Title 40 CFR Part 191
Compliance Certification
Application
for the
Waste Isolation Pilot Plant

MASS Attachment 13-1

WPO 30790

see also
WPO 30791

S-7: GAS EXSOLUTION
Summary Memo of Record

INFORMATION ONLY

TO: D. R. Anderson
PVaughn RMack
FROM: M. Lord, P. Vaughn, R. MacKinnon

SUBJECT: FEP Screening Issue S-7

STATEMENT OF SCREENING DECISION

FEP Screening Issue S-7 need not be included in future system-level performance assessment calculations.

STATEMENT OF SCREENING ISSUE

This screening effort evaluates the need for including effects of dissolved gas in future system-level performance assessment calculations. During early time when the waste cavity is filling with brine, dissolved gas in brine may contribute an additional drive mechanism. As brine is drained from the near-waste formations and pressure declines within these formations, gas will be released from the brine resulting in potentially higher pressures. This mechanism may enhance the flow of brine to the waste region. At later time, when gas generation in the waste cavity is the principal drive mechanism, gas will go into solution as the pressure increases. This behavior will result in lower fluid pressures and altered fluid flow.

The impact of gas exsolution on direct releases to the surface during a drilling intrusion into the repository is also considered. Direct releases to the surface may occur during drilling due to cuttings and spallings in the drilling fluid and brine circulation from the repository to the surface in the wellbore. These releases are controlled by the prevailing pressure, permeability, and saturation conditions in the disposal room at the time of intrusion. The effect of dynamic alterations of the DRZ/TZ on these conditions may be important and needs to be evaluated.

APPROACH

The baseline two-phase flow model in BRAGFLO does not account for dissolved gas in brine. To simulate the effects of dissolved gas on fluid flow, a model was implemented to permit gas exsolution and dissolution in brine according to Henry's Law.

A series of BRAGFLO simulations were performed to determine if dissolved gas has the potential to enhance contaminant migration to the accessible environment. Effects of all other FEP issues were disabled in the simulations. Two basic scenarios were considered in the screening analysis, undisturbed performance and disturbed performance. Both scenarios included a 1.0 degree formation dip downward to the south. Intrusion event E1 is considered in the disturbed scenario and consists of a borehole that penetrates the repository and pressurized brine in the underlying Castile Formation. One variation of intrusion event E1 is examined, E1 Down-Dip. In the E1 Down-Dip event the intruded panel region is located on the down-dip (south) end of the repository. Based on FEPs screening analyses of issues DR-2, DR-3, DR-6, DR-7, and S-6, it can be concluded that the E1 Down-Dip configuration yields consistently larger predicted releases to the accessible environment than the E1 Up-Dip configuration. These larger releases are due to higher brine saturations down-dip of the borehole. For this reason, E1 Up-Dip calculations were not performed for this FEP issue. To incorporate the effects of

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uncertainty in each case (E1 Up-Dip, E1 Down-Dip, and undisturbed), a Latin hypercube sample size of 20 was used resulting in a total of sixty simulations. To assess the sensitivity of system performance on puddling, conditional complementary cumulative distribution functions (CCDFs) of normalized contaminated brine releases to the Culebra via human intrusion and shaft system, as well as releases to the subsurface boundary of the accessible environment, were constructed and compared to the corresponding baseline model CCDFs. In the baseline model calculations, the effects of all FEP issues were disabled. These comparisons provide direct information about how the inclusion of dissolved gas may influence repository performance. In addition, performance measures are examined for direct releases during drilling due to both cuttings and spallings and brine circulation from the repository to the surface. Potential releases to the surface during drilling are strongly influenced by three drivers, brine pressures, brine saturations, and permeability in the waste disposal area. Spallings, cuttings, and brine releases tend to increase with an increase in each of these drivers. The exception to this trend is that at high brine saturations (or low gas saturations) brine releases tend to decrease because gas volumes become to small to maintain an appreciable gas drive (gas expansion).

RESULTS AND DISCUSSION

CCDFs for releases to the Culebra and subsurface boundary of the accessible environment for E1 Up-Dip, E1 Down-Dip, and undisturbed cases are provided in Figure 5 of Appendix 1. Each figure compares CCDFs of normalized releases predicted by the baseline model and normalized releases predicted with gas exsolution. Note that releases to the Culebra via the shaft and intrusion borehole are shown on the left side of the figure, whereas releases to the subsurface boundary of the accessible environment are presented on the right side of the figure. In both cases (E1 Down-Dip and undisturbed), the gas exsolution curves for releases to the Culebra via the shaft and borehole are very close and consistently below and to the left of the baseline curves for all but a very narrow range of insignificant releases. Similarly, CCDFs for releases to the subsurface boundary via the Marker Beds show that the gas exsolution curves are below and to the left of the baseline CCDFs for all but a very narrow range of insignificant releases. In summary, differences in releases between the baseline and gas exsolution results are minor with the baseline model predicting consistently higher releases.

Performance measures for direct release during drilling, which include maximum, mean, medium, and minimum values of volume averaged brine pressures, brine saturations, porosity, and permeability in the waste region for undisturbed conditions at 100, 1000, and 10000 years, are given in Table 4 of Appendix 1. Comparison of these values with the baseline values given in Table 2 indicate that brine pressures are consistently higher in the baseline case. All other metrics (drivers) are nearly equal between the baseline and gas exsolution cases. In summary, the baseline case is sufficiently conservative (over estimates potential release) with respect to releases due to brine, spalling, and cuttings.

BASIS FOR RECOMMENDED SCREENING DECISION

Based on the CCDFs, the inclusion of gas exsolution in BRAGFLO results in overall lower computed releases to the accessible environment than the baseline case. In addition, gas exsolution has an insignificant effect on waste room conditions relevant to releases due to drilling intrusion. As a result, the baseline model is conservative in its approach of neglecting dissolved gas effects and gas exsolution can be eliminated from consideration in system-level PA calculations.

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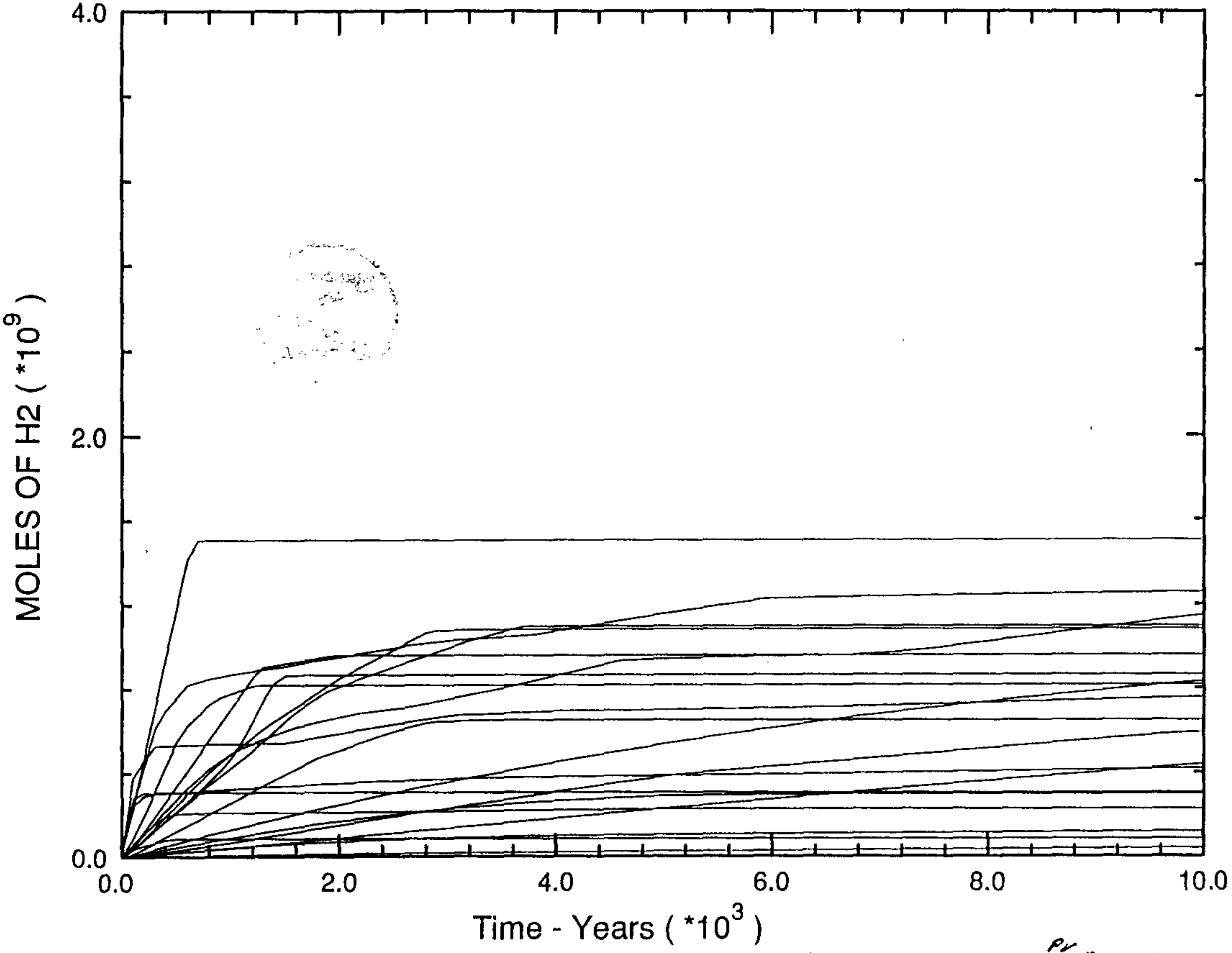
FIGURE 8. MOLES OF H2 GENERATED DUE TO CORROSION AND BIODEGRADATION



SWCF:1.1.6.3:PA:NG:TSK:GG1 and S7

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QA JC 12/20/95

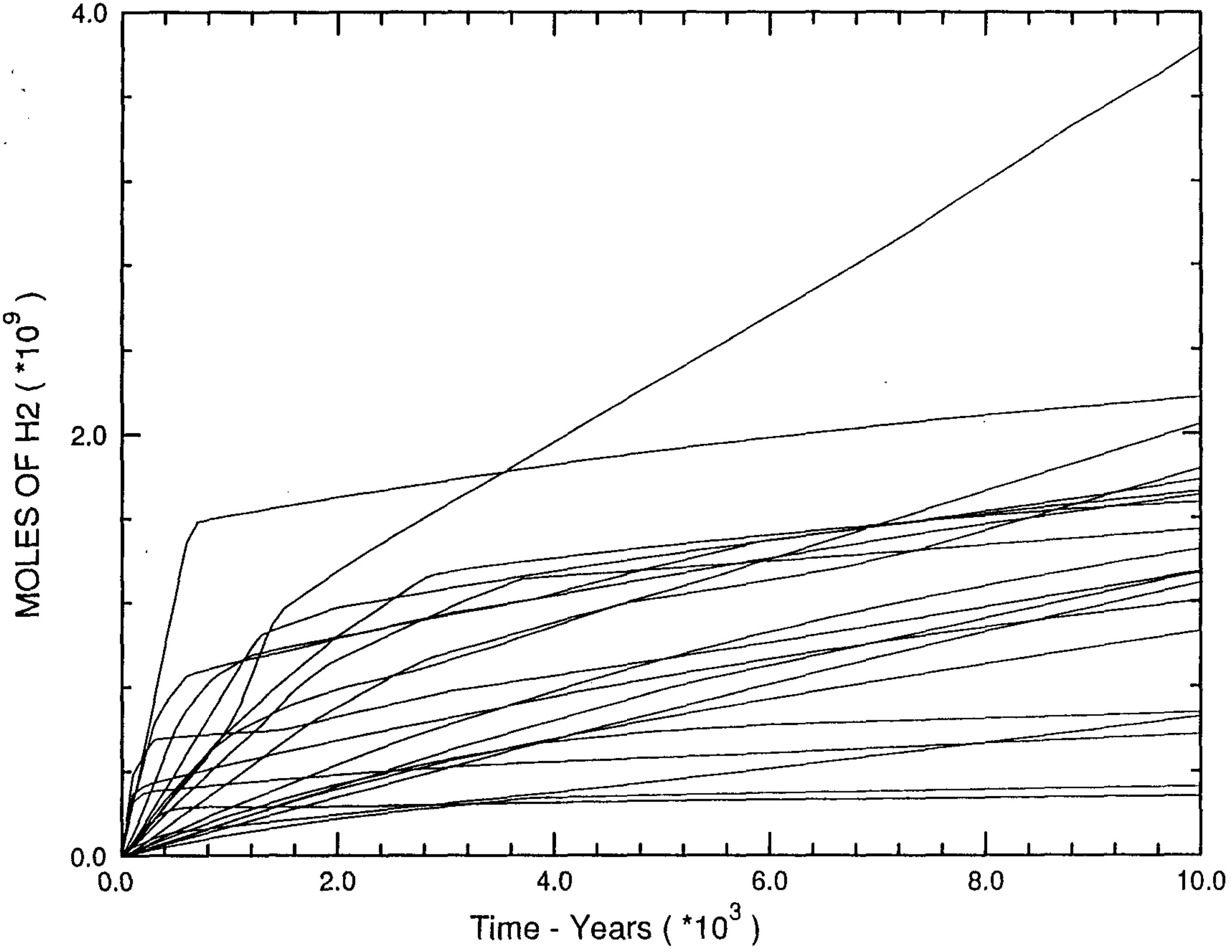
F1:[FEP.RAD.UNDIST]SPLAT_H2.INP;9

SPLAT X2.0 12/22/95 10:47:35

PV 12/22/95

QA

FIGURE 9. MOLES OF H2 DUE TO RADIOLYSIS, CORROSION, AND BIODEGRADATION



SWCF:1.1.b.3:PA:NG:TSK:GG1 and S7

RJM 12/22/95

QA JC 12/20/95

F1:[FEP.RAD.UNDIST]SPLAT_H2C.INP;6

PV 12/22/95

SPLAT 12/22/95 12:21:25

Table 5. SOLUBILITY LIMITS (mole/m^3)

Th229 (3.0250E-03) Th330 (3.0250E-03) Th232 (3.0250E-03) U233 (1.0003E+03)
U234 (1.0003E+03) U235 (1.0003E+03) U236 (1.0003E+03) U238 (1.0003E+03)
Np237 (1.0300E+01) Pu238 (7.0000E-01) Pu239 (7.0000E-01) Pu240 (7.0000E-01)
Pu241 (7.0000E-01) Pu242 (7.0000E-01) Am241 (1.0003E+03)

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Table 4. Performance Measures For Blowout, Spalling, and Cuttings (Gas Exsolution Model Results)

TIME = 0.100000E+03 years

	BRINE PRESSURE (Mpa)	BRINE SATURATION	POROSITY	PERMEABILITY (m^2)
MIN	0.623238E+06	0.161922E-01	0.128635E+00	0.558470E-11
MAX	0.773898E+07	0.329942E+00	0.300751E+00	0.558470E-11
MEAN	0.258056E+07	0.154919E+00	0.181337E+00	0.558470E-11
MED	0.193918E+07	0.173379E+00	0.162942E+00	0.558470E-11

TIME = 0.100000E+04 years

MIN	0.197624E+07	0.956873E-05	0.646636E-01	0.558470E-11
MAX	0.210255E+08	0.412832E+00	0.258960E+00	0.558470E-11
MEAN	0.970278E+07	0.198533E+00	0.112481E+00	0.558470E-11
MED	0.809752E+07	0.179574E+00	0.975377E-01	0.558470E-11

TIME = 0.100000E+05 years

MIN	0.571118E+07	0.180534E-03	0.819800E-01	0.558470E-11
MAX	0.172035E+08	0.891735E+00	0.257772E+00	0.558470E-11
MEAN	0.856382E+07	0.304707E+00	0.114075E+00	0.558470E-11
MED	0.675711E+07	0.240683E+00	0.971745E-01	0.558470E-11

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Table 2. Performance Measures for Blowout, Spalling, and Cuttings (Baseline Model Results)

TIME = 0.100000E+03

	BRINE PRESSURE (Mpa)	BRINE SATURATION	POROSITY	PERMEABILITY (m^2)
MIN	0.646341E+06	0.164512E-00	0.129134E+00	0.558470E-11
MAX	0.781343E+07	0.328766E+00	0.300751E+00	0.558470E-11
MEAN	0.261626E+07	0.159652E+00	0.182226E+00	0.558470E-11
MED	0.197089E+07	0.175252E+00	0.163546E+00	0.558470E-11

TIME = 0.100000E+04

MIN	0.405960E+07	0.144595E-03	0.753411E-01	0.558470E-11
MAX	0.213275E+08	0.829489E+00	0.260317E+00	0.558470E-11
MEAN	0.993771E+07	0.223267E+00	0.114298E+00	0.558470E-11
MED	0.841570E+07	0.185228E+00	0.986526E-01	0.558470E-11

TIME = 0.100000E+05

MIN	0.596549E+07	0.162282E-03	0.831857E-01	0.558470E-11
MAX	0.177650E+08	0.891300E+00	0.259204E+00	0.558470E-11
MEAN	0.904791E+07	0.295925E+00	0.115752E+00	0.558470E-11
MED	0.686144E+07	0.224458E+00	0.106594E+00	0.558470E-11

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MASS Attachment 13-2

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UPO 39166

INFORMATION ONLY

Sandia National Laboratories

Albuquerque, New Mexico 87185-1341

Memorandum of Record

DATE: June 5, 1996

SUBJECT: Memorandum of Record for meeting held 1/22/96 to discuss symmetry of intact rock properties, possible gas pressure-induced fracture properties, and fluid flow properties around the WIPP

DISTRIBUTION: 2 Copies w/att:
SWCF-A:WBS# 1.1.7.1:PA -Modeling and Analysis - Hydrologic Modeling:NQ:Salado Flow Symmetry

Kurt Larson
7/11/96 DS.

On January 22, 1996, a meeting was convened by Dr. Wendell Weart, Dept. 6000, and attended by Dr. Norman Warpinski, Dept. 6114, Dr. Wolfgang Wawersik, Dept. 6117, Dr. Stephen Brown, Dept. 6117, Dr. Peter Davies, Dept. 6115, Dr. Margaret Chu, Dept. 6801, Dr. Palmer Vaughn, Dept. 6749, and Kurt Larson, Dept. 6751. Dr. David Borns, Dept. 6116, was invited but could not attend. The meeting began at 8:30 and was scheduled as open-ended. The group decided a reasonable discussion had been pursued and an ending point reached after 3½ hours.

The meeting was held to discuss whether rock properties, fracture processes, or other evidence indicate that fluid flow in the Salado away from the repository will occur in a preferred direction, and to suggest for use in performance assessment a BRAGFLO model geometry consistent with the conclusion of the discussion. The topic is perceived as critical with respect to estimated performance of the disposal system, so a conservative approach for the sake of bounding the problem is not feasible.

Several packages of supporting information were provided and are attached to this memorandum. Peter Davies prepared and distributed prior to the meeting a packet of nine attachments summarizing previous work on the subject of flow and geometry, Kurt Larson brought a photocopy of stratigraphy in vicinity of the repository from Beauheim et al. SAND92-0533, Kurt Larson brought figures of geometry of present model, Palmer Vaughn brought a handout of the PA fracture model, and Palmer Vaughn brought a figure of pressures in the repository from modeling studies conducted in support of the PA.

An author's draft of this memorandum was submitted to all meeting participants for their review. Reviews were received from Dr. Warpinski and Dr. Wawersik. Their reviews are attached. This current memorandum has been revised from the draft circulated for review to reflect the concerns and comments made in the reviews received.

Discussion about rock properties focused on whether significant anisotropy exists in the lateral hydraulic properties of interbeds. Discussed were the effects of the depositional environment of the interbeds, uplift and unloading history, geometry and orientation of existing and partially-healed fractures, and the observed heterogeneity of composition, permeability, and porosity. Dr. Brown wondered whether features in the interbeds might have directional components resulting from energy patterns impacting the depositional environment, such as prevailing winds or tides. Wendell Weart answered that his interpretation of Dave Borns' work was that interbeds show no directional trends or fabrics evident from any origin. The group concluded that present knowledge suggests absence of significant anisotropy. However, further work would strengthen this suggestion including two follow-on studies. First, examination of cores from surface boreholes might demonstrate pervasive preexisting subhorizontal fracture systems in Marker Bed 139 (and perhaps other interbeds) throughout the WIPP are representative of site-wide conditions. Second, mapping the thickness of overburden above the repository horizon within the Land Withdrawal Area could confirm that the stresses acting on preexisting fractures are similar over the region of interest for actinide transport. At the request of Dr. Weart, Dr. Borns investigated the suggested issues and has documented results in an attached memorandum. In summary, Dr. Borns, Dr. John Lorenz, and Dr. Dennis Powers examined eight available cores and found vertical or horizontal fractures in six, and found approximately 100 meters increased overburden moving from ERDA-9 eastward across the site.

Discussion about possible directional propagation of fractures induced by high repository pressure focused on results from WIPP-specific experiments, insight from other sites, and theory.

Hydrofrac experiments conducted at the WIPP by Dr. Wawersik and others in Marker Bed 139 and Marker Bed 140 below room C1 show that fractures remained in these interbeds within relatively narrow zones of anhydrite. The zones are basal or within the upper third of the interbed. Fractures propagated easily within these zones. Fractures did not propagate through clay-rich layers. For these small-scale hydrofracs, the maximum fracture opening was on the order of 0.5 cm, with a residual (post-fracturing) opening of 0.02 cm. Fracture extension of at least 30 m was observed. Dr. Wawersik expressed his opinion that (i) all of his hydraulic fracturing were influenced by the presence of room C1 and that generalizations of fracture paths for very long fractures must be carried out cautiously. (ii) Gas driven fractures would remain in the interbeds because the magnitude of the horizontal principal stresses in interbeds tested appeared to be similar to the magnitude of the overburden stress and because preexisting weakness such as partially-healed fractures probably would act as fracture guides. (iii) Theoretical, fracture-mechanics based analyses leave open the possibility that hydraulically driven fractures, including gas-driven, might curve upward and cross into the overlying salt if the length of a fracture becomes long compared with the depth of the fracture below surface.

The behavior of hydraulically-induced fracturing at other sites and fluid flow through fractures at other sites was discussed. Oak Ridge hydrofrac experiments were discussed as these may be good analogues to possible WIPP behavior. Dr. Wawersik followed up on the Oak Ridge experiments. The Oak Ridge hydrofrac work identified possible parallels (analogues) in the propagation characteristics of horizontal, fluid-driven fractures. Points of particular interest are: (i) the magnitude of in-situ stress states to maintain horizontal fracture growth, (ii) the possible influence of preexisting inclined fractures on horizontal hydraulic fracturing paths, and (iii) the possibility of fracture towards shallower depths and towards the surface as the lengths of the grout-driven fractures became long compared with their depth below surface.

Fracturing experiments in coal fields show that coal fines prevent easy propagation because the fracture tip gets clogged and fractures bifurcate. Such bifurcations may produce multiple fractures. Hydrofracs conducted by the petroleum industry were thought not to be good analogues because in most oil-field applications fractures are oriented vertically rather than horizontally. The Edsel gas storage field in Germany and experiments conducted by Shell in Holland were mentioned because there gas has moved along grain boundaries at high pressures. Specifically, Shell R&D results indicate that grain boundaries in rock salt around storage caverns will open to absorb liquid or gas when the cavern pressure reaches the prevailing lithostatic pressure. If true, such a scenario might create gas storage volume outside of new or reopened fractures in any WIPP interbeds.

Stripa was mentioned. However the relevance of fracture studies there is questionable because Stripa is looking at pre-existing fracture behavior but significant flow in the Salado at WIPP, if it occurs, will be in induced fractures. Dr. Warpinski mentioned that small-scale effects in western gas sands are thought to be insignificant.

It was the consensus of the group that propagating fractures are not likely to have a strong directional component propagating fractures in all directions to a similar distance is energetically more favorable than propagating a fracture or network of fractures in a single direction or limited arc. At the scales of interest for WIPP performance assessment, areas between propagated fractures will tend to be bridged by new fractures before the propagated fractures extend further. It was noted by Dr. Warpinski that vertical fractures created during oilfield operations have extended as far as 1500 feet; Dr.

Warpinski thought that it would be difficult to extend fractures greater than 2000 feet.

Dr. Warpinski advanced three conceptual models for possible conditions in the interbeds. In interbeds that have not been affected by high repository pressure, a network of preexisting fractures, partially healed, controls fluid flow. As pressures rise above the point where alteration begins, two things could happen. Dilation and interconnection of preexisting fractures could occur, resulting in increased porosity and permeability. Creation of new fractured zones and networks could also occur.

The impact of dip was discussed briefly. Dr. Warpinski stated that any dip would likely have an impact on segregation of gas and brine and some impact on the direction of fractures. Palmer Vaughn reported the present PA model incorporating dip and fractures did yield some directionality in fractures and segregation of fluids.

The performance assessment model for incorporating the effect of induced fractures was discussed. Palmer Vaughn introduced the model. The opinion of Dr. Wawersik and Dr. Warpinski was that the parameters in the model should be set such that the effect of a linear elastic fracture mechanics (LEFM) model is mimicked at a pressure slightly above lithostatic. Additionally, it was stated that pressures in the repository greater than a few to several MPa greater than lithostatic were unbelievable on physical grounds - some portion of the system would dilate or fracture if such pressures were attained. Thus the fracture model parameters should be set so the increase in interbed porosity and interbed permeability (i.e., propagation properties) at a pressure a couple or several MPa above lithostatic is sufficient to prevent any additional pressure increase. Kurt Larson and Palmer Vaughn followed up on this with help from Mike Lord (see attachments).

Summary:

- The group concluded that most available evidence and relevant experience rules out strong, obvious effects of anisotropy, and supports radial flow and radial propagation of fractures away from the repository rather than directional propagation of fractures. It was noted that the available evidence is not sufficient to prove that radial flow and propagation of fractures will occur but the preponderance of scientific judgement favored that interpretation.

- The parameters in the interbed fracture model implemented in BRAGFLO should be set such that the effect of a linear elastic fracture mechanics (LEFM) model is mimicked at a pressure slightly above lithostatic. Additionally, the fracture model parameters should set so the system porosity increase and permeability increase (i.e., propagation properties) at a pressure a couple or several MPa above lithostatic is sufficient to prevent any additional pressure increase. Identification of a parameter set intended to accomplish this has since been completed (see attachments for details).

Attachments: Not Attached in CCA. Available in SWCF. Kurt Larson 8/5/96.

Borns, David J. Memorandum to Wendell Weart, January 19, 1996. The symmetry of flow within Marker Bed 139.

Borns, David J. Memorandum to Wendell Weart, May 30, 1996. Lateral Variability of Fractures and Fracture Susceptibility in the Marker Beds of the Saladao [sic] Formation.

Davies, Peter. Memorandum to Distribution, January 19, 1996. Additional Background Information for Tuesday's Meeting on Salado Brine Outflow.

Vaughn, P. and Fewell, M. Memorandum to Margaret Chu, January 10, 1996. Recommendations on Preferential Flow in the Salado Formation.

Warpinski, N.R. Memorandum to W.D. Weart, March 19,1996. Review of *Salado Flow Geometry Meeting* Summary.

Wawersik, W.R. Memorandum to W.D. Weart, March 25, 1996. Salado Flow Geometry.

Wawersik, W.R. Memorandum to Kurt Larson, February 15, 1996. Fracture and fluid flow in Salado marker beds.

Wawersik, W.R. Memorandum to M.S.Y. Chu, September 14, 1996. Gas-driven fracture development in WIPP - CORRECTION.

Unauthored Attachments:

Parameters describing the variable porosity and permeability within anhydrite material and supporting information.

Plot of pressure versus time in the repository for FEP baseline calculations

Figure 2-3: Salado Formation lithology figure.

Figure 2-2: Detailed stratigraphy near the WIPP facility.

Table A-1: Description of generalized stratigraphy.

Top-down figure of BRAGFLO long-term release mesh. Figure in Section 6 of CCA. Kurt Larson

To-scale side view of BRAGFLO long-term release mesh.

Figure in Section 6 of CCA.
Kent Larson.

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D. Borns	MS 0750	
S. Brown	MS 0751	
M. Chu	MS 1335	
P. Davies	MS 1324	
M. Fewell	MS 1328	
K. Larson	MS 1341	Day File
P. Vaughn	MS 1328	
N. Warpinski	MS 0705	
W. Wawersik	MS 0751	
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L. Dotson	MS 1341
M. Lord	MS 1328