SAND80-0812
Unlimited Release
UC-70

27
6-23-80
24 DWT/IS
mmms

Recommended Analysis Plan for the Borehole Plugging Program Potash Core Test

MASTER

Steven J. Lambert

Prepared by Sandia Laboratories, Albuquerque, New Mexico 87185
and Livermore, California 94550 for the United States Department
of Energy under Contract DE-AC04-76DP00789
Printed May 1980

Sandia National Laboratories

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Issued by Sandia Laboratories, operated for the United States Department of Energy by Sandia Corporation.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Printed in the United States of America
Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Price: Printed Copy ~~\$4.00~~; Microfiche ~~\$3.00~~ ⁵²

5.40

ONWI/SUB/80
E511-03700-TRGC-1
April 1980

SAND80-0812

Recommended Analysis Plan for the
Borehole Plugging Program
Potash Core Test

by

Steven J. Lambert
Nuclear Waste Technology
Division 4511
Sandia National Laboratories
Albuquerque, NM 87185

April 1980

This report was prepared by Sandia National Laboratories under subcontract E511-03700 with Battelle Memorial Institute, Project Management Division, under contract E4-76-C-06-1830 with the Department of Energy. The subcontract was administered by the Office of Nuclear Waste Isolation

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

24

ABSTRACT

A four-year old plugged potash core hole near the Waste Isolation Pilot Plant (WIPP) site in southeastern New Mexico has been proposed for overcoring, in order to examine the behavior of known grout mix constituents in contact with a variety of rock types during an extended grout-curing interval. This report recommends that various geochemical analyses be applied to the core samples containing both grout and rock and the interface between the two. The methods to be used include optical petrography, electron microscopy, electron probe microanalysis, x-ray diffraction, thermal analysis (TGA, DSC, DTA) with gas chromatography/mass spectrometry, and bulk chemical analysis. These analyses would allow identification of phases which have developed during grout curing, and provide evidence of reactions which may have taken place among constituents in the system grout-rock-groundwater. These reactions, and their sequence of occurrence will be compared with reactions predicted by thermodynamic modeling as the system seeks its lowest Gibbs' free energy. Identification of reactions which have the potential for compromising the integrity of a grout plug will receive special attention. Since not all such detrimental reactions can be observed directly in a human lifetime, due to kinetic inhibitions, and since a capability of time-dependent prediction of their degree of occurrence cannot be developed, thermodynamic modeling is the only known way of evaluating the long-term stability of a grout plug. The analysis of the plug-rock system will give an indication of in situ curing history of grout plug, and will allow an early occurrence of potentially-detrimental reactions to be detected. Thus, this activity will be a case-study of suitability of certain grout mixtures for use in evaporites, as an example of evaluation of grouts for long-term compatibility with a variety of rock types.

INTRODUCTION

Background

In September of 1976, twenty-one holes were drilled in the southern part of the WIPP (Waste Isolation Pilot Plant) site in the northern Delaware Basin of southeastern New Mexico, in order to core the McNutt member of the Salado Formation for evaluation of the potash mineralization. All but four of those holes were plugged with cementitious grout of known mix constituents. These seventeen plugs have cured in place in rocks of various lithologies (siltstones, carbonates, evaporites) for about four years. Previous studies in field and laboratory have suggested that specially-formulated cementitious grouts are adequate for plugging boreholes and shafts in a radioactive waste repository in evaporites. Additional experimentation in the field and analysis in the laboratory will provide confidence in this suggestion. This report proposes an analysis program which could be used to address the long term adequacy of the plug.

Rationale

The long-term stability of cementitious grouts (or any plugging material) in geological environments cannot be directly observed in a human lifetime. Consequently, an approach similar to that of safety assessment is proposed.

The grout plug will in general not be in chemical equilibrium with its host rock or with natural groundwater solutions which may accumulate in the rocks. Chemical reactions can be formulated from various combinations of components in grout, rock and groundwater. The reactions will be sluggish at the ambient temperatures (less than 40°C), but calculations using thermodynamic data for postulated products and reactants can be used to identify the reactions that may ultimately take place (Lambert, 1980).

The recovery of grout and coexisting rock from the in situ curing environment will allow (1) phase changes to be identified in rock and grout, (2) evidence of interactions between rock and grout (during several years' curing) to be sought, and (3) evaluation of the suitability of the thermodynamic modeling to be made. The search for phase changes, interactions and specific postulated reactions is ideally facilitated by samples of grout plug and coexisting host rock. A potash core hole is appropriate for overcoring

because the plug is in contact with a variety of rock types, including the complex mineralogies of the McNutt potash zone. These mineral sources of magnesium and sulfate are of particular interest to those responsible for grout mix specification, since these components influence the properties of the plug (Gulick, 1978). In addition, the McNutt contains a variety of soluble components greater than that anywhere else in the section penetrated by the potash holes. The water-bearing zones, which it was desirable to isolate from the soluble zones, are also of interest, with respect to the influence of water on the plug and the efficiency of sealing of rocks immediately above and below water-bearing zones.

An example of reactants which can occur in old cement plugs is illustrated by Buck and Burkes (1979). In a 17-year old cement plug in an exploratory hole intercepted in the Duval Nash Draw potash mine (Christensen, 1979), abundant Ca(OH)_2 (portlandite) was found, presumably an original component of the cement mix which had not reacted with pozzolanic components. A possible reaction can be formulated:

The aqueous magnesium ion can occur in great abundance, up to 50,000 mg/l in natural subsurface seeps (Lambert, 1978) in the potash zone. This reaction bears a ΔG° value of -8.24 kcal/mole, and a ΔV value of -8.42 cc/mole. The thermodynamic calculations indicate that (a) the reaction can take place and (b) the reaction results in a decrease in molar volume (i.e., shrinkage) leading to an increase in permeability should this reaction occur in the future. This reaction is but a single example of the many that should be evaluated for (a) their possibility of occurrence and (b) the consequence of their occurrence. An important consequence of analyzing cores containing grout and rock is to determine the degree of interaction between the two, which would not take place in either grout or rock alone.

CORE-HANDLING PROCEDURES

Coring Intervals

Christensen (1979) has proposed that core of grout and rock (including interface) be taken from sections of the Dewey Lake, Rustler and Salado Formations. The hole to be cored is P-13 (Section 18, T22S, R31E). Jones (1978) has described in detail the stratigraphy of this hole, and presents the mineralogy of the potash zone in detail.

The ideal set of overcores to be taken consists of the following depth intervals in P-13:

1. Dewey Lake Red Beds, 130 to 200 feet below surface. This includes a lost-circulation zone. The ability of grout-squeezing to seal such zones as this is of considerable interest. The morphology of the grout-rock interface in this zone will provide an indication of the nature of the zone and the ability of the grout to seal it. In addition, the interval will provide some normal bedded siltstone in contact with grout.
2. Rustler Formation, 465 to 795 feet below surface. This includes the Magenta and Culebra dolomite (water-bearing) members, the suspected "brine aquifer" zone at the Rustler-Salado contact, and the uppermost Salado Formation. The interval includes residual rock products of partial dissolution by natural processes. The importance of grout behavior in the vicinity of water-bearing rock has been discussed above.
3. Salado Formation, 1210 to 1550 feet below surface. This includes the entire McNutt potash zone, with the minerals halite, sylvite, polyhalite, langbeinite, kainite, leonite, kieserite and bloedite, as well as clay partings. The potential for interaction between grout and complex soluble mineral assemblages has been discussed above.

The total cored footage under this proposal is 745 feet, slightly less than half of total hole depth.

As an alternative, the minimum required core from P-13 is as follows:

1. Dewey Lake Red Beds, 130 to 170 feet.

This is the lost circulation (and locally fluid-producing) zone.

2. Rustler Formation 477 to 527 feet (Magenta member)
591 to 640 feet (Culebra member)
711 to 731 feet (Rustler-Salado contact)

These intervals would sample the water-bearing units, with little sampling of dissolution residue.

3. Salado Formation 1312 to 1325 feet (10th ore zone)
1471 to 1485 feet (4th ore zone)
1491 to 1501 feet (3rd ore zone)
1282 to 1292 feet (marker bed 118)

These will afford a variety of mineral assemblages in contact with cement plug, for a total of 166 feet.

Taking Core

As pointed out by Christensen (1979) attempts must be made to obtain a minimum of two inches and preferably four inches outside the plug radius (which is four inches). This requires a minimum core diameter of 12 inches, and a desirable diameter of 18 inches. The equipment (i.e., core barrel) and techniques remain to be developed. As complete a core recovery as possible will be expected (100%), but the experimental nature of the taking of such large diameter cores dictates that difficulties are to be expected. In this case, core obtained should be documented according to actual percentage of recovery, and origin depths of recovered core should be approximately determined through combinations of other techniques, including geophysical logs and comparison with stratigraphically equivalent cores from other holes.

Lubricant used in the coring shall not be such as to appreciably dissolve the evaporites.

Curating Core

The actual coring, removal from barrel, logging, cleaning, photography, preservation, handling and storage, and record keeping shall be in accordance with established procedures. No coating shall be applied to the core. The core will ultimately be quartered lengthwise, using lubricant (preferably oil) so as not to dissolve evaporites and repackaged for distribution. One quarter will be permanently retained as a sample of record, and thus only three investigators may have the same interval for destructive analyses.

Distribution of core for analyses will be made to the principal investigator and to two other investigators, who may apply to the principal investigator for justifiable destructive use. In this sense, all analyses are considered destructive, since virtually all handling perturbs the mineralogy and/or texture of original rock and/or grout.

ANALYTICAL PROCEDURES

Cutting

All cutting and sawing of the core shall be done using a light oil, preferably cooking oil. This will provide lubrication and cooling, will afford some measure of protection of grout and rock from interaction with the surrounding air, and will deter hydration and dehydration reactions at ambient humidity. Cut fragments will be sealed in air-tight containers when not otherwise in use.

Sectioning

Standard petrographic thin and polished sections of grout, rock and interface will be prepared to facilitate optical microscopy, electron microscopy and electron probe microanalysis. The documented preparation and quality assurance procedure for petrographic sections (used by the principal investigator) will be used.

Petrography

Optical microscopic examination will be undertaken in order to characterize the core samples at a relatively low magnification (less than 1000X), as a prelude for other petrologic analyses. Attention will be given to mineralogy,

texture, inhomogeneities, microstructure (e.g., fractures) and evidence of reaction (rims, haloes, aureoles, etc.). The analysis and quality assurance procedure documented for optical petrography (used by the principal investigator) will be used.

X-ray Diffraction

As an aid to the identification of phases in grout and rock, x-ray powder diffraction will be performed on selected samples. The analysis and quality assurance procedure (documented and used by the principal investigator in this activity) will be applied.

Electron Microscopy and Probe Analysis

One of the principal means of characterizing mineralogy and textures of grout and grout/rock interface will be scanning electron microscopy (SEM) and electron probe microanalysis (EPM). An energy-dispersive x-ray spectrometer may be employed as an attachment to an SEM for qualitative chemical analyses to determine the presence of elements of $Z \geq 11$, but unambiguous identification of phases must rely upon the quantitative determination afforded by the EPM. As with optical microscopy, attention will be given to mineralogy (including composition of solid solutions), texture (including sequence of growth of phases), inhomogeneities (including unusually large grains), microstructure (including history of development of fractures before, during and after curing of grout), and evidence of reaction rims, haloes and aureoles (including paragenetic relations among the late-stage reaction products).

The analysis and quality assurance procedure documented for this activity will be followed by the principal investigator for this activity.

Thermal Analysis

Three kinds of thermal analysis will be considered here: thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), and differential thermal analysis (DTA).

Thermogravimetric Analysis. The volatile content (particularly water and carbon dioxide) of the grout, and the record of fractional devolatilization as a function of temperature, would be used to determine the role of volatiles in the hydration and carbonation of grout phases. TGA would also be used to

establish a data base for pure grout phases, so as to supplement identification of volatile-bearing grout phases and aid in modal analyses. The effluent gas would be quantitatively analyzed by gas chromatography/mass spectrometry.

Differential Thermal Analysis. DTA would be used to identify thermodynamic transitions as a function of temperature, which do not necessarily entail devolatilization. As for TGA, a DTA data base would be used to supplement the identification of phases by other techniques. The temperatures of transition would also aid in the collection and use of thermodynamic data.

Differential Scanning Calorimetry. DSC would be performed on single phases in order to determine their heat capacities between temperatures of about -190°C and 40°C . The data would allow the calculation of entropies and enthalpies of the phases, as a function of temperature, for use in thermodynamic calculations. Both rock and grout phases would be so treated.

The analysis and quality assurance procedure for this activity will guide the principal investigator in thermal analysis.

Chemical Analysis

Bulk chemical analysis would be used to determine the bulk compositions of rock and grout phase assemblages. The resulting compositions would be used in the application of the phase rule (see below).

The analysis and quality assurance procedures for chemical analysis (including instrumental methods) will be used in this activity.

DATA INTERPRETATION

Phase Assemblage Identification

The grout and rock phases identified in samples from this core will be compared with phases found in samples of rock alone and samples of laboratory-cured grout. From this it can be determined if the curing of grout in the presence of subsurface rock results in the formation of phases not observed in grout or rock alone. The presence of any "new" phases will require additional laboratory evaluation of the grout mix, as indicated by the thermodynamic modeling. The "new" phases will have indicated that an interaction has taken place in the system rock-grout-groundwater, and require an evaluation of other such interactions, both observed and hypothetical.

Sequence of Phase Development

A history of sequence of crystallization of phases in the system will be used to document the reactions that have taken place during the in situ curing of the grout. The presence of reaction rims, haloes and aureoles will indicate that events will have taken place late in the formation of the curing. The sequencing (paragenesis) of reactions will lead to the identification of intermediate products, some of which may be preserved if the reactions have not gone to completion. These intermediate and late-stage products will be evaluated in other hypothetical reactions in a thermodynamic modeling activity.

The Role of Volatiles

Phases whose chemical composition includes bound volatiles have come in contact with mobile components at some time during their crystallization history. Mobile components are an important part of any geological environment containing man-made openings to be sealed. In grout samples, a significant negative deviation of volatile content from expected values will indicate a premature withdrawal of water from the curing grout. A significant positive deviation will indicate that water has been added to the curing grout, probably from a geological source. In both cases, the anticipated state of hydration of grout phases will have been perturbed, and the possible resultant reactions in the system would have to be formulated and evaluated by means of thermodynamic modeling.

Variations in Bulk Composition

Goldschmidt's mineralogical phase rule shows the relationship between number of phases and number of components at various physicochemical conditions for a given bulk composition. The knowledge of bulk composition is essential to a prediction of phases which may develop over long (greater than human life) periods of time. Bulk compositions for grout and rock systems are required data for thermodynamic modeling.

Thermodynamic Modeling

In its most general statement, Goldschmidt's mineralogical phase rule states that

$$f = c + n - \phi$$

for a given bulk composition, where

ϕ = number of phases in system

c = number of components in systems

n = number of intensive variables which

may assume arbitrary values

f = number of degrees of freedom.

If the number of phases is greater than that allowed by the phase rule, disequilibrium is indicated. Disequilibrium allows for the possibility of components in a system of grout, rock and groundwater recombining to seek a phase assemblage with a lower value of Gibbs' free energy. As discussed above, the reactions governing the recombination are commonly far too sluggish to observe directly in a few years' time, but a few such reactions may have taken place and been recorded in this core. A time-dependent prediction of extent of hypothetical reactions is not possible. That would require the determinations of rate laws, constants and mechanisms by direct observation of even the most sluggish reactions.

The alternative approach (discussed in detail by Lambert, 1980) is similar to that of safety-assessment modeling of hypothetical migration of radionuclides out of a waste repository, a process that is also indicated to be too slow to observe directly and fully in a human lifetime. Specifically:

1. Phases in the system are identified.
2. All possible reactions among components of rock, grout and groundwater are formulated.
3. Thermodynamic data are acquired for all hypothetical reactants and products.
4. Reactions determined by thermodynamics to be possible are assumed to take place.
5. The consequences of the reactions and their products are evaluated for their potential severity in compromising the integrity of a borehole or shaft seal.

Comparison of observed phases in the grout-and-rock system with thermodynamically predicted phases will be made, but a failure to find predicted phases cannot be taken as prediction of their failure to form for all time. In any case, the ultimate objective of this analysis is to try to model the formation of phases in grout cured in situ.

REQUIRED RESOURCES

Equipment and Facilities

A perusal of the "Analytical Procedures" section will reveal a need for the following:

Facilities for storing, packaging and quartering the core by nonaqueous sawing.

Facilities for cutting, grinding and polishing in oil and cold-cementing petrographic sections of evaporite and grout.

A research-quality petrographic microscope, and accessories for photomicrography.

X-ray powder diffraction apparatus, sample preparation facilities and data file.

Combination scanning electron microprobe and microscope, with data system for quantitative and qualitative (energy dispersive x-ray) analysis, together with sample preparation facilities.

Differential scanning calorimeter, thermogravimetric balance, and differential thermal analyzer with data system, and gas chromatograph/mass spectrometer.

An aqueous geochemistry laboratory, equipped for atomic absorption and UV/visible spectrophotometry.

A large digital computer.

Personnel

The equivalent of the following human resources (with the appropriate training) are estimated to be required to make reasonable progress on the proposed program. Lesser commitment of resources will result in slower analysis of samples.

One person half-time in the laboratory.

One computer programmer, quarter-time.

One person half-time on the SEM/EMP.

One person half-time on thermal analysis/GC/MS.

One person quarter-time on x-ray diffraction.

One person half-time in optical petrography.

One person half-time making thin sections.

One person, occasionally, to assist with sawing, packaging and curating core.

One person, half to full time to guide the development of the thermodynamic model and the laboratory experiments and analyses.

Scheduling

No schedule or "milestones" at this time can be established, without a definite commitment of availability of equipment, facilities, personnel, and expense budget. When the resources are specifically available, network analysis (PERT) will be used to determine times required to perform various tasks. With a full complement of the above resources, the various treatments of approximately 50 samples together with development of the thermodynamic model would consume 2 years for P13 alone. During this time, some tasks would be accomplished sooner and some later, due to their interdependencies. A more detailed projection of progress is not possible at this time.

Quality Classification Level

At the time of this writing, this study would be classified as a minor (Level III) QA item (see WMP II-3 in the Sandia WIPP Quality Assurance Program Plan). This classification stems from the parent program, which is also a

minor task (Christensen, 1979). These determinations are made according to the criteria that (1) a failure of this activity would result in failure to achieve minor research and development goals within cost and schedule restraints, and (2) erroneous research data or conclusions would lead to conditions having minor programmatic impact. Since this may be a relatively long-term type of activity, the quality level may be revised to reflect changes in programmatic policies toward these analyses. Also, since obtaining some of these samples might not be repeatable, quality assurance controls should be applied to this activity so as to be consistent with a classification level of major. Consequently, special guidance has been given above for the selection of coring intervals, taking, curating and cutting core. Similarly, special guidance will be given in those analytical procedures which entail the disaggregation or destruction of samples.

REFERENCES

- Buck, Alan D., and Jerry P. Burkes, 1979, Examination of grout and rock from Duval Mine, New Mexico: Miscellaneous paper SL-79-16, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.
- Christensen, Charles L., 1979, Test plan - potash core test, WIPP experimental program, borehole plugging: SAND79-1306 (ONWI/SUB/79, E511 03700-PCTTP-1), Sandia National Laboratories, Albuquerque, New Mexico.
- Gulick, Charles W., 1978, Borehole plugging - materials development program: SAND78-0715, Sandia National Laboratories, Albuquerque, New Mexico.
- Jones, C. L., 1978, Test drilling for potash resources: Waste Isolation Pilot Plant site, Eddy County, New Mexico: U. S. Geological Survey Open-file Report 78-592 (2 volumes).
- Lambert, Steven J., 1978, Geochemistry of Delaware Basin groundwaters, in Geology and mineral deposits of Ochoan rocks in Delaware Basin and adjacent areas: New Mexico Bureau of Mines and Mineral Resources, Circ. 159, p 32-38.
- Lambert, Steven J., 1980, A strategy for evaluating the long-term stability of hole-plugging materials in their geological environments: SAND80-0359, (in preparation), Sandia National Laboratories, Albuquerque, New Mexico.

DISTRIBUTION

U.S. Department of Energy, Headquarters
Office of Nuclear Waste Management
Washington, DC 20545

Eugene F. Beckett, Project Coordinator (WIPP) (1)
Colin A. Heath, Director, Division of Waste Isolation (2)
Sheldon Meyers
Raymond G. Romatowski
R. Stein
Carl L. Cooley
R. B. Chitwood

U.S. Department of Energy, Albuquerque Operations
P.O. Box 5400
Albuquerque, NM 87185

D. T. Schueler, Manager, WIPP Project Office (2)
R. Rudolph, Acting Deputy Manager, WIPP Project Office
G. Dennis, Director, Public Affairs Division
S. C. Taylor, C&TI Division (for Public Reading Rooms)
J. F. Bresson
G. W. Johnson, Waste Management Branch

U.S. Department of Energy
Carlsbad WIPP Project Office
Room 113, Federal Building
Carlsbad, NM 88220

U.S. Department of Energy
c/o Battelle
Office of Nuclear Waste Isolation
505 King Avenue
Columbus, OH 43201
Jeff O. Neff (2)

Battelle Memorial Institute
Office of Nuclear Waste Isolation
505 King Avenue
Columbus, OH 43201
Neil Carter, General Manager (3)
F. Burns (7)
S. Basham (2)
R. Heineman
Wayne Carbiener
P. Hoffman
A. A. Bauer

Westinghouse Electric Corporation
P.O. Box 40039
Albuquerque, NM 87196
R. C. Mairson
D. Hulbert
V. F. Likar
H. H. Irby

Hobbs Public Library
509 N. Ship Street
Hobbs, NM 88248
Ms. Marcia Lewis, Librarian

Lokesh Chaturvedi
Department of Civil Engineering
Box 3E
New Mexico State University
Las Cruces, NM 88003

Bechtel Inc.
P. O. Box 3965
San Francisco, CA 94119
R. A. Langley (2)

National Academy of Sciences, WIPP Panel

Frank L. Parker, Chairman
Department of Environmental and
Water Resources Engineering
Vanderbilt University
Nashville, TN 37235

Konrad B. Krauskopf, Vice Chairman
Department of Geology
Stanford University
Stanford, CA 94305

Neville G. W. Cook, Member
Dept. of Material Sciences and Engineering
University of California at Berkeley
Heard Mining Building, #320
Berkeley, CA 94720

Merril Eisenbud, Member
Inst. of Environmental Medicine
New York University Medical Center
Box 817
Tuxedo, NY 10987

Fred M. Ernsberger, Member
Glass Research Center
PPG Industries, Inc.
Box 11472
Pittsburgh, PA 15238

Roger Kasperson, Member
Center for Technology, Environment and Development
Clark University
Worcester, MA 01610

Richard R. Parizek, Member
Department of Hydrogeology
Pennsylvania State University
University Park, PA 16802

Thomas H. Pigford, Member
Department of Nuclear Engineering
University of California
Berkeley, CA 94720

Roger W. Staehle, Member
Dean, Institute of Technology
University of Minnesota
Lind Hall
Minneapolis, MN 55455

John W. Winchester, Member
Department of Oceanography
Florida State University
Tallahassee, FL 32306

D'Arcy A. Shock, Consultant
233 Virginia
Ponca City, OK 74601

John T. Holloway, Executive Secretary
2101 Constitution Avenue, NW
Washington, DC 20418

WIPP Public Reading Room
Atomic Museum, Kirtland East AFB
Albuquerque, NM 87185
Ms. Gwynn Schreiner

WIPP Public Reading Room
Carlsbad Municipal Library
101 S. Hallagueno St.
Carlsbad, NM 88220
Lee Hubbard, Head Librarian

Thomas Brannigan Library
106 W. Hadley St.
Las Cruces, NM 88001
Don Dresp, Head Librarian

Roswell Public Library
301 N. Pennsylvania Avenue
Roswell, NM 88201
Ms. Nancy Langston

Dr. Bruno Giletti, Co-Chairman
Department of Geological Sciences
Brown University
Providence, Rhode Island 02912

Dr. Raymond Siever, Co-Chairman
Department of Geological Sciences
Harvard University
Cambridge, Massachusetts 02138

Dr. John Handin, Director
Center of Tectonophysics
Texas A & M University
College Station, Texas 77840

Dr. John Lyons
Department of Earth Sciences
Dartmouth College
Hanover, New Hampshire 03755

Dr. George Pinder
Department of Civil Engineering
Princeton University
Princeton, New Jersey 08540

New Mexico Advisory Committee on WIPP
NMIMT Graduate Office
Socorro, NM 87801

Marvin H. Wilkening, Chairman (2)

State of New Mexico
Environmental Evaluation Group
320 Marcy Street
P.O. Box 968
Santa Fe, NM 87503

Robert H. Neill, Director (2)

NM Department of Energy & Minerals
P. O. Box 2770
Santa Fe, NM 87501

Larry Kehoe, Secretary
Kasey LaPlante, Librarian

J. E. Magruder
Sandia Carlsbad Representative
401 North Canal Street
Carlsbad, NM 88220

D'Appolonia Consulting Engineers, Inc.
2350 Alamo, SE
Suite 103
Albuquerque, NM 87106

R. H. Goodwin
D. Stephanson

Fenix & Scisson, Inc.
401 N. Canal
Carlsbad, NM 88220

J. G. McCray
Department of Nuclear Engineering
University of Arizona
Tucson, AZ

The Pennsylvania State University
Materials Research Laboratory
University Park, PA 16802
Dr. Della Roy

Mr. Michael J. Smith
Rockwell International
Atomics International Division
Rockwell Hanford Operations
P. O. Box 800
Richland, WA 99352

Systems, Science, and Software
Box 1620
La Jolla, CA 92038
E. Peterson
P. Lagus

U.S. Army Engineers
Waterways Experiment Station
P. O. Box 631
Vicksburg, MS 39180
J. Boa
K. Mather

U.S. Geological Survey
Special Projects
MS954, Box 25046
Denver Federal Center
Denver, CO 80255
C. Jones
W. S. Twenhofel

U.S. Geological Survey
Water Resources Division
P. O. Box 26659
Albuquerque, NM 87125
J. W. Mercer

Sandia Internal:

1100 C. D. Broyles
1110 J. D. Plimpton
1120 T. L. Pace
1125 G. L. Ogle
1125 J. T. McIlmoyle
1130 H. E. Viney
1133 R. D. Statler
1133 C. W. Gulick
1135 P. D. Seward
3141 T. L. Werner (5)
3151 W. L. Garner, For: DOE/TIC (Unlimited Release) (3)
3154-3 R. P. Campbell, For: DOE/TIC (25)
3310 W. D. Burnett
4004 M. J. Beckett
4500 E. H. Beckner
4510 W. D. Weart
4511 W. D. Weart (Acting)
4511 G. E. Barr
4511 L. J. Barrows
4511 D. D. González
4511 S. J. Lambert (10)
4511 D. W. Powers
4511 K. L. Robinson
4511 S. E. Shaffer
4512 T. O. Hunter
4512 C. L. Christensen (10)
4512 D. R. Fortney
4512 M. A. Molecke
4514 M. L. Merritt
4530 R. W. Lynch
4540 M. L. Kramm
4541 L. W. Scully
4542 J. W. McKiernan
4542 J. T. Henderson
4542 Sandia WIPP Central Files (2)