>Beauheim (1987)</td>
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<td>* H-3</td>
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<td>0.86</td>
<td>Mercer (1983)</td>
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<td>* H-4</td>
<td>1.8</td>
<td>0.075</td>
<td>Gonzalez (1983)</td>
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<td>Seward (1982)</td>
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<td>* H-6</td>
<td>88.0</td>
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<td>25.0</td>
<td>Mercer (1983)</td>
</tr>
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<td>0.69</td>
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<td>33.0</td>
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<td>1.2</td>
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<td>0.10</td>
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<tr>
<td>USGS-1</td>
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<td>Cooper (1962)</td>
</tr>
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</table>

* Test wells located at or within one mile of the WIPP site.
This southeasterly flow path crosses the WIPP site boundary south of H-11, "where it narrowly lies between the P-17 and H-17 boreholes" (CCA, Appendix TFIELD, p. TFIELD-125). Culebra transmissivities at P-17 and H-17, as measured during the multiwell pump test centered in the Culebra at H-11 (Beauheim, 1989, Table 6-1) are moderately high (21.0 ft²/day and 13.0 ft²/day, respectively), so these test wells probably missed the active solution conduits. LaVenue et al. (1988, SAND88-7002), when attempting a numerical simulation of this flow path, recognized that a "relatively high transmissivity zone between wells H-17 and P-17" is required (p. iii) in order "to reduce the differences between the calculated and observed heads at H-11 and DOE-1" (p. 4-10) to a smaller amount than the margin of error of field measurement. They concluded that the calibrated transmissivities between P-17 and H-17 are approximately $5 \times 10^5$ m²/sec (pp. 4-12, 6-2), or 46 ft²/day.

CARD represents that this flow path then turns westward, following an avenue of low resistance beneath a vast karstic depression with disrupted surface drainage, four miles long and up to 7000 feet wide, extending from the James Ranch dune field to Nash Draw. It then flows beneath a sinuous karst trench walled by high dunes, 2.5 miles long, leading directly to the collapse sink where test well H-7 was drilled. At H-7 a dry cave was found in the Dewey Lake Redbeds, five water-filled caves were found in the Culebra, and transmissivity of 1430 ft²/day was measured in the Culebra. When viewing the WIPP site air photos, the disrupted surface drainage immediately south of the site is indistinguishable in character from Nash Draw. The karst trench, when viewed stereoscopically, is unmistakable. The entire flow path from the WIPP site boundary to Nash Draw demonstrates unconfined flow under water-table conditions. Typical of karst channels, the hydraulic heads in the Culebra are equal at H-11, H-17, P-17 and H-7.

DOE, in its modeling assumptions, recognizes that Culebra flow is "strongly affected by a high-transmissivity zone in the southeastern portion of the WIPP site" (CCA, Appendix MASS, p. MASS-77). DOE prefers a flow path continuing southward from H-17 to H-12 and thence toward Malaga Bend; however, there is no evidence of a hydraulic connection between H-17 and H-12. During the multiwell pump test centered in the Culebra at H-11, there was no response at H-12 for 33 days, and the maximum drawdown was only 6 inches (Beauheim, 1989, Table 5.1), which could not be attributed to the pumping at H-11 (Beauheim, 1989, p. 79). But DOE does allude to H-7 when describing the "high-transmissivity zone" between P-17 and H-17 (CCA, Appendix TFIELD, p. TFIELD-125; see also LaVenue et al., 1988, SAND88-7002, p. 6-1). In SEIS-II (p. 4-25), DOE describes Culebra flow patterns, stating that "flow above the WIPP repository is to the south," "flow south of WIPP is possibly toward the west" (toward Nash Draw), and "flow in Nash Draw is to the southwest" (toward Laguna Grande de la Sal).

It should be noted that H-19, the latest WIPP hydropad, consisting of an array of seven test wells, is located between H-3 and DOE-1, within the zone of high transmissivity. Multi-well pumping tests and tracer tests have been performed at H-19, but the results remain unpublished, tucked away in the Sandia central files, unavailable to the public or even to the Peer Review Panel (CCA, Appendix PEER, pp. 3-60, 3-61). The CCA (Appendix TFIELD, p. TFIELD-126) does allude to the H-19 tracer test of December 1995 through March 1996, and does provide hydrographs (Appendix TFIELD, Figures TFIELD-39 and TFIELD-40) which indicate a rapid response at test wells H-1, H-3, WQSP-4 and WQSP-5 and no response at H-15. EPA should not be content without full disclosure of these most recent drillholes and tracer tests. Reportedly, a triple-tube core barrel produced high-quality core, and hydraulic and tracer testing procedures were superior to the older tests conducted.
CARD, in its original paper, identified a second zone of high transmissivity through the northwestern part of the WIPP site, further described in pages 2 and 3 of this paper. The flow path leads from the WIPP shafts to WIPP-13 through a zone of high transmissivity between H-18 and WIPP-18. The flow path continues from WIPP-13 to H-6 to WIPP-33 to WIPP-25. This flow path ultimately involves all five members of the Rustler Formation. CARD has discovered additional evidence in support of this flow path.

It has been noted that the WIPP exhaust shaft responded to the multi-well pump test at WIPP-13, and that LaVenue et al. (1988, SAND 88-7002, p. 6-3) believe that a high transmissivity zone between WIPP-13 and the WIPP shafts is necessary to explain the response. Lappin (1989, SAND 88-0157, p. 76, reprinted as CCA, Appendix SUM) observes that WIPP-21 “responded strongly and rapidly” to both the multiwell pump test at H-3 and the sinking of the WIPP ventilation and exhaust shafts. “This behavior probably reflects the presence of ... a single fracture or fracture zone connecting the region near WIPP-21 with the two WIPP shafts, but not intersecting WIPP-21 itself.” Lappin notes that even if a given borehole does not indicate local fracturing, there may be fracturing nearby. From these observations, CARD infers that there is a zone of high transmissivity to the west of WIPP-21, from the WIPP shafts to WIPP-13.

CARD stated in its original paper that hydraulic heads in the Culebra and Magenta are equal at WIPP-25 in Nash Draw and at H-6 within the northwestern corner of the WIPP site. Somewhere between the WIPP shafts and H-6 the Culebra and Magenta lose their hydraulic distinction and become a single, unconfined aquifer (see also LaVenue et al., 1988, SAND 88-7002, pp. 2-4, 2-5). CARD also observed that the Culebra head at WIPP-13 (3064 feet) is higher than at H-6 (3057 feet) and concluded that the Culebra and Magenta heads are equal at WIPP-13 as well, stating that hydraulic heads in the Magenta should confirm this, but the data are not available. CARD has since discovered that the Culebra head at H-18 (3059 feet) is also higher than at H-6; again, hydraulic heads in the Culebra and Magenta may be equal, but the data are not available. DOE needs to perform the necessary testing to determine where the Culebra and Magenta lose their hydraulic isolation from each other.

At the public hearings in February 1997, CARD noted that geophysical logs for H-4, H-5 and H-6 were never published; only brief lithologic descriptions were provided (Mercer and Orr, 1979). At H-6 the Culebra was described as “dolomite, light-olive-gray to olive-gray, pitted; some gypsum, light gray; trace mud.” Directly above and below the Culebra are dissolution residues described as “mud matrix with mudstone, clay, and gypsum.” No information was given about the nature and extent of fracturing or the amount of core recovery. CARD has since discovered that only 2.3 feet of core was recovered at H-6b (Jones et al., 1992, SAND92-1579, Figure 9-2). It is described as “dense dolomite with minor vugs and some vertical fractures.” Altogether, 90% of the core was lost, indicative of conditions of dissolution. The release of the geophysical logs for H-4, H-5 and H-6 is required.

In its original paper, CARD observed that hydraulic heads in the Magenta dolomite are higher than hydraulic heads in the Forty-Niner member everywhere that heads have been measured in the Forty-Niner (at H-3, H-14, H-16 and DOE-2). From this DOE concludes that flow between the Magenta and the Forty-Niner at these locations “would be upward.” This, observes DOE, “is not consistent with the results of groundwater modeling, and this inconsistency may be the result of local heterogeneity in rock properties that affect flow on a scale that cannot be duplicated in regional modeling” (SEIS-II, p. 4-27). Upward flow between the Magenta and the Forty-Niner is indeed inconsistent with DOE’s concept of the Culebra dolomite as a confined aquifer,
sandwiched between two anhydrite beds with zero permeability. These data indicate a discrete flow path which DOE cannot reproduce in its modeling. There is direct evidence that the Forty-Niner member is involved in groundwater flow at these locations. At H-14 and DOE-2 the measured transmissivity of Forty-Niner claystone was more than an order of magnitude (more than ten times) greater than the transmissivity of the Magenta dolomite (Lappin, 1989, SAND88-1057, Table 4.3, reprinted as CCA, Appendix SUM).

Lappin (1989) observes that “there must be a qualitative increase in the transmissivities of the Tamarisk and Forty-Niner anhydrites somewhere between the WIPP site and Nash Draw,” because “evaporite karst in and near Nash Draw involves formation of small caverns and sinkholes within the Tamarisk and Forty-Niner members.” He states that “karstic hydrology might occur within the Rustler Formation at the WIPP site,” which would involve rainwater recharge to the Rustler dolomites and/or anhydrites. In order for this to occur, the Forty-Niner heads would have to be greater than those of the underlying Magenta dolomite, at least in places. The hydraulic heads at H-3, H-14, H-16 and DOE-2 “do not rule out fluid movement from the surface downward” into the Forty-Niner claystones and anhydrites and/or into the Magenta dolomite elsewhere, in areas “where the Dewey Lake is saturated.” Vertical flow from the Magenta to the Culebra would require downward movement through the Tamarisk member; however, “it has not been possible to measure either transmissivities or head potentials within either the claystones or anhydrites in the Tamarisk at or near the WIPP site.” But such measurements may not be necessary; rainwater recharge could happen “near the center of the WIPP site,” where Magenta heads are greater than those of the Culebra, “consistent with downward flow between these two units.” (Lappin, 1989, SAND88-1057, pp. 79, 81, reprinted as CCA, Appendix SUM). This is a fair and honest assessment by Al Lappin, who observed Phillips’ trenches, stood upon the Dewey Lake Redbeds where Mescalero caliche is absent, and evidently understood that rainwater recharge is occurring.

CARD, in its original paper, identified a third groundwater flow path along the northern boundary of the WIPP site, in the Culebra and lower unnamed members of the Rustler, from the WIPP-14 sinkhole to DOE-2 to WIPP-13, where it merges with the flow path from the WIPP shafts. The confluence of two underground flow paths in the Culebra at WIPP-13 is consistent with the interpretation that the Magenta becomes important at WIPP-13, that some Culebra water rises through the interconnected vertical fractures of the Tamarisk member and into the “broken and shattered” Magenta dolomite. When viewed in plan, flow paths converge at WIPP-13. When viewed in cross-section, flow paths diverge at WIPP-13. This illustrates the necessity of modeling the Rustler aquifer in three dimensions.

As the flow path continues toward Nash Draw, the Magenta and higher units become increasingly important. At WIPP-33, five underground caverns, all of them filled with water, were found in a nested sequence: two in Magenta dolomite, two in Forty-Niner gypsum, and one in Dewey Lake siltstone. The four Rustler caverns totaled 22.5 feet within a 50.5-foot stratigraphic section, and the siltstone cavern was 7.0 feet from top to bottom. These are large caverns, connected to extensive conduits carrying water from the WIPP shafts all the way to Nash Draw and thence to Laguna Grande de la Sal and the Pecos River.

The multiwell pump test centered at WIPP-13 has demonstrated a hydraulic connection between the WIPP exhaust shaft and WIPP-25 in Nash Draw. CARD has discovered additional evidence for the tributary flow path from the WIPP-14 sinkhole. In the CCA (Appendix DEF, p. DEF-30), DOE distinguishes between “Nash Draw, where karst features are developed, and a more easterly
region, including the WIPP site," where, according to DOE, "there is no significant shallow dissolution of halite, anhydrite, or dolomite." DOE states that: "These two regions are separated by a transition zone which includes a prong of dissolution extending from Nash Draw towards the site of WIPP-14." The next paragraph refers the reader to Figure DEF-7, which displays a black dot at the location of WIPP-14, together with this description: "Depression Areas North of WIPP Site." It should be noted that although the WIPP-14 borehole is 98 feet north of the current WIPP site boundary, the depression into which it was drilled is 600 feet in diameter, straddling the WIPP site boundary. This is direct evidence of karst geomorphology at the WIPP site.

CONCEPTUAL ERRORS IN THE DOE MODEL OF GROUNDWATER FLOW IN THE RUSTLER FORMATION

DOE must defend its conceptual model of groundwater flow, lest it be shown that the highly dependent performance assessment is fatally flawed. DOE's charges are dealt with in CARD's point-by-point rebuttal. However, there is one criticism contained in CARD's original paper which DOE made no attempt to refute: Borehole data should not be assumed to be representative of hydraulic conditions beyond the immediate vicinity of the borehole.

In karst, hydraulic conductivity along solution-enlarged fractures may be three orders of magnitude greater than that of the adjacent unaltered rock (Fetter, 1980). Because the active solution conduits comprise a small part of the total area of the watershed, most boreholes will miss them, and will show values for hydraulic conductivity which are not representative of karst conditions (Bloom, 1978; Barrows, 1982). Borehole measurements may reflect aquifer properties only within the immediate vicinity of the borehole (Konikow, 1995). The technique of interpolation between data points, although useful in porous, homogeneous media, should not be applied to a karstland (LeGrand, 1973).

DOE's performance assessment is said to be supported by the work of Corbet and Knupp (SAND96-2133). Their three-dimensional conceptual model of Rustler hydrology is said to justify the two-dimensional mathematical model used in performance assessment (EPA Docket, A-93-02, Item # II-H-46, p. 33). CARD, in its original paper by the above title, assailed the use of geologic data to infer hydraulic conductivity values for areas in which conductivity measurements were not available. CARD, on page 5 of its original paper, presented numerous specific instances of assumed values which were inconsistent with borehole data in the vicinity. The entire page stands unchallenged, and CARD now presents more examples.

Figure 2-7: Zone IV is said to represent "intact strata" in the Rustler. This zone includes the WIPP air intake shaft, where much of the Culebra dolomite exhibits "extensive subvertical to vertical fracturing." About half of the fractures are filled with gypsum, and the rest are open. Fractures interconnect all vugs, which are as large as 7.6 cm (3 inches) in diameter. The lower 0.15 m (6 inches) consists of brecciated dolomite (Jones, 1992, SAND92-1579, p. 2-19 and Figure 2-10). This description is especially significant in view of the fact that DOE told EPA that "it does not appear that the Culebra is extensively fractured in the vicinity of the WIPP shafts." This led EPA to conclude that DOE's assumption of dual porosity (fracture flow and matrix diffusion) "may be conservative." (EPA Docket, A-93-02, Item # III-B-3, p. 38) This zone also includes borehole H-11, where Culebra core is described as "highly fragmented." (Jones et al., 1992, SAND92-1579, Figures 10-4, 10-5)
Figure 2-9: The zone assumed to have hydraulic conductivity of $1 \times 10^{-12}$ m/sec ($2.8 \times 10^{-7}$ ft/day) in Rustler anhydrite includes borehole WIPP-13 where, according to the lithologic description, 56 feet of Tamarisk anhydrite has been converted to gypsum; 7.1 feet of dissolution residue consisting of mudstone with angular clasts of gypsum breccia was encountered; steeply dipping veins and fractures, one of them filled only with silt, were found throughout the Tamarisk member; the overlying Magenta dolomite is “broken and shattered by numerous fractures dipping 60°-80° and displacing bedding planes 0.5-1.0 cm.;” and the Culebra is believed to be hydraulically connected to the Magenta. This zone also includes borehole WIPP-19, where solution cavities were found in Forty-Niner anhydrite (SAND79-7110, p. 17). This zone also includes the WIPP ventilation shaft, where mudstone in the lower unnamed member of the Rustler contains 24 vertical to subvertical fractures, all but one of them open, most of them interconnected (TME 3177, Figure 5; EEG-32, 1985, Plate 1), and produces water in a dissolution residue immediately beneath the Culebra (EEG-32, 1985, p. 39).

Admittedly, these occurrences may be anomalous, but that is exactly the point. To disregard lithologic descriptions of the most disrupted ground is not a conservative assessment, because groundwater selectively follows the paths of least resistance.

POINT-BY-POINT REBUTTAL TO DOE’S RESPONSE TO CARD’S COMMENTS

1. No one has previously correlated evidence for karst from DOE boreholes and test wells. CARD is first to do so. The mere submission of Basic Data Reports for DOE boreholes as “supporting references” does not mean that the implications of these data have been “considered” by DOE in its performance assessment (PA); indeed, it is CARD’s position that the data were subjectively filtered for EPA examination.

2. If CARD had presented “few arguments” that were not discussed in the Compliance Certification Application (CCA), then DOE should have been able to reprint them, submit them to Larry Weinstock, and respond to them in detail. DOE chooses instead to refer to three of the scientific papers presented by Drs. Richard H. Phillips and David T. Snow as one “comment” each, parts of a “letter,” so that the detail, depth and validity of CARD’s work might go unrecognized by EPA.

3. DOE continues to describe the Culebra dolomite as “fractured,” but not karstic. DOE’s groundwater model may be “consistent with international practice,” but it is not appropriate for karstic media, which are inherently unpredictable. It is not “international practice” to consider disposal of radioactive or toxic waste in karstic regions. Barrows (1982, p. 17) cites 16 papers by 20 authors who have identified karstlands as unacceptable waste disposal environments.

4. CARD does not “confuse” DOE’s “simplifying assumptions” with a “statement of reality.” DOE, specifically Corbet and Knupp, has applied simplifying assumptions, conceptual errors, and misrepresentative data in its modeling of groundwater flow, then called the output “reality.”

5. CARD disagrees that DOE’s Culebra flow model is “consistent with the WIPP borehole data.” In its paper entitled “Conceptual Errors in the DOE Model of Groundwater Flow in the Rustler Formation,” CARD presents numerous examples of boreholes where measured data are inconsistent with DOE’s simplifying assumptions. In each case, CARD has identified the
locations of the boreholes and has contrasted the data measured therein with DOE's misrepresentation. The "detailed localized information" presented by CARD has not been accounted for by DOE, "implicitly" or otherwise.

6 DOE admits that groundwater geochemistry in the Culebra can only be explained by "vertical leakage," synonymous for rainwater recharge. But DOE remains committed to a miniscule rate of rainwater recharge to the Culebra that is unrealistic in view of the geochemistry. Within the WIPP site, total dissolved solids (TDS) vary by a factor of 25 (8,890 mg/l at H-2 to 230,000 mg/l at H-15). Dissolved sodium and chloride (NaCl) also vary by a factor of 25 (4,835 mg/l at H-2 to 124,100 mg/l at H-5), well below saturation (318,000 mg/l NaCl). Such a discrepancy cannot be explained by a recharge rate of 0.2 to 2.0 mm/yr, requiring transit of "several tens of thousands of years," as assumed by DOE. This assumption has no basis in fact, but it would be consistent with an equally slow rate of groundwater flow in the Rustler which, if believed, might support an erroneous finding that the WIPP site is suitable for waste isolation.

7 Regarding climatic change, full-glacial conditions would not "raise the water table to the land surface." Such a concept on the part of DOE reflects a lack of understanding of karst hydrology. An increased amount of groundwater (due to increased precipitation, decreased evaporation, or both) would flow more rapidly than before through existing karst channels, enlarging them through corrosion as it does so. As proof, CARD refers EPA to the Mescalero caliche, which forms in the capillary fringe and dissolves when exposed to standing water. The Mescalero caliche is said to be older than the most recent glacial advances. If the water table had been at the land surface during glacial maxima, the caliche would have been obliterated.

8 It can never be stated categorically that "there are no examples of karstic features" within the WIPP site. A nearly continuous mantle of desert soil and windblown sand up to 13.5 feet thick covers the entire WIPP site and vicinity, obscuring all but the largest and most obvious karst features. One example of a karst feature within the WIPP site is at WIPP-14, where a solution-subsidence doline 600 feet in diameter straddles the current WIPP site boundary.

9 DOE has never considered the human consequences of contamination of the Pecos River (part of the accessible environment) by plutonium from the WIPP site. In restricting its analysis to the WIPP site boundary, and by postulating very long groundwater travel times to that boundary, DOE vouches for the safety of the WIPP site even while claiming not to know the ultimate discharge point for contaminated water.

10 "The DOE has not denied the presence of karst features ____ the WIPP site." This sentence lacks a preposition. What is it - "near," "at," or "within"? There is a space here. A word has been deleted.

11 It is interesting that DOE cites Barrows (1982) without having provided this landmark report to EPA, except as Appendix A to Chaturvedi and Channell (EEG-32, 1985).

12 Harry LeGrand did not carry out an "investigation" of the karst issue. He wrote informal reports, based upon his previous work in other karst regions. To our knowledge, he conducted no field work at the WIPP site other than participating in a one-day field trip led by Larry Barrows. LeGrand's reports were reprinted as appendices to Chaturvedi and Channell (EEG-32, 1985). Nowhere does EEG state that it agrees with LeGrand's conclusions.
13 DOE states that Nash Draw is "some 6 miles (10 kilometers) to the west of the Land Withdrawal Area." This is an erroneous statement which could have misled EPA into thinking that Nash Draw, one of the largest karst features with surface expression in North America, is "some" safe distance from the WIPP site. DOE personnel drive through Nash Draw every day on their way to the WIPP site. The truth is that the fluvial incisions of Livingston Ridge, which mark the eastern boundary of Nash Draw, reach to within one mile (1.6 kilometers) of the northwest corner of the WIPP site, and to within 1.2 miles (1.9 kilometers) of the southwest corner of the WIPP site, 400 feet from the WIPP site turnoff.

14 DOE states that "there is no evidence from hydraulic conductivities" that the karst development found at WIPP-33 extends into the Land Withdrawal Area (LWA). There are two reasons for this: (1) WIPP-33 is no longer within the LWA, having been gerrymandered out of the WIPP site when its boundaries were reduced. (2) WIPP-33 was never converted to a hydrologic test well, and so there are no multiwell pump tests designed to determine whether or not the five water-filled caverns found at WIPP-33 are hydraulically connected to the zone of anomalously high transmissivity within the northwestern part of the WIPP site (test wells H-6, WIPP-13, and DOE-2). If there is "no evidence," this is because DOE has not done the necessary testing. WIPP-33 was drilled in 1979. DOE has had 18 years to measure hydraulic conductivity under certifiable karst conditions in the immediate vicinity of the WIPP site. Absence of evidence is not evidence of absence.

15 The "heterogeneous transmissivities" in the Culebra should be cause for grave concern. Within one mile of the WIPP site, measured Culebra transmissivities vary by five orders of magnitude (0.003 ft²/day at P-18 to 324 ft²/day at P-14). DOE interprets these as preferential flow along "fracture networks," citing Beauheim (1989). EPA should not dismiss CARD's interpretation that these linear zones of anomalously high transmissivity could be indicative of karstic channels, especially in light of DOE's own admission that groundwater flow in all members of the Rustler "is primarily controlled by fractures that have been affected by shallow dissolution processes." (SEIS-II, p. 4-30) In Jones et al., (1992, pp. 3-9, 3-10, 12-19), DOE admits that a variable-aperture channel model, with the bulk of the flow occurring in channels, "could fit the observed data equally as well." Yet DOE adheres to its "stochastic" model, treating the "heterogeneous transmissivities" in the Culebra as "random variables" without geographic orientation. Given the observed data, the conservative approach would be: (1) to acknowledge that paths of anomalously high transmissivity, being interconnected paths of least resistance, are representative of actual site-scale groundwater flow paths and to assess the suitability of the WIPP site according to these data; and (2) to convert WIPP-33 and WIPP-13 into hydrologic test wells in order to measure Rustler transmissivity under actual karst conditions in the immediate vicinity of the WIPP site. That was done at H-7 in Nash Draw, where Culebra transmissivity is 1430 ft²/day and hydraulic conductivity is at least 31.0 ft/day, or 2.1 miles per year. Figure TFIELD-5 in the CCA does not present "the same data" as Figure 3 in CARD's paper entitled "Cavernous Zones at the WIPP Site." CARD presents its data in ft²/day, showing the great range of values. DOE presents its data logarithmically, which obscures the range for most readers. In addition, DOE seldom presents the highest measured transmissivities for a given test well, as CARD does, and as DOE should do if its performance assessment is to be conservative. CARD has subsequently revised its data base with the receipt of reports containing even higher measured transmissivities at twenty-five WIPP test wells (LaVenue et al., 1988; Beauheim, 1989).

16 DOE contends that "the measured head data can be contoured as continuous smooth surfaces and so argue against karstic flow." This statement is misleading. Any data can be mapped with
smooth contour lines if the data is used selectively. EPA should compare Figure 2-31 (CCA, p. 2-125) with Figure TFIELD-7 (CCA, Appendix TFIELD, p. TFIELD-27). On Figure 2.31, thirty test wells are shown, all in their correct geographic locations. The contour lines are on the wrong side of four test wells (H-2, H-3, H-4 and H-15). Six test wells are missing altogether. Four of them (H-8, H-16, WIPP-27 and WIPP-29) do not fit with DOE's "continuous smooth surfaces," falling on the wrong side of the contour lines; one of them (H-19) is an unknown quantity, the data still unpublished; and one of them (AEC-7) fits perfectly, right on the 932-meter contour line. The most significant problem with Figure 2-31 is that the data are inconsistent, partly confined, partly unconfined, especially in the western half of the field. In places, Culebra water rises through the Tamarisk member and into the Magenta. This is true at WIPP-25 in Nash Draw and at H-6 within the northwestern corner of the WIPP site, where the Culebra and Magenta heads are equal. It is probably true as well at WIPP-13 in the northwestern part of the WIPP site, where the Magenta is broken and shattered by numerous steeply-dipping fractures, the Tamarisk exhibits a zone of mudstone/gypsum breccia (dissolution residue) and steeply-dipping fractures throughout, and the Culebra freshwater head is higher than at H-6. Just northwest of the waste panels is H-16, where the Culebra freshwater head is anomalously low (3005 feet), which is why it does not fit with the contour lines on DOE's map. CARD believes that some water from the rainwater recharge area in the central part of the WIPP site flows through the Rustler in a northwesterly direction, bypassing H-16 and H-18 on its way to WIPP-13, H-6, WIPP-33 and WIPP-25. No generalized map of the Culebra potentiometric surface, with or without all the data points, can reflect such a discrete channelized flow path. Interpolation between data points is not appropriate for hydraulic heads in unconfined aquifers.

17 DOE proclaims that "head changes in boreholes indicative of rapid recharge at the WIPP site during times of heavy rainfall have not been observed." There are two reasons for this: (1) boreholes which intercepted karst channels (e.g. WIPP-33 and WIPP-14) were not converted to test wells; and (2) water levels in test wells which did not intercept karst channels cannot be expected to fluctuate with rainfall. Within the WIPP site, the top of the Culebra is 413 ft (at P-15) to 899 ft (at H-5c) below the surface. Rapid infiltration to such depth can only be expected in the sinkholes themselves, as at WIPP-33, where five feet of standing water was observed to sink into the sand in a matter of days (Phillips, 1987, p. 86). However, a steady rise in water levels in the Magenta at test wells H-2 and H-3, and in the Culebra at test wells H-1, H-3 and H-4, all located within the recharge area, were recorded between mid-1977 and mid-1981 (Gonzalez, 1983, SAND83-0210, pp. 22-25). This occurred in undisturbed hydraulic conditions, before the sinking of the first WIPP shaft in July 1981 (CCA, Appendix TFIELD, Table TFIELD-9). DOE says that this rise in hydraulic heads is "unexplained" (CCA, Appendix TFIELD, p. TFIELD-17). CARD offers an explanation. During this four-year period 68.55 inches of rain (17.14 inches per year) was recorded in Carlsbad, compared to an average of 10.85 inches per year during the preceding 25 years. While the rise in Magenta and Culebra water levels cannot be correlated with individual rainstorms, it can be correlated with short-term trends in precipitation.

18 DOE misrepresents CARD's position regarding the significance of a lack of core recovery. If one omits the word "particularly," then CARD's position regarding carbonate rocks is correctly stated. However, evaporite rocks are not typically fractured, so a consistent lack of core recovery in horizons identified by the drill loggers as containing dissolution residues is a clear indication of unconsolidated or cavernous zones capable of transmitting water with little resistance. When these occurrences are correlated and mapped, as CARD has done in its paper entitled "Cavernous Zones at the WIPP Site," it is shown that these zones snake across the WIPP site, penetrating its heart at the ventilation shaft, extending from the repository to the discharge area in Nash Draw.
On the authority of Powers and Holt, DOE takes the position that these zones are not dissolution residues at all — that no subsurface dissolution of halite has ever occurred in the Rustler Formation, because no halite was ever deposited where today it is absent. No one besides Powers and Holt and their collaborators subscribe to this. There is “ample published evidence for the real extent of dissolution,” (Anderson, 1996, p. 6). The works of two scientists on the DOE payroll does not “largely rule out this explanation,” as contended by DOE (CCA, p. 2-38).

CARD, in its paper entitled “Potential Flow Paths from the WIPP Site to the Accessible Environment” (p. 4), has cited fifteen reports which describe extensive dissolution of halite in the Rustler Formation, and now, in its rebuttal to DOE, cites eight more: Jones et al. (1960), Vine (1963), Cooper and Glanzman (1971), Brokaw et al. (1972), Jones (1978), Ferrall and Gibbons (1979), LaVenue et al. (1988), and Anderson (1996). Many of these authorities are or were consultants to DOE on the WIPP project. DOE, in the CCA, cites Powers and Holt 25 times in 7 pages (beginning at p. 2-38), more often than DOE cites the works of all other scientists combined. Anderson states that “the extensive character of Rustler dissolution at WIPP is recognized by virtually all scientists who have examined this area.” (Anderson, 1996, p. 1) “By disregarding the weight of professional opinion regarding the extent and history of dissolution, and by using the Holt and Powers study to claim that dissolution is ‘physically unreasonable,’ when in fact it is real and ongoing,” DOE reveals unacceptable bias. “Climate-related failure of shaft seals has important ramifications for both undisturbed and disturbed containment scenarios, and the DOE application cannot simply eliminate the problem by citing a minority opinion that dissolution is not a significant factor at the WIPP site.” (Anderson, 1996, p. 2) The work of Lowenstein (EEG-36, 1987) should be sufficient to resolve the issue. Lowenstein performed a detailed sedimentological analysis of Rustler cores from four test wells (DOE-2, WIPP-19, H-11 and H-12). This included visual examination of the cores, petrographic analyses of 52 thin sections from selected locations of the cores, and X-ray diffraction analyses of 40 samples from selected locations of the cores. Lowenstein found evidence of late-stage alteration in every member of the Rustler — in gypsum/anhydrite, mudstone, and dolomite. The alteration has involved physical processes such as brecciation, slumping, fracturing and faulting, and chemical processes such as rehydration of anhydrite to gypsum, precipitation of gypsum, and dissolution of halite, anhydrite, and gypsum. The abundance of gypsum-cemented breccias and gypsum-filled fractures that crosscut all other sedimentary features indicate that dissolution in the Rustler is a recent process. Moreover, the zones described by CARD in the Forty-Niner, Tamarisk, and lower unnamed members of the Rustler, are specifically identified as dissolution residues in the Basic Data Reports for at least twelve boreholes (ERDA-6, ERDA-9, H-1, H-6, WIPP-13, WIPP-18, WIPP-19, WIPP-21, WIPP-22, WIPP-25, WIPP-26 and WIPP-33), and for the ventilation shaft. Most of this data is republished in the CCA (Appendix BH). The Peer Review Panel is rightfully concerned that alternative hydrogeologic models which attribute spatially varying porosity and permeability in the Culebra to solution of halite within the Rustler Formation “were considered and discarded.” (CCA, Appendix PEER, p. 3-12)

In order to deny that subsurface dissolution has ever occurred in the Rustler Formation, Powers and Holt attribute all fracturing and brecciation in the Rustler to dissolution at the top of the underlying Salado Formation. Powers and Holt have confused the cause with the effect. Dissolution proceeds from the top down, due to infiltrating rainwater. Dissolution at the top of the Salado cannot occur without dissolution of the Rustler, and the more fractured and brecciated the Rustler, the more likely that dissolution will affect the top of the Salado.

Livingston Ridge does not mark “the eastern limit of significant karst development.” It is not a geomorphic divide. In fact, it is not a ridge at all, but an eastward-retreating escarpment
marking the eastern edge of Nash Draw. There is significant karst development east of Livingston Ridge, sometimes localized, sometimes extensive, as can be seen by stereoscopic viewing of the WIPP site air photos.

22 DOE admits that WIPP-33 is not the only sinkhole east of Livingston Ridge. Phillips (1987, Chapter IV) demonstrated through structure contour maps based upon 347 augur holes that WIPP-33 is one of a chain of four sinkholes, all of which are evident in the air photos. Phillips also recorded, following a torrential rainstorm, the sudden appearance of a new arroyo which disappeared into the easternmost sinkhole. DOE considers this chain of sinkholes to be a "prong of dissolution" that extends eastward "as far as WIPP-33." If DOE would examine its own air photos, DOE would discover that the sinkhole drilled as WIPP-33 is the westernmost in this "line of sinkholes described by CARD." In fact, by confirming that these are sinkholes, DOE inadvertently admits that proven karst features extend 2000 feet east of the WIPP-33 borehole, to within 1000 feet of the current WIPP site boundary. It is exceedingly dangerous for DOE to assume that this is the eastern limit of karst development, that the WIPP site is a karst-free island in the midst of a regional karstland.

23 DOE, citing Powers and Holt (1995), says that "there is no indication that the Salado at the WIPP site has been thinned by dissolution," and that "evidence for a dissolution residue at the top of the Salado is limited to the west of the WIPP site." In the CCA (Appendix DEF, p. DEF-30), DOE states that "the edge of halite dissolution at the top of the Salado will not reach the controlled area until well after the period of regulatory concern." Yet at least seven boreholes east of Livingston Ridge encountered dissolution residue at the top of the Salado. All seven, at the time they were drilled, were located within the WIPP site boundary. Three of them (P-12, P-14 and WIPP-33) are no longer within the WIPP site, having been gerrymandered out of the WIPP site when its boundaries were reduced. Four of them (H-3, H-6, P-6 and P-13) are within the current WIPP site boundary. Dissolution residue at the Rustler/Salado contact was also encountered in the WIPP ventilation shaft, at the heart of the WIPP site. Moreover, this dissolution residue is a water-bearing unit, commonly known as the "brine aquifer," which is why at least seven hydrologic test wells located within the WIPP site (H-1, H-2, H-3, H-4, H-5, H-6 and H-16) have been completed to this depth. In SEIS-II, after stating that the brine aquifer "is absent under the WIPP site" (SEIS-II, 1997, p. 4-28), DOE observes that, "in Nash Draw," it "contains the largest concentrations of dissolved solids in the WIPP area," ranging from 41,500 mg/l in borehole H-1 to 412,000 mg/l in borehole H-5c (SEIS-II, 1997, p. 4-29). These boreholes are not in Nash Draw: they are both within the WIPP site.

### SALADO DISSOLUTION EAST OF NASH DRAW

<table>
<thead>
<tr>
<th>hole</th>
<th>top of Salado</th>
<th>top of salt</th>
<th>dissolution residue</th>
</tr>
</thead>
<tbody>
<tr>
<td>vent shaft</td>
<td>844.5 ft</td>
<td>845.5 ft</td>
<td>1 ft</td>
</tr>
<tr>
<td>H-3</td>
<td>821 ft</td>
<td>823 ft</td>
<td>2 ft</td>
</tr>
<tr>
<td>H-6</td>
<td>721 ft</td>
<td>723.4 ft</td>
<td>2.4 ft</td>
</tr>
<tr>
<td>P-6</td>
<td>659 ft</td>
<td>661 ft</td>
<td>2 ft</td>
</tr>
<tr>
<td>P-12</td>
<td>749 ft</td>
<td>752 ft</td>
<td>3 ft</td>
</tr>
<tr>
<td>P-13</td>
<td>721 ft</td>
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<td>4 ft</td>
</tr>
<tr>
<td>P-14</td>
<td>687 ft</td>
<td>695 ft</td>
<td>8 ft</td>
</tr>
<tr>
<td>WIPP-33</td>
<td>675.3 ft</td>
<td>678.0 ft</td>
<td>2.7 ft</td>
</tr>
</tbody>
</table>
DOE has always been reluctant to admit to the extent of shallow dissolution. No later than November 1981 a map was prepared by Richard P. Snyder of USGS, based upon the borehole data cited above, showing the shallow dissolution front extending eastward into the WIPP site itself. This map was stamped "OFFICIAL USE ONLY" and was withheld from the public until March 1983 when it was finally published by Sandia Labs (Borns et al., 1983, Figure A-12). In the meantime, DOE published a map which falsely depicted all of the WIPP site as being free of dissolution in the Salado (WIPP SAR, Figure 2.7-33). And even the map prepared by Snyder does not tell the whole story. Borehole H-3 is anomalous, being located nearly two miles east of the shallow dissolution front. H-3 represents an isolated pocket of Salado dissolution deep within the WIPP site, 400 feet south of the proposed waste disposal area. This implies localized recharge and vertical flow through solution conduits. It is interesting that DOE cites Dennis Powers as its authority for the statement that the Salado at the WIPP site has not been thinned by dissolution. Powers was a co-author of Borns et al. (1983), the very report in which Snyder’s map was first published.

24 It cannot be stated that “there are no examples of karstic solution channels” within the WIPP site unless and until: (1) DOE employs field techniques capable of detecting karstic solution channels up to 1000 feet below the land surface; (2) DOE covers the entire WIPP site with such technology; and (3) DOE turns WIPP-33 and WIPP-14 into hydrologic test wells and conducts multiwell pump tests in them. CARD, in its paper entitled “Cavernous Zones at the WIPP Site,” has shown ample evidence of karstic solution channels that cannot be disproven by DOE.

25 CARD does indeed conclude that WIPP-14 is a sinkhole, but not because “lost core represents dissolution zones into which there has been collapse.” WIPP-14 is probably not a collapse sink, but is more likely an alluvial doline (solution-subsidence doline), for which the Pecos River valley is well known. CARD specifically differentiates between subsidence and collapse, stating that no collapse is evident at the surface at WIPP-14. Nor is there evidence of collapse beneath the surface, which explains the “normal stratigraphic sequence” claimed by DOE. However, at WIPP-14 the Culebra is directly underlain by 71.4 feet of mud with gypsum and anhydrite fragments, interpreted by CARD as transported cave sediments into which collapse of overlying strata has not yet occurred and through which groundwater can flow almost unimpeded. 71.4 feet of mud (not mudstone -- mud) does not constitute a “normal stratigraphic sequence.” Culebra dolomite was not deposited and lithified on top of 71.4 feet of mud; it was formed as a residue of salt dissolution. DOE has not offered an alternative explanation for the presence of mud beneath the Culebra, an occurrence reported nowhere else east of Nash Draw. In the CCA (Appendix DEF, p. DEF-30) DOE states that Nash Draw and the WIPP site “are separated by a transition zone which includes a prong of dissolution extending from Nash Draw towards the site of WIPP-14.” The CCA goes on to say that: “only a few small clusters of shallow dolines on the Mescalero caliche have been identified on the Los Medanos plateau east of Livingstone (sic) Ridge.” The CCA refers the reader to Figure DEF-7, which identifies “Depression Areas North of WIPP Site” at the precise location of WIPP-14. It is important to note that although the WIPP-14 drillhole is located 98 feet north of the current WIPP site boundary, the sinkhole into which WIPP-14 was drilled is 600 feet in diameter and straddles the WIPP site boundary, which constitutes direct evidence of karst at the WIPP site. In 1990, when Phillips led EPA officials on a tour of the WIPP site and vicinity, he found that the road to WIPP-14 had been barricaded.

26 Radiocarbon dates as young as 11,250 years B.P. (before present) have been reported for Mescalero caliche (Phillips, 1987, p. 67). Thus, the conclusion that Livingston Ridge assumed its present position hundreds of thousands of years ago is unsubstantiated. Livingston Ridge is an
eastward-retreating escarpment; its rate of retreat is uncertain, and it could indeed reach the WIPP site within “the regulatory time frame.” The edge of halite dissolution at the top of the Salado will not only “reach the controlled area (WIPP site) during the period of regulatory concern (10,000 years),” it has already reached the WIPP site, as shown above. DOE’s position is more explicitly stated in SEIS-II (1997, p. 4-30), where DOE contends that “dissolution at the top of the Salado at the edge of the WIPP site would not take place for some 225,000 years...” This time frame dates to a paper by Bachman (1973), as quoted in DOE’s response to Anderson (CCA Docket, A-93-02, Item # II-H-23, pp. 5-6). Bachman’s paper was written before the DOE even existed, before any of its test wells were drilled, when it was generally believed that the brine aquifer at the Rustler-Salado contact was confined to Nash Draw. DOE, in its defense of the WIPP site, is compelled to fall back upon an outdated report which preceded most data collection.

27 The issues in dispute are, indeed, the amount of recharge and its infiltration rate to the Culebra. DOE errs by one to two orders of magnitude on both related rates, adopting one which is tantamount to no recharge and infiltration at all. In its performance assessment, DOE relies upon the simplifying assumption that groundwater flow is two-dimensional, confined to the Culebra. DOE assumes that no other subsurface pathway exists above the Salado (CCA, Appendix MASS, pp. 67, 68), contrary to its own admissions that “flow in the Rustler Formation is three-dimensional and occurs to some degree in all Rustler units” (SEIS-II, p. 4-21), and that the two-dimensional model “does not properly account for vertical leakage into the Culebra” (CCA, Appendix MASS, Attachment 15-7, p. 22). DOE admits that the “confined model” is a necessary simplification for performance assessment (CCA, p. 9-18). If the assumption of confined flow was made to avoid the difficulties of three-dimensional modeling, it is a mistake. DOE has speculated about the percentage of rainwater recharge that reaches the Rustler Formation, with guesses ranging from 25% (CCA, p. MASS-69) to 30% (CCA, p. 2-128) to 66% (CCA, Appendix MASS, Attachment 15-7). DOE has never even attempted to measure infiltration rates at the WIPP site. Reliance on a chloride mass balance method is no substitute for measured data. DOE admits that, in its groundwater model, the recharge value was chosen in order to yield the desired result. DOE then claims that the model reveals the locations of the recharge areas, all of which just happen to be distant from the WIPP site. CARD, in its paper entitled “Rainwater Recharge at the WIPP Site,” has already shown that the recharge area for the Dewey Lake Redbeds and the Rustler Formation is at and near the WIPP site, everywhere that the Santa Rosa sandstone is not present. CARD will not restate its supporting evidence here.

28 Since April 1979, when the Draft Environmental Impact Statement (DEIS) was issued, DOE has proceeded on the assumption that Culebra groundwater from the WIPP site would discharge at Malaga Bend on the Pecos River. DOE now concedes that it will not. This admission invalidates the WIPP performance assessment, which charts all flow paths southward toward Malaga Bend only. Phillips (1987, Chapter VIII) showed through geochemical analysis that while groundwater from the Rustler/Salado brine aquifer discharges at Malaga Bend, the dolomite and anhydrite members of the Rustler Formation discharge at Laguna Pequena and Laguna Grande de la Sal in Nash Draw. DOE admits that the Tamarisk discharges at Laguna Grande de la Sal, but denies that the Culebra discharges there (SEIS-II, p. 16-17), seemingly unaware that the Culebra is exposed there (Vine, 1963). Phillips (1987, Chapter VIII) showed through analysis of evaporation rates that Laguna Grande de la Sal may account for ten times as much groundwater flow as do the brine springs at Malaga Bend. DOE denies this (SEIS-II, p. 4-21), citing Hunter (1985, p. 32) who thought the surface of Laguna Grande de la Sal is 660 acres, when in fact it is 2,120 acres (Robinson and Lang, 1934, Plate 4). On one occasion, Phillips (1987, Chapter VIII) measured 394 cubic feet per second (177,000 gallons per minute)
of water flowing from Laguna Pequena into Laguna Grande de la Sal. However, in 1990, when Phillips led EPA officials on a tour of the WIPP site and vicinity and attempted to show them Laguna Pequena, DOE personnel intervened and prevented him from doing so. DOE now recognizes discharge at Laguna Pequena, but still is "not clear" why groundwater from WIPP must discharge at Laguna Grande de la Sal. Such statements reflect a lack of understanding of groundwater hydrology. In Nash Draw, the lowest point of the watershed, both topographically and potentiometrically, is Laguna Grande de la Sal. Such an argument is not "entirely irrelevant with respect to compliance." Evaporation rates suggest that nearly 600 million cubic feet per year of Rustler groundwater flows into Laguna Grande de la Sal (Phillips, 1987, Chapter VIII). If none of this water comes from the WIPP site, then DOE must propose another discharge point for Rustler groundwater, based upon field observation. In the CCA (Appendix SCR, p. SCR-29), DOE states that: "In the region around WIPP, the principal discharge areas are along Nash Draw and the Pecos River." If groundwater from WIPP does not discharge to the Pecos River, then it must discharge to Nash Draw. If DOE cannot identify another groundwater discharge point, then EPA certification should be denied because a basic understanding of the regional groundwater hydrology is lacking. DOE must not be allowed to restrict its calculations to the WIPP site boundaries, since that permits DOE to divorce its groundwater model from reality. By ignoring Laguna Grande de la Sal, DOE underestimates by one to two orders of magnitude the amount of rainwater recharge in the Rustler groundwater system.

DOE misrepresents CARD's presentation of groundwater flow paths. DOE observes that the geochemistry of Culebra groundwater varies markedly across the WIPP site and vicinity. "Zone A," primarily east of the WIPP site, has water with moderately high concentrations of dissolved halite. "Zone B," south of the WIPP site, has water with lower concentrations of dissolved halite than of dissolved gypsum. "Zone C," including most of the WIPP site and immediate vicinity, has water with concentrations of dissolved halite steadily decreasing from east to west. "Zone D" has water contaminated by effluent from potash refineries in Nash Draw. CARD does not believe that Culebra water flows from "Zone C" to "Zone B," as suggested in the CCA. CARD believes that the simplest explanation which accounts for observed groundwater geochemistry is that Culebra water flows from "Zone C" to "Zone D," that is, from the WIPP site to Nash Draw. So does water in the Forty-niner, Magenta, and lower unnamed members of the Rustler. CARD has never "assumed" that groundwater flow is confined to the Culebra; to the contrary, CARD has given evidence that groundwater flow in the Rustler is three-dimensional. DOE admits that Corbet and Knupp (1996) sought a "coherent explanation" of Culebra groundwater geochemistry "consistent with the flow directions presented in the CCA." Anyone can produce a groundwater model consistent with the desired conclusion. CARD's interpretation is consistent with field observations and all measured data. In "Zone C," the steady decrease in concentrations of dissolved halite from east to west, from the WIPP site to Nash Draw, together with the presence of dissolved halite in test wells to the west of the WIPP site (H-6, P-14, WIPP-25 and WIPP-26), where there is no halite in the Rustler, does indeed indicate a westward component to groundwater flow. DOE makes the very same argument for "Zone A" east of WIPP, while insisting that westward flow cannot be happening in "Zone C." Moreover, the concentrations of dissolved halite in the Culebra at P-14 (18,100 mg/l) are low enough to indicate direct rainwater recharge and a short residence time. Lambert (1983, SAND 82-01, p. 72) made the same observation. DOE generalizes that "the sites of recharge can be found in a groundwater basin model by tracing various flow paths from the WIPP site upstream to the water table." If the model is wrong, so are the flow paths deduced from it. Such flow paths "were not identified." (CCA, Appendix MASS, p. MASS-71). DOE cannot rely on speculation that there are three distinct areas of recharge at unknown locations distant from the WIPP site. DOE must either
accept that recharge to the Dewey Lake Redbeds and the Rustler Formation occurs at the WIPP site itself, wherever the Santa Rosa sandstone is not present, or admit that it lacks a rudimentary understanding of the regional groundwater system.

30 DOE claims that Culebra groundwater is more than 12,000 years old. Let us examine DOE's evidence. (1) According to DOE, no tritium from nuclear testing has been detected in Culebra groundwater. DOE does not reveal which Culebra test wells have been tested for tritium; one would certainly not expect to find it where the Santa Rosa sandstone impedes infiltration. Even if every Culebra test well were tested and found not to contain tritium, this would only mean that Culebra water, at these specific locations, is at least 52 years old, and then only if it could be shown that tritium contamination from nuclear testing had actually occurred in the region. Moreover, tritium was found in WIPP test wells 15 years ago (Barrows, personal communication, May 1983). The data are not revealed by DOE. (2) Stable isotope signatures and radiocarbon dating are not reliable means for determining the age of groundwater; the reader is referred to Chapman (EEG-35, 1986) and Chapman (EEG-39, 1988). (3) DOE says that recharge rates "in excess of 12,000 years are consistent with the flow pattern predicted by the groundwater basin modeling." A flow pattern, even if correct, reveals nothing about the age of the water. (4) DOE says that "overlying anhydrites are not thought to have been fractured by upper Salado dissolution." DOE is referring to "Zone C," where overlying anhydrites are commonly converted to gypsum (e.g. at P-1, P-4, P-12, P-13, P-14, P-15, H-11, H-14, H-16, H-17, H-18, WIPP-11, WIPP-12, WIPP-13, WIPP-14, WIPP-18, WIPP-19, WIPP-33, WIPP-34 and DOE-2) by solution processes due to fresh water recharge proceeding from the top down, regardless of whether dissolution has reached the underlying Salado. (5) The geochemistry in "Zone B" is not relevant. Test wells H-8 and H-9 are far from groundwater flow paths from the WIPP site to the accessible environment in Nash Draw. (6) Not all Culebra water at WIPP is saturated with respect to gypsum. The lowest reported concentrations of dissolved gypsum in the Culebra at test wells within the WIPP site vary by a factor of seven, from 1,170 mg/l at H-5 to 8,180 mg/l at H-1, as compared to 13,180 mg/l at WIPP-29 in Nash Draw. (7) Undersaturation with respect to halite can and should be attributed to short residence times (Ramey, EEG-31, 1985, p. 21). Undersaturation occurs even where halite is present above the Magenta (89,200 mg/l NaCl at P-18), where hydraulic conductivity is said to be very slow (0.0001 ft/day). Under these conditions, a residence time of far less than the 12,000 years postulated by DOE should be sufficient to achieve saturation (318,000 mg/l NaCl).

31 The evidence says that the recharge area for the Dewey Lake Redbeds and the Rustler Formation is at and near the WIPP site, everywhere that the Santa Rosa sandstone is not present. DOE claims that recharge occurs far from the WIPP site precisely because it would "not affect the model results." The discharge area for groundwater from the WIPP site is at Laguna Pequena and Laguna Grande de la Sal in Nash Draw. It is here that plutonium contamination from WIPP would reach the accessible environment. DOE denies that anything beyond the WIPP site boundary is part of the accessible environment. The argument is that plutonium concentrations in groundwater would be diluted as it travels away from the WIPP site boundary, and therefore would be of less consequence to the victim. The flaws in this argument are: (1) Large amounts of Rustler groundwater, nearly 600 million cubic feet per year, flow into Laguna Grande de la Sal; this is more than ten times as much as DOE has acknowledged (Hunter, 1985, p. 44). DOE argued unsuccessfully for years that Laguna Grande de la Sal is an artificial lake entirely attributable to effluent discharge from potash refineries. (2) The huge volume of Laguna Grande de la Sal does not comport with the very slow recharge rates and groundwater travel times predicted by DOE. (3) Laguna Grande de la Sal has no outlet, either at the surface or
underground, and plutonium entering Laguna Grande de la Sal would concentrate in the lake sediments until (4) Laguna Grande de la Sal overflows into the Pecos River during times of major flooding, at which time actual victims downstream would be affected.

32 DOE has made no "measurements" of rainwater recharge. Campbell et al. (1996) used a chloride mass balance method, which is no substitute for measured data. The derived values (0.2 to 2.0 mm/yr), which Corbet and Knupp (1996) assumed for their equations, are too low. Precipitation at Carlsbad averages nearly 40 cm/yr. Corbet and Knupp are saying that evapotranspiration equals 99.5% to 99.95% per year, that only 0.05% to 0.5% of annual precipitation ever reaches the Rustler Formation. This cannot account for the nearly 600 million cubic feet per year of naturally occurring groundwater flowing into Laguna Grande de la Sal. Hunter (1985) concluded from a literature review that evapotranspiration is 96% in the vicinity of WIPP. Her calculation of 98% to 99.5% (Hunter, 1985, SAND84-2233, p. 44), cited by DOE, was erroneous, based upon a severe underestimate of evaporation from Laguna Grande de la Sal, and an unwarranted assumption that the discharge to the Pecos River at Malaga Bend comes from the Rustler Formation. Phillips (1987, Chapter VIII) calculated an evapotranspiration rate of 95%, based upon water balance equations for which all other variables are well known. A recharge rate of 20 mm/yr is necessary to account for the discharge to Laguna Grande de la Sal.

33 The claim that Corbet and Knupp (1996) have bounded the hydrologic effects of karst, potash mining, and climatic change, simply by analyzing the effects of a three order of magnitude increase in hydraulic conductivity (applied randomly) in the Culebra dolomite was made by an EPA scientist in Albuquerque, New Mexico in January 1997. DOE made a similar claim in SEIS-II (1997, p. H-99). In view of evidence that the Rustler is integrated by dissolution features, this treatment of future effects is unduly restrictive. DOE acknowledges that early interest in the effects of climatic change on the WIPP site "focused on the possibility that wetter climates might increase the rates of salt dissolution. ... Questions have also been raised about whether dissolution or precipitation of fracture fillings in the Culebra could occur during climatic changes and alter the rate of radionuclide transport in groundwater." (CCA, Appendix MASS, pp. 99, 100) In fact, Anderson (1996) and Phillips (1997) are still interested in these points. In DOE's performance assessment, however, the climate change model is implemented through the use of a single parameter, an increase in hydraulic conductivity in the Culebra dolomite, because EPA criteria erroneously allows DOE to do so.

34 DOE admits that the hydrologic conditions of a full-glacial maximum were not incorporated into its computer simulations. Corbet and Knupp (1996) began their simulations at 14,000 years before present, "when there was a clear decline in the annual precipitation rate." This is not the same as the full-glacial conditions of 18,000 years before present, when the precipitation rate was higher and the evaporation rate was lower. DOE states that Swift (1992), reproduced as Appendix CLI in the CCA, "forms the basis for the DOE's present understanding of climatic change." (CCA, Appendix MASS, p. MASS-100) Swift clearly states that the precipitation rate during the late-Pleistocene full-glacial climate should be the conservative upper limit for DOE's groundwater model for the next 10,000 years (p. 11, 19), even though he believes a return to full-glacial conditions to be "highly unlikely" (p. 22). DOE states in the CCA (Appendix MASS, pp. 99, 100) that climate change during the next 10,000 years "should be bounded by the extremes of the late Pleistocene glaciation." It is unfortunate that DOE disregards its own advice. Phillips (1987, Chapter IX), citing future decreases in incoming solar radiation due to predictable changes in the tilt of the earth's axis, disagrees that a return to full-glacial conditions is highly unlikely, but otherwise agrees with Swift. If such conditions are plausible within the next 10,000 years,
they should be modeled by DOE. Placing the water table at the land surface does not suffice because, as explained above, the water table was not at the land surface during the Pleistocene, as proven by the continued existence of Mescalero caliche.

35 It is not sufficient that Corbet and Knupp (1996) considered the “cyclical nature” of climatic change during the Holocene - that is, since the Ice Age. The issue is that full-glacial conditions, cyclical or otherwise, have never been incorporated into DOE groundwater models.

36 DOE explains that, in its performance assessment (PA), it has “screened out” surface waters, including Laguna Grande de la Sal and the Pecos River, “on the basis of low consequence.” DOE cites Appendix SCR, Section SCR.1.5.4., which screens out river flooding and lake formation because the WIPP site itself will not be flooded. That is not the issue. The problem is that Laguna Grande de la Sal, the discharge point for contaminated water from the WIPP site, will overflow into the Pecos River during glacial conditions, as it has during major flooding events of this century. The Pecos River is where the people live. Contaminated surface water is of the highest consequence to them, now and in the foreseeable future.

37 Regarding water quality and quantity in the Dewey Lake Redbeds, it is not true that CARD merely “repeats the documentation given in Appendix USDW of the CCA.” Only two WIPP test wells (H-4c and WQSP-6a) are listed by DOE in Table USDW-4. Reports of water in the Dewey Lake Redbeds at eleven other WIPP test wells were collected by CARD from a variety of sources and presented in Table 2 of its paper entitled “Rainwater Recharge at the WIPP Site.” DOE’s failure to present this data to EPA is an indication that geologic evidence has been used selectively. None of the data on the Dewey Lake Redbeds was included in the Draft CCA. It was at the insistence of the EEG that DOE divulged the information (EEG-61, 1996, p. 2-6).

Moreover, the neutron logs and caliper logs for H-1, H-2 and H-3, the hydrologic test wells closest to the center of the WIPP site, have never been published at all; CARD obtained them from the USGS. DOE still claims that the Dewey Lake Redbeds have “not produced water within the WIPP shafts or in boreholes in the immediate vicinity of the panels.” (CCA, p. 2-131). To the contrary, EEG has reported that the Dewey Lake Redbeds produce water in the WIPP exhaust shaft at a depth of approximately 100 feet below land surface (CCA Docket, A-93-02, Item # II-E-36). The Dewey Lake produced water in the WIPP air intake shaft as well (EEG-61, 1996, p. 2-6). The Dewey Lake has also produced water in test wells H-1, H-2, H-3 and WQSP-6, all in the immediate vicinity of the waste panels. EEG believes that the CCA should be modified to include the Dewey Lake Redbeds as a potential pathway for release of radionuclides because they contain significant quantities of potable water (CCA Docket, A-93-02, Item # II-E-36). In addition, CARD points out that Culebra water is potable in test well H-2b, located only 0.7 miles west of the center of the WIPP site, within the Land Withdrawal Area (LWA), 0.25 miles from the proposed waste disposal area. Perhaps DOE should calculate the dose to a victim drinking water from this well after institutional control of the WIPP site is lost.

38 When analyzing groundwater flow in a karst terrain, using the highest measured values of transmissivity is both realistic and conservative. It is realistic because the highest measured values are real; they represent the ability of the rocks to transmit water along discrete, localized flow paths at a rate which is orders of magnitude higher than elsewhere in the drainage basin. It is conservative because these are the paths of least resistance, the actual effective groundwater flow paths; to be sure, groundwater flow through karstic solution channels is the worst-case scenario, but this is inevitable, and it is precisely what a conservative person must analyze. Within one mile of the WIPP site, Culebra transmissivities vary by five orders of magnitude.
Corbet and Knupp (1996), by "using the geometric mean of measured values," have averaged the test values and eliminated karst conditions from consideration.

39 In order to discount the existence of karst conditions at the WIPP site, DOE attributes "fracturing and disruption of Rustler strata" to dissolution of underlying Salado salt. No such correlation has been demonstrated. Each foot of dissolution residue at the top of the Salado represents perhaps 10 to 20 feet of missing salt. At P-14 there is 8.0 feet of dissolution residue at the top of the Salado, and no cavernous zones were reported in the Rustler. At WIPP-33 there is only 2.7 feet of dissolution residue at the top of the Salado, and there are four nested caverns totaling 22.5 feet within a 50.5-foot section of the Rustler. Two of these caverns are in the Magenta, totaling 7.0 feet within a 19.0-foot section of dolomite. Elsewhere the Magenta ranges in thickness from 19 ft (at H-6) to 28 ft (at H-2), but at WIPP-33 only 12.0 feet of Magenta dolomite remains. The missing dolomite is due to dissolution and removal by groundwater; it cannot be attributed to dissolution of Salado salt 209 feet below the Magenta. Within the WIPP site are four drillholes (H-3, H-6, P-6 and P-13) where 2 to 4 feet of dissolution residue was found at the top of the Salado. DOE's response is to deny its own Basic Data Reports by insisting that there has been no dissolution of Salado salt at the WIPP site. Corbet and Knupp (1996) may have "clearly described" their "mapping of the boundaries marking the extent of these processes," but their "boundaries" are wrong.

40 DOE concedes that its technique of dividing the WIPP site into model "cells" of four square kilometers (1000 acres each) means that "local-scale variations" are not "represented." These would include zones of high transmissivity attributable to karst conduits. This "limitation" cannot be "offset" by emphasizing "larger-scale features," which only compounds the distortion caused by ignoring smaller-scale, but dominant, dissolution features. Nor can this "limitation" be "offset" by emphasizing aspects of groundwater systems that are "less sensitive" to "local-scale variations;" this completely ignores the transport implications of karst.

41 CARD must reiterate its statement that Corbet and Knupp's assumed value of 0.28 ft/day for hydraulic conductivity in the Dewey Lake Redbeds is pure speculation. It is not based on measured data. DOE admits that it is "based on literature data for similar rock types." DOE claims that "use of the highest measured conductivities" would be "unrealistic." To disregard the highest measurements of hydraulic conductivity is to throw out the evidence for karst, and to ignore the significance of maximum values observed in channel flow.

42 CARD did not say that the Santa Rosa sandstone has sufficiently small conductivity to "block" recharge. CARD stated, based on the mapping of actual measured data, that (where it is present) "the Santa Rosa sandstone retards, but does not prevent, rainwater recharge to the underlying Dewey Lake Redbeds."

43 DOE characterizes Culebra transmissivity as varying "significantly" across the WIPP site. More precisely, it varies by nearly three orders of magnitude, from 0.1 ft²/day at P-15 to 88.0 ft²/day at H-6. Within one mile of the WIPP site, Culebra transmissivity varies by more than five orders of magnitude, from 0.003 ft²/day at P-18 to 324 ft²/day at P-14. DOE claims to "capture the uncertainty associated with the spatial variability of the available data" through the use of a "stochastic model." The word "stochastic" is defined as "involving or containing a random variable." Indeed, DOE's model assumes "that the spatial variation is random." It is not random. It is spatially dependent. The anomalously high measured transmissivities have distinct directional orientation in the northwestern and southeastern portions of the WIPP site; these
represent preferential flow paths for groundwater and should be treated as such. They are linked, highly correlated. The Peer Review Panel made the same objection, noting that “some localities have implied high permeabilities over distances of several kilometers.” These are hypothesized to be “interconnected fracture zones.” They are “too large in magnitude to be explained by variation in sample interval” in the Culebra; they have distinct spatial orientation; and they “have not been clearly associated with a conceptual model of the geology of the dolomite or of the Rustler Formation as a whole.” (CCA, Appendix PEER, p 3-8) “All hypotheses failed to correlate the detailed hydrogeology of the Culebra with its tested hydrologic character.” (CCA, Appendix PEER, p. 3-12). The DOE “agrees with this assessment.” (CCA, p. 9-18) The Peer Review Panel concluded that DOE’s “single and multiwell and tracer testing in the Culebra are an attempt to characterize the hydrology of the Culebra ... by numerical modeling alone.” (CCA, Appendix PEER, p. 3-11). Having failed to propose a conceptual model that accounts for all the observed data and satisfies the Peer Review Panel, DOE relies instead upon a method more applicable to a sand and gravel aquifer, treating the data as random variables. It is interesting to note the other definitions of the word “stochastic.” The word also means “characterized by conjecture,” or “involving chance or probability.” It is derived from the Greek word stokhazesthai, meaning “to guess at.”

44 DOE takes the position is that it does not matter how transmissive the Culebra is to groundwater, because any radionuclides in Culebra groundwater would be sufficiently retarded that there would be “no releases to the accessible environment.” Unless and until the DOE demonstrates matrix diffusion, and performs sorbing tracer tests in the field within solution-enhanced conduits, this statement is without foundation.

45 CARD, in its paper entitled “Potential Flow Paths from the WIPP Site to the Accessible Environment,” presents Table 2, “Comparison of Fresh Water Hydraulic Heads,” for the benefit of the reader. To our knowledge, DOE has never compiled all of it in one table. The “point” that CARD makes with this table is that the data set is incomplete.

46 The groundwater flow directions modeled by DOE are not consistent with the observed Culebra heads. The DOE deduces a southerly flow path from the WIPP site, bypassing Nash Draw altogether. This is impossible, for it would require that Culebra groundwater flow up the hydraulic gradient from H-17 to H-12, (2995 ft to 2998 ft), and from H-9 to H-8 (2975 ft to 2991 ft). Moreover, the multiwell pump test centered in the Culebra at H-11 revealed no hydraulic connection between H-17 and H-12 (Beauheim, 1989, p. 79).

47 Both CARD and EEG have observed that hydraulic heads for the Culebra and Magenta are equal at H-6 and WIPP-25. At these locations the Culebra and Magenta are not hydrologically isolated from each other, and the Rustler is one complex aquifer with five members. Whether this is also true at WIPP-13 is not known for certain because of insufficient data. However, the Culebra head at WIPP-13 (3064 ft) is higher than at H-6 (3057 ft) and WIPP-25 (3054 ft), and it is predicted that if the DOE would conduct the necessary testing at WIPP-13, it would be found that the Culebra and Magenta heads are equal there as well.

48 We have already noted that potential victims beyond the WIPP site boundary have been discounted by DOE. As for the two-dimensional model of the Culebra, the equal heads for the Culebra and Magenta at H-6, located within the WIPP site boundary, disprove “the validity of the assumptions.” Demonstrably, the Culebra is not a confined aquifer at H-6.
DOE's failure to characterize fractures in the Culebra through slant-coring or any other method enables DOE to attribute fracturing in the Culebra to dissolution in the underlying Salado, which is inconsistent with the claim that no dissolution has ever occurred at the WIPP site. The Peer Review Panel stated that fracture distribution, aperture, and orientation have not been sufficiently characterized to make possible any correlation between hydraulic properties and geologic features. Such characterization would require slant-coring and three-dimensional modeling (CCA, Appendix PEER, p. 3-9). To be sure, slant coring would be expensive, but not compared to the $2 billion which DOE has spent already. This is not a new suggestion. Gibbons and Ferrall, then under contract to Sandia Labs, proposed a slant-coring program in 1980; DOE declined to publish their proposal.

DOE does not address the issue. The Culebra should not be modeled as a porous, homogeneous medium. Karstic rocks have dual porosity, and groundwater flow in karst cannot be approximated by modeling flow through a single-porosity medium. Moreover, it is disingenuous for DOE to deny that there are "significant (i.e., large-scale)" features with higher transmissivities than those measured in boreholes. The problem is that there are small-scale features with higher transmissivities. They are called "sinkholes" and "solution channels," none of which have been tested.

DOE does not address the issue. The fracture model, of very limited use without fracture data, should not assume isotropic flow. DOE concedes that "Culebra transmissivity is controlled by the abundance of open fractures," but does not take into account that some of these open fractures have been enlarged by solution and are now karst conduits. DOE confuses the issue by presenting the false choice of modeling the Culebra as having randomly-variable transmissivity or randomly-oriented fractures. Neither one is random. The zones of anomalously high transmissivity have preferred direction according to the orientation of solution-enlarged fractures, and they provide linked pathways for groundwater flow, bypassing the rock matrix.

DOE relies on a two-dimensional model which treats the Culebra as a confined aquifer and completely ignores the other four members of the Rustler -- even the Magenta dolomite, long recognized as an important water-bearing unit. DOE claims that "all of the outward flow" from the WIPP site is "by lateral flow along the Culebra." The hydraulic heads at H-6, where the Culebra and Magenta heads are equal, and the water-filled caverns at nearby WIPP-33, two of which were found in the Magenta, are sufficient evidence to negate DOE's model. DOE's neglect of the Magenta dolomite as a potential pathway is based on a number of claims, all of which are erroneous or unsubstantiated. DOE did claim that the Magenta "is unfractured at WIPP" (CCA, p. 2-98). This claim was later modified to read that "the Magenta is a porous medium with no hydraulically significant fractures" at the WIPP site (CCA, p. 6-147). The Peer Review Panel was unconvinced, and stated that: "The principal hydrogeologic difference between the Culebra and Magenta is purported to be the absence of hydrologically active fractures in the Magenta. This assertion is based on two slug tests and very limited field observation in shaft excavations." DOE, in response, stated that: "The only location on the WIPP site at which open fractures have been observed in the Magenta is WIPP-13." (CCA, p. 9-29) We draw attention to WIPP-19, where open high-angle fractures were found in Magenta core (SAND 79-7110, p. 15), and to the WIPP ventilation shaft, where eleven fractures in the Magenta, all of them vertical to subvertical, all of them open, were observed and mapped (TME 3177, Figure 2). Groundwater seepage from the Magenta was reported to produce enough water to wet the shaft wall for about 20 feet below the Magenta (TME 3177, pp. 1-2, 4-4, 5-3). DOE correctly stated that the highest Magenta transmissivity measured at the WIPP site was 0.3 ft²/day (at H-6) (CCA, p. 9-29).
However, Magenta transmissivities were derived from single-well tests rather than multiwell pump tests which, in the Culebra, have found transmissivities in some wells to be an order of magnitude higher than previously thought (LaVenue et al., 1988, Table C.1). DOE also stated that there are no regions of high transmissivity due to fractures and that all flow in the Magenta is matrix flow. The Peer Review Panel called these conclusions "weak," due to "a very limited observational and testing data base" (CCA, Appendix PEER, p. 3-55) which does not include, for example, WIPP-13 or WIPP-33. A similar statement was made in SEIS-II, where DOE claimed that: "The Magenta does not have hydraulically significant fractures in the vicinity of WIPP." (SEIS-II, 1997, p. 4-27). However, the Magenta does have two hydraulically significant caverns at WIPP-33, 0.5 miles west of the current WIPP site boundary. DOE twice stated to the Peer Review Panel that at four locations (DOE-2, H-3, H-6 and H-19), "the Culebra has been found to be fractured and have a high transmissibility, whereas the Magenta has not." (CCA, pp. 9-29, 9-30). CARD is unaware of any published lithological descriptions for the Magenta at any of these four test wells, except for one paragraph describing the Magenta at H-6 as: "Dolomite, light-olive gray to olive-gray, silty; some gypsum." (USGS WRI 79-98, p. 4). DOE admits that "transmissivities of the Magenta" are "based on sparse data." (SEIS-II, p. 4-27). This is well illustrated by DOE's map of hydraulic heads in the Magenta, which contains almost as many contour lines as data points (CCA, p. 2-129). DOE, in its response to CARD's comments, states that Corbet (1995, Appendix MASS, Attachment 15-7) "carried out an analysis specifically to ensure that the two-dimensional model is adequate" for performance assessment. In this memo, Corbet states that "all of the vertical leakage between the Magenta and the Culebra in the controlled area is directed downward," and that "zero percent of the flow out of the Culebra is by vertical leakage across its upper surface." Corbet further states that: "These results are supported by field observations of fresh-water heads in the Magenta and the Culebra." (CCA, Appendix MASS, Attachment 15-7, p. 21). Corbet overlooks test well H-6, within the controlled area, where the Culebra and Magenta fresh-water heads are equal. In his next sentence Corbet hedges, stating that: "In areas in which the Tamarisk is intact, observed fresh-water heads are higher in the Magenta than in the Culebra." (CCA, Appendix MASS, Attachment 15-7, p. 21) This would seem to exclude WIPP-13 where, according to the published lithologic log, the Magenta dolomite is "broken and shattered by numerous fractures dipping 60°-80° and displacing bedding planes 0.5-1.0 cm," and the Tamarisk member includes gypsum/mudstone breccia and steeply-dipping fractures, one of them filled only with silt. Corbet concedes that "fluid pressures and densities in the strata between the Magenta and Culebra are not known." (CCA, Appendix MASS, Attachment 15-7, p. 21) Yet DOE told the Peer Review Panel that "the Culebra is under pressured with respect to the Magenta and Dewey Lake. Therefore, any cross flow between the units will occur from the Magenta and Dewey Lake to the Culebra." (CCA, p. 9-30) Corbet concludes that "all flow out of the Culebra in the controlled area is by lateral flow," and that "a two-dimensional model is able to represent realistic release paths." This, says Corbet, "is perhaps the most important point to be considered in evaluating the applicability of the two-dimensional model and the strongest argument in its favor." (CCA, Appendix MASS, Attachment 15-7, pp. 21-22). But there are parties within DOE who know that this argument is not true. In SEIS-II, "DOE concluded that flow between the Forty-Niner and Magenta would be upward in H-3, H-14, and H-16, three boreholes which yielded reliable pressure data for the Forty-Niner. This conclusion is not consistent with the results of groundwater modeling, and this inconsistency may be the result of local heterogeneity in rock properties that affect flow on a scale that cannot be duplicated in regional modeling." (SEIS-II, 1997, p. 4-27) On the other hand, this conclusion is consistent with one of the karstic groundwater flow paths described by Phillips and Snow in CARD's paper entitled: "Potential Flow Paths from the WIPP Site to the Accessible Environment." CARD notes that flow between the Forty-Niner and Magenta would also be
upward at DOE-2. In the CCA, the DOE tries to rationalize the Magenta flow path, which is predominantly westward from WIPP-13 to H-6 to WIPP-33 to WIPP-25, by saying that “flow in shallower units (than the Culebra) is expected to be more sensitive to local topography.” (CCA, p. 2-128) This argument does not bear scrutiny. At WIPP-13 the Magenta is 564 feet below the surface and only 118 feet above the Culebra. At H-6 the Magenta is 490 feet below the surface and only 90 feet above the Culebra. At WIPP-33 the Magenta, or what is left of the Magenta, is 449 feet below the surface and only 82 feet above the Culebra. The difference in flow directions between the Culebra and Magenta has nothing to do with topography; it has everything to do with karst. The Peer Review Panel concluded that DOE’s “assumption” that the Dewey Lake Redbeds and Magenta dolomite” are not flowpaths “is not well supported. ... If the need to assess transport in the Magenta and Dewey Lake were shown to exist, the small hydrologic testing data base and the existing conceptual model would not be adequate to such an assessment.” (CCA, Appendix PEER, p. 3-57) CARD contends that the need to model all members of the Rustler as one complex three-dimensional aquifer is shown to exist. DOE has ignored the advice of the Peer Review Panel, as it has with so many others.

DOE concedes that “CARD is correct in stating that matrix diffusion becomes less important as fracture apertures widen and groundwater flow rates consequently increase.” DOE then claims that “double-porosity groundwater transport models account for this effect.” Unfortunately, DOE’s model is unrealistic, because its assumed dual porosity involves fracture flow and matrix diffusion, and does not incorporate enhanced conductivity through solution-enlarged channels. More appropriate models do exist. In Jones et al., (1992, SAND 92-1579, pp. 3-9, 3-10, 12-19), there is a discussion, with references to published literature, of a “variable-aperture channel model,” where the bulk of groundwater flow occurs in “preferred flow paths” or “channels.” It is stated that this model fits the breakthrough curves yielded by the converging-flow tracer tests performed at the H-3, H-6 and H-11 hydropads, but channel-model interpretation approaches were not attempted by DOE. The model preferred by DOE starts with the measured porosities of the Culebra dolomite (which vary by an order of magnitude, from 3% to 30%) (CCA, p. 2-119), and averages this to 16%. Of this “average effective porosity,” DOE assumes that fracture flow is represented by 1% porosity and matrix diffusion is represented by 15% porosity (CCA, Appendix PEER, p. 3-59), that matrix diffusion is much more effective than fracture flow. It would follow that retardation of radionuclides by matrix diffusion would be effective. These assumptions are not based upon empirical field data. DOE states that fracture porosity “is thought to be a small percentage of the total volume of the Culebra involved in transport” (CCA, Appendix MASS, p. MASS-80). These values for fracture porosity and matrix porosity are assumed to be constant throughout the WIPP site and vicinity. Never does DOE consider groundwater movement and radionuclide transport through karst channels. Franklin et al. (1981, p. 57), under contract to the NRC, warned against the siting of nuclear facilities in karst terrains. They stated that “flow velocities are often orders of magnitude greater in karst,” and that “filtration, which acts in porous media to remove many contaminants from the water, is virtually absent in the karst environment.” In the vicinity of WIPP there are large underground caverns, filled with flowing water, at WIPP-33, H-7, and surely elsewhere. Under such conditions, the conservative assumption is that Kd approaches zero, that most radionuclides will travel at the speed of water. Sandia Labs (SEIS-II, Appendix H, p. H-103), the EEG (Chaturvedi and Channell, EEG-32, 1985) and the EPA (SEIS-II, p. H-103) have all calculated that if there is no matrix diffusion, the WIPP will violate EPA standards for groundwater contamination. The Peer Review Panel is concerned that “zones of relatively rapid fracture flow, without significant retardation of radionuclides by physical or geochemical processes, could cause accelerated transport in the Culebra.” (CCA,
Appendix PEER, p. 3-13) EEG does not believe that sufficient evidence exists to prove that matrix diffusion will be effective (EEG-61, 1996). Until effective matrix diffusion is demonstrated, and Kd values are measured by the performance of sorbing tracer tests in the field, WIPP should not be licensed.

54 DOE admits that its model for Culebra groundwater transport “does not account for dissolution and consequent widening of fracture apertures” during the next 10,000 years, but this is not CARD’s primary concern. Enlargement of fractures into solution channels at the WIPP site has already occurred. The WIPP site is in karst already, and karst will become more and more developed over time. DOE’s model should account for this not only in the future, but now.

55 It has not been said that “solution collapse” has occurred at the center of the WIPP site. One would expect not to find it in the WIPP exhaust shaft. However, one should not infer from this that there is no relationship between fracturing and dissolution anywhere else within the 10,240-acre WIPP site, especially in areas west of the repository.

56 DOE says that Culebra groundwater is saturated with respect to gypsum. DOE made this statement in response to EPA’s concerns about the potential for dissolution of gypsum fillings in fractures in the Culebra dolomite. DOE convinced EPA that “dissolution processes are not presently occurring the the Rustler” (EPA Docket, A-93-02, Item # III-B-3, p. 38) and that “conditions are not expected to change during the regulatory period,” that is, in the next 1,000 years (EPA Docket, A-93-02, Item # III-B-3, p. 82). DOE’s argument is that infiltrating waters that would cause the dissolution would become saturated with respect to calcium sulfate and therefore would be unable to dissolve anhydrite or gypsum (EPA Docket, A-93-02, Item # III-B-3, pp. 48, 83, 91). As supporting evidence, DOE calculates a gypsum saturation index for Magenta groundwater at test well H-4 (Corbet et al. to Chu, January 16, 1997, p. 10, Attachment to CCA Docket, A-93-02, Item # II-H-23), where measurements of dissolved calcium and sulfate are higher in the Magenta (7210 mg/l to 7760 mg/l) than in the Culebra (4180 mg/l to 7000 mg/l). The truth is that infiltrating rainwater will not be saturated with respect to gypsum until it has dissolved enough gypsum to become saturated. Presently, some Rustler groundwater is saturated with respect to gypsum, and some is not; concentrations of dissolved calcium and sulfate vary not only from well to well, but also from time to time. At test well H-5, measured concentrations of dissolved gypsum in Culebra waters range from 170 mg/l to 9600 mg/l, varying by a factor of 8.2X. At H-4, the range is 4180 mg/l to 7000 mg/l (1.67X). Along the southeastern flow path, the range is 5800 mg/l to 7200 mg/l (1.24X) at H-3, 7260 mg/l to 9200 mg/l (1.27X) at DOE-1, 7400 mg/l to 8900 mg/l (1.20X) at H-11, and 6520 mg/l to 8900 mg/l (1.37X) at P-17. Along the entire flow path, dissolution of gypsum fillings in Culebra fractures is presently occurring. Anderson (1994, p. 5) has also observed that Culebra groundwater in this area of high transmissivity “is relatively fresh and unsaturated for gypsum,” and that “gypsum cement has been removed by dissolution.” In addition, measured amounts of dissolved calcium and sulfate in Magenta waters ranges from 2700 mg/l to 4600 mg/l (1.70X) at H-3 (Ramey, EEG-31, 1985, pp. 52-60; Chapman, EEG-39, 1988, pp. 50-58; Lappin et al., 1989, SAND89-0462, Table 3.12). Fracture apertures will increase and matrix diffusion will decrease over time, and the rates of these changes will be accelerated during glacial conditions. DOE’s failure to characterize and evaluate the potentially rapid dissolution of gypsum and salt is a flaw in its groundwater model.

57 The examples of Kd values (distribution coefficients) given by CARD are for Pu-239, and are taken from the Geologic Characterization Report (CCA, Appendix GCR), as cited in CARD’s paper. The Kd values clearly demonstrate why DOE prefers measurements made upon crushed
powder (7300) to measurements made upon solid rock (19); there is almost a 40-fold difference between the two values. Moreover, the laboratory experiments were made in water which was not representative of Culebra groundwater geochemistry. CARD did say that the surface area per volume of rock is much greater for crushed powder than for fractured or karstic rocks, and thus the laboratory measurements are not representative of actual conditions. The Peer Review Panel made a similar observation (CCA, Appendix PEER, p. 3-62). CARD did not ask that DOE “attempt to scale the data.” The only way to obtain reliable distribution coefficients is to perform sorbing tracer tests in the field. DOE complains that such testing would be costly and difficult, but CARD finds these to be unconvincing excuses, considering the opportunities lost during decades of study of WIPP hydrology. As recently as 1996 the EEG made the same objections to DOE’s distribution coefficients (EEG-61, March 1996, pp. 6-8, 6-9; Neill to Salisbury, June 10, 1996). Even if EEG has abandoned this position, CARD has not done so. DOE has recently performed tracer tests at the H-19 hydropad, but the results of these tests are unpublished, unavailable to the public or to the Peer Review Panel (CCA, Appendix PEER, p. 3-60).

58 CARD is not “mistaken.” As recently as November 1996, when the Draft SEIS-II was issued, DOE “anticipated that, in the final compliance certification application, clay fracture linings will be assumed and credit will be taken for some degree of chemical retardation.” (Draft SEIS-II, 1996, p. H-86) EEG called this “a mechanism which may not exist.” (EEG-61, 1996, pp. 6-12, 6-13) In fact, as CARD stated, DOE’s adsorption studies were performed not upon fractures in the Culebra, which contain only small amounts of clay, but upon corrensite clay taken from a black shale layer in the lower unnamed member of the Rustler.

In closing, CARD wishes to pay tribute to Roger Anderson. He is the disinterested patriarch, the man who has investigated the WIPP site and vicinity longer than anyone else, and his words should carry weight:

“A disturbing conclusion is that DOE has selectively presented evidence in support of the application and disregarded evidence which is highly relevant to containment and performance. In so doing, DOE has greatly complicated the task of evaluating the suitability of the site. The non-objective character of the document means that EPA cannot accept even supported conclusions without further investigations.” (EPA Docket, A-93-02, Item # II-H-03, p. 6)