PEER 21 - Fracture Expert Group Summary Report

1993 WIPP Performance Assessment
Fracture Expert Group Meeting
Albuquerque, New Mexico
March 23-25, 1993

I. INTRODUCTION

The initial meeting of the WIPP Fracturing Expert Group (FxG) was held March 23-25, 1993, at the La Posada Hotel in Albuquerque, New Mexico. The meeting was a joint meeting of the WIPP Geostatistics, Conceptual Modeling Uncertainty, and the Fracturing Expert groups[1]. The FxG met in plenary sessions with the other groups and separately. The agenda for the plenary sessions and the separate FxG sessions are included in Apendices A, B, and C respectively. The joint meetings of these groups stimulated information flow among the groups and provided an efficient way to orient members of emerging groups - the FxG and the Conceptual Model Uncertainty Group (CMUG) - to the project. The FxG Agenda was designed to compliment the plenary agenda. The Orientation and State of Current Technology sessions provided information that led up to the group's critique of the "first cut" fracture model that is to be used in the Land Withdrawal Act 93 Performance Assessment (LWA 93 PA). The Defensible Fracture Modeling, Testing, Simulation Program session elicited input from the FxG for establishing a program that will produce a defensible fracture simulation for compliance demonstration.

II. SUMMARY

The FxG sessions are summarized in this section. The FxG sessions were divided into three parts: (a) Orientation; (b) *Current Technology State; and (c) FxG Recommendations.* Presentation titles are included in parenthesis for cross-reference with presentation slides in Appendix E.

A. Orientation Session

Sam Key gave a brief introduction and welcome to the FxG members.

Mel Marrietta described anhydrite layer fracturing concerns at WIPP (*Regulatory Framework* by Mel Marietta). He discussed the no-migration variance petition that covers the storage and disposal of hazardous wastes that is included in the land ban restrictions in federal regulation 40 CFR 268.6[2]. Mel explained that gas generated in the repository has the potential for migrating through fractures in anhydrite layers and violating the no-migration variance.

Peter Swift gave an overview of the WIPP project that discussed the history, mission, repository design, and waste forms that are to be stored (*Introduction to the WIPP* by Peter Swift). The federal regulations that apply to the WIPP repository were also discussed and a generalized description of the geology and hydrology of the WIPP site was presented.

Dave Borns presented a more detailed description of the site geology and a detailed description of the geology of the anhydrite layers (*WIPP Geology/Hydrology* by David J. Borns). In

[1] Appendix D contains the membership of the FxG.

[2] This regulation is commonly referred to as the RCRA–Resource Conservation and Recovery Act-- regulation in the WIPP project.

addition, Dave provided core and other material samples taken from the WIPP site for examination and discussion.

Sam Key discussed the rational for membership in the FxG. Sam noted that gas migration in the WIPP anhydrite layers is a coupled process involving the mechanics of the media and multiphase flow in fractured and porous media and as such requires an interdisciplinary team.

Sam Key stated the group charter as twofold (*FxG - Charter*):

1. Review the proposed PA93 BRAGFLO models for permeability and porosity as a function of pressure for their adequacy as first order representations of the changes in the anhydrite beds adjacent to the waste disposal horizons due to pressurization of the formation.
2. Recommend for PA94 improvements in the characterization of changes in permeability and porosity in the anhydrite beds adjacent to the waste disposal horizons due to pressurization of the formation.

He discussed activities that may be required before the FxG can make improvements for PA94. Sam also described the WIPP Performance Assessment cycles and the schedule for FxG work (FxG - *PA "Rounds"*).

B. State of Current Technology Session

The following collection of light presentations focused on the current state of understanding of the anhydrite marker beds above and below the WIPP repository horizon. The material provided the context for the work of the FxG.

Peter Davies provided an overview of the technical work that has led up to the current state of the technology for understanding and quantifying the potential for fracturing in the anhydrite layers at the WIPP site and the impact on gas migration (*Evolution of Technical Work on Interbed Fracture Dilation/Growth Due to Pressurization by Waste-Generated Gas* by Peter B. Davies). Peter described the coupling between processes that may occur in the WIPP repository due to waste generated gas. The early geomechanical analysis of fracture initiation adjacent to a pressurized waste disposal region and the early multiphase flow analyses of gas migration through the anhydrite layers were discussed.

Wolfgang Wawersik and Richard Beauheim discussed hydraulic fracturing and hydrologic tests at the WIPP site in two anhydrite layers (MB 139 and MB 140). Wolfgang discussed the technical motivation for these tests and described the tests (*Hydraulic Fracturing and Hydrologic Tests in Marker Beds 139 and 140* by W. R. Wawersik and R. L. Beauheim). He also discussed pre-test analyses and summarized the results obtained to date. Richard Beauheim discussed the hydrogeologic characterization of anhydrite interbeds at the WIPP site (*Hydrologeologic Characterization of Anhydrite Interbeds at the WIPP Site* by Richard L. Beauheim and Randall M. Roberts). He described the anhydrite interbeds tested to date, the types of tests conducted, and observations about hydraulic parameters based on these tests. Richard Beauheim also discussed the evaluation of the effects of hydraulic fracturing on permeability of anhydrite interbeds based on constant-pressure injection and constant-pressure withdrawal tests performed in boreholes before and after hydraulic fracturing (*Evaluation of Effects of Hydraulic Fracturing on Permeability of Anhydrite Interbeds*).

Barry Butcher discussed the mechanisms that are expected to be active during fracturing of the anhydrite layers in response to elevated gas pressure (*Interbed Fracture Mechanisms* by B. M. Butcher). Barry Butcher described two theoretical geomechanical analyses that may be used to bound fracture openings in the anhydrite layers.

Darrell Munson discussed constitutive models of the behavior of the halite surrounding the waste rooms following excavation (*Constitutive Models and Observations* by Darrell E. Munson). These constitutive models are based on observations and measurements from tests at the WIPP site. These models predict room closure due to creep of the halite. Although these models are not directed at fracturing in the anhydrite layers, the closure of the excavated rooms is coupled to fracturing in the anhydrite layers through the gas pressure.

Susan Howarth discussed the laboratory program for measuring two-phase flow properties of the Salado formation at the WIPP site (*Salado Two-Phase Flow Laboratory Program* by Susan Howarth). The program is to provide data that will support the development of mechanistic models and performance assessment models of multi-phase flow in and around the WIPP repository. FY93 were discussed in detail and an overview of FY94 activities was given. Studies that are planned to support investigations of outstanding issues were also discussed.

Peter Davies discussed the results of multi-phase flow studies using models with fracture-like features in the anhydrite layers (*Preliminary "Fracturing" Model Results* by Stephen W. Webb and Peter B. Davies). Peter Davis concluded, based on the results of these studies, that the peak gas pressure and gas migration may be significantly altered by fracturing and that additional work is needed to develop a comprehensive fracture model.

Palmer Vaughn discussed probabilistic two-phase flow modeling in the WIPP performance assessment (*Probabilistic Two-Phase Flow Modeling in the WIPP Performance Assessment* by Palmer Vaughn). Palmer Vaughn described the probabilistic approach and the two-phase flow modeling objectives. He described the computer code BRAGFLO and explained its role in performance assessment. Palmer Vaughn also described the WIPP performance assessment model geometry and discussed the values of fluid pressures in the repository calculated in the 1992 performance assessment simulations. He also introduced the proposed anhydrite layer fracture model for the PA93 calculations.

Mike Lord discussed the PA93 Fracture Model and results of calculations to date using the model (*Proposed Anhydrite Fracture Treatment BRAGFLO Simulation* by Michael Lord). Mike Lord compared results with and without anhydrite fracturing. Mike Lord concluded his presentation with a video showing the dynamics of the repository system including anhydrite fracturing over the 10,000 year regulatory time period.

C. PA93 Fracture Model Critique and Defensible Fracture Modeling, Testing, and Simulation Program for PA94

These sessions were facilitated (Sam Key) discussions among the FxG members and attendees. These sessions produced the recommendations discussed in the next section.

III. RECOMMENDATIONS AND DISCUSSION

The WIPP Performance Assessment Fracture Expert Group (FxG) was asked to respond to the following two directives[3]:

1. Review and comment on the adequacy of the proposed first-order model in BRAGFLO for representing changes in permeability and porosity due to pressure-induced changes in

[3]These directives are a restatement of the FxG charter.

the anhydrite beds above and below the WIPP repository horizon (Marker Beds 138 and 139) that is scheduled for use in the 93 LWA PA simulations.[4]

2. Identify additional factors to be considered or studies needed to support an extended and improved, second-order model in BRAGFLO for pressure-induced hydrological changes in the anhydrite beds above and below the WIPP repository horizon that will be used in the 95 LWA PA simulations.

The FxG provided comments in response to both of these directives.

A. FxG 93 LWA PA Recommendations

The following recommendations were put forward by the FxG regarding the proposed first-order model in BRAGFLO for representing changes in permeability and porosity due to pressure-induced changes in the anhydrite beds above and below the WIPP repository horizon (Marker Beds 138 and 139):

1. "The proposed first-order model in BRAGFLO for representing changes in permeability and porosity due to pressure-induced changes in the anhydrite is an acceptable first approximation."

By way of elaboration on the suitability of the first-order model the FxG noted that:

A. The pore compressibility is taken as a piecewise linear function of pore pressure, a reasonable first approximation;

B. The variability of the anhydrite porosity in the simulation is derived from the compressibility as it should be; and

C. The changes in permeability are related in a reasonable way to the changes in porosity, that is, permeability changes are derived from changes in fracture aperture, the expected dominant form of porosity alteration occurring in the anhydrite.

2. Further, the FxG recommended the following adjunct steps and activities be undertaken to assure the BRAGFLO modeling of the two-phase flow occurring in the altered anhydrite marker beds is an adequate and reasonable representation of the behavior that typically takes place in fracture flow:

   A. Examine the literature on relative permeability for flow in jointed rock masses and in individual rock joints to identify the best accepted functions, considering the possibility that phase interference may be a factor under some conditions.

   B. Incorporate non-zero residual saturations in the simulation as a variable factor, that is, introduce residual saturation as a variable to be sampled in the Monte Carlo simulation suites.

   C. Examine the numerical convergence of the BRAGFLO simulation results by conducting a series of calculations with decreasing grid size and time step size to determine if the grid size and time step size routinely used for the performance assessment simulations is sufficiently fine to produce acceptably accurate simulation solutions.

   D. Conduct 3-D hydrological simulations with independent software to verify the sub-3-D simulations used in BRAGFLO.

[4]During the workshop, 93 LWA PA was known as PA93 and 95 LWA PA was known as PA94. The terminology henceforth in this text is changed to be in conformance with *au courant* terminology. (4/93)

E. Examine repository design alternatives to provide additional volume within the repository for gas storage as a means of limiting the pressure generated by gas emitted during iron-brine corrosion reactions and organic waste decay.

B. FxG 95 LWA PA Recommendations

The FxG made recommendations for 95 LWA PA work to support an extended and improved, second-order model in BRAGFLO for modeling the two-phase flow occurring-in the altered anhydrite marker beds (Marker Beds 138 and 139). The recommendations address the following four separate areas of investigation:

1. In Situ and Field Measurements and Experiments,
2. Laboratory Measurements of Hydrological and Mechanical Properties,
3. Character and Final Spatial Extent of Fracturing, and
4. Coupled Mechanical and Hydrological Simulations.

In each of these, a number of specific requests and/or issues were identified by the FxG for which new or additional work is essential to a credible extension of the BRAGFLO treatment for modeling the two-phase flow in altered anhydrite marker beds.

1. In Situ and Field Measurements and Experiments

In light of the concerns for gas migration, examining existing tests and data on anhydrite and conducting in situ tests and field experiments that focus on determining hydrological properties before, during and after fracturing of the anhydrite beds were considered the most significant activities.

The specific recommendations were:

- Conduct fluid- and gas-driven slow fracturing tests in undisturbed anhydrite in which the entire history of fracture flow and joint aperture are recorded. There are three important points to this recommendation.
    1. The testing should be conducted slower than the natural time scales connected with the damage processes that alter or fracture the anhydrite beds. The information obtained from a "slow" test will more nearly relate to the damage occurring on the time scale over which gas generation and formation pressurization take place.
    2. A fluid should be used first to induce fracturing in the experiments followed by reloading with gas because it is the waste generated gas during the first 1000 years that is to be contained. That is, from a performance assessment perspective, it is the two-phase flow characteristics of gas and brine flow at pressures exceeding the formation pressures that must be understood and modeled.
    3. The relationship between flow rates and fracture aperture must be evaluated to obtain a complete picture of the changes in matrix hydrological properties with pressurization and alteration.
- Determine the horizontal components of the in-situ stress in anhydrite Marker Beds 138 and 139, respectively.
- Examine available cores from MB 138 and MB 139 for structures and features that are or will be important to porosity and permeability before, during, and after damage/alteration.

- Design and field a hydrological repository analog experiment in conjunction with parallel BRAGFLO simulations in order to obtain some degree of software simulation validation.
- Study existing experimental data and bracket the parameters needed for the first-order model for representing changes in permeability and porosity due to pressure-induced changes in the anhydrite beds.
- Use field-scale averaging of locally measured hydrological parameters to develop the values appropriate for the far-field simulations conducted with BRAGFLO.

2. Laboratory Measurements of Hydrological & Mechanical Properties

There was a recognition that laboratory testing and characterization of the anhydrite marker beds significantly lags the characterization of halite. These recommendations address the need for more detailed mechanical property testing and hydrological characterization for the anhydrite beds.

- Bracket the variability in hydrological flow parameters and cross correlate the hydrological flow parameters to limit the diversity in the response predictions to physically attainable behavior.
- Measure anhydrite mechanical properties, particularly, those properties tied to quantifying the alteration and damage that occurs with high internal pore pressure.
- Conduct controlled laboratory experiments in anhydrite to measure multiphase flow characteristics, including gas permeability testing.
- Study flow characteristics in altered/damaged anhydrite to establish the appropriateness of using a Darcy flow representation.

3. Character and Final Spatial Extent of Fracturing

To date, the majority of the performance assessment studies on the pressure-induced alteration in the anhydrite marker beds have been based on two assumptions: (1) the areal extent of the alterations occurring in the anhydrite marker beds is a perfect circular disk (comes from using axisymmetric modeling), and (2) very elementary alteration rules in BRAGFLO are sufficient to define the pressure induced alterations. The adequacy of both of these idealizations needs to be examined. Both idealizations can be studied without resorting to extensive numerical simulations. The field of fracture mechanics frequently considers a number of these issues in examining the failure of manufactured materials, as well as, studying oil well hydrofracturing. The following independent studies will either support the validity of the existing assumptions or support a redefinition of an appropriate description of the pressure-induced alterations expected in the anhydrite:

- Examine various factors such as crack path stability and site heterogeneity factors (dip, anhydrite properties, anhydrite in-situ stress, et cetera) to determine if the final expected crack front should be circular or non-circular at its maximum extent.
- Examine various factors to determine if the crack profile should or is likely to exhibit large scale fingering and channeling around the perimeter at its maximum extent.
- Examine the in-situ stress conditions to see if the expected fracture surfaces within the anhydrite should be horizontal or vertical; in the event that vertical surfaces are preferred, identify the conditions under which the fractures might be expected to propagate into the surrounding halite.

- Examine the possibility that in spite of the complex processes and geometric interactions initially occurring within the repository, the final "equilibrium" state (diameter and thickness) of the fractured anhydrite domain can be predicted from first principles.

4. Coupled Mechanical and Hydrological Simulations

The FxG recognized that performance assessment out of necessity must use a repository containment simulation that for any single discipline might be considered a "reduced" model. However, the FxG felt that a considerable amount of work was needed to relate mechanical alteration and damage in both the halite and anhydrite to a continuum porosity and permeability used in the BRAGFLO hydrological simulation. That is, once mechanical alterations and damage in anhydrite can be predicted due to pressurization and once continuum porosity and permeability can be evaluated from mechanical damage descriptions, coupled mechanical and hydrological simulations need to be undertaken to assure the adequacy of the uncoupled BRAGFLO hydrological simulations.

- Develop expressions for continuum porosity and continuum permeability based on observed mechanical damage in anhydrite.
- Develop stress-strain models for anhydrite and halite that include damage and healing components related to material mechanisms and capable of predicting porosity and permeability for coupling to hydrological simulations.
- Conduct simulations of room closure followed by subsequent "inflation" that include porosity and permeability changes generated by mechanical damage/healing in the domain surrounding the waste disposal room.
- Relate continuum porosity and permeability to "crack extension" generated from mechanical damage in the anhydrite beds.
- Perform coupled mechanical-hydrological simulations to substantiate uncoupled PA hydrological simulations.

Appendix A. Plenary Agenda