WASTE ISOLATION PILOT PLANT

Additional Panels Performance Assessment (APPA) Changed Conceptual Models

Peer Review Report

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EXECUTIVE SUMMARY

The Waste Isolation Pilot Plant (WIPP) site has been developed near Carlsbad, New Mexico, by the U.S. Department of Energy (DOE) as the United States' first underground repository certified and permitted to safely and permanently dispose of transuranic (TRU) radioactive waste resulting from the research and production of nuclear weapons. The first shipment of TRU waste arrived at the WIPP on March 26, 1999.

Peer review of conceptual models developed by the DOE for the WIPP is required by 40 Code of Federal Regulations (CFR) Part 194.27, which was promulgated by the U.S. Environmental Protection Agency (EPA) in 1996. In accordance with this requirement, the Carlsbad Field Office (CBFO) of the DOE has conducted a peer review of the changed conceptual models required to support a planned change request for two replacement waste panels.

Sandia National Laboratories (SNL) is responsible for the development, maintenance, and conduct of the WIPP performance assessment (PA). As part of the PA methodology included in the Compliance Certification Application (DOE, 1996), the DOE identified and developed conceptual models that describe the features, events, and processes relevant to the WIPP disposal system and its subsystems. These conceptual models were peer reviewed by the Conceptual Models Peer Review Panel and the Panel's results were approved by the EPA during the original WIPP certification (EPA, 1998).

With respect to the two replacement panels, there are three changed conceptual models of the 24 conceptual models used in the WIPP PA. The three changed models are: Disposal System Geometry, Repository Fluid Flow, and Direct Brine Release.

The Disposal System Geometry conceptual model expresses the dimensionality of the engineered system and surrounding geologic/hydrogeologic formations. The addition of new repository areas to the BRAGFLO (brine and gas flow) grid is a change in this conceptual model.

The Repository Fluid Flow conceptual model addresses (1) fluid distribution in the waste, (2) long-term fluid flow to-and-from the Salado Formation and shafts, and (3) long-term fluid flow between the repository and intrusion boreholes. The Repository Fluid Flow conceptual model is a complex description of simultaneous, interacting hydrologic, chemical, geomechanical, engineering design, and human intrusion scenarios whose effects can be described separately, but require numerical modeling to identify the combined, integrated outcome. The conditions controlling repository fluid flow include brine inflow rates, halite creep rates, and gas generation from anoxic iron corrosion and microbial degradation, which are themselves the objects of related but separately described conceptual models. The Repository Fluid Flow model accepts inputs from these related models and provides descriptions of pressures, saturations, flow rates, and flow directions for brine and gas within the excavated areas of the repository.

The key elements of the repository layout pertaining to the Repository Fluid Flow conceptual model are the waste disposal area (the waste panels and access drifts), the panel closures, the

operational area, the experimental area, the shafts, the WIPP site characterization boreholes in the vicinity of the repository, and any future exploration boreholes that might penetrate the repository at random times and random locations.

The Direct Brine Release (DBR) conceptual model addresses the scenario where brine containing actinides may flow from the waste panels up a borehole to the surface during drilling. In general, the important features of the DBR grid are retained in the APPA DBR grid; the representation of TRU waste disposal panels in the western waste area in the DBR grid is a change to the conceptual model.

This report presents the results of an independent technical peer review of the adequacy of the three changed conceptual models representing features, processes, and events involved in assessing the long-term performance of the WIPP repository.

This independent peer review was conducted by a five-member interdisciplinary team having the requisite broad experience and expertise to assess the impact of changes in these conceptual models on the ability of WIPP to successfully meet the EPA containment requirements in 40 CFR 191.13 for the 10,000-year regulatory time frame. The peer review presentations were conducted primarily in Carlsbad, New Mexico, in the DOE CBFO auditorium. The Peer Review Panel was given access to the conceptual model descriptions, scientific reports, briefings, and SNL staff. The Panel also had access to reports of prior peer reviews and was given the full cooperation of the DOE and SNL throughout the review. Representatives of the EPA, DOE, and CBFO Technical Assistance Contractor quality assurance personnel observed the SNL technical presentations and the Panel's questions and deliberations.

A conceptual model is a statement of how important features, events, and processes such as fluid flow and intrusion scenarios are to be represented in PA. To be useful in PA, a conceptual model must be successfully translated into analytical statements and mathematical analogs. The Peer Review Panel reviewed the three changed conceptual models in detail, including the assumptions and scientific information used as the basis to change the models, and they considered alternative models, the areas of uncertainty associated with the models, adequacy of the models, accuracy of the models, and the validity of the conclusions reached. The Panel also made an assessment of the information used to change the models and whether the conceptual models are adequate for implementation in an overall WIPP PA.

The three changed conceptual models were reviewed in the context of the overall approach to the WIPP PA. The review evaluated the structure of the conceptual models and the mathematics that are used to embody the models in code. The review also included an assessment of the reasonableness of outputs based on sensitivity to parameter inputs.

The Peer Review Panel has utilized the applicable plans and procedures; applied their respective areas of technical expertise and experience; considered the assessment criteria provided in NUREG-1297, *Peer Review for High-Level Nuclear Waste Repositories*, and they have determined that the changes to the three conceptual models reviewed are adequate and reasonable for their intended use.

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LIST OF ACRONYMS AND ABBREVIATIONS

APPA	Additional Panels Performance Assessment
CBFO	Carlsbad Field Office
CCA	Compliance Certification Application
CCDF	complementary cumulative distribution function
CFR	Code of Federal Regulations
CH	contact-handled
cm	centimeter
CRA	Compliance Recertification Application
CTAC	CBFO Technical Assistance Contractor
DBR	Direct Brine Release
DOE	U.S. Department of Energy
DRZ	disturbed rock zone
EPA	U.S. Environmental Protection Agency
FEPs	features, events, and processes
km	kilometer
LANL	Los Alamos National Laboratory
LWA	Land Withdrawal Act
LWB	Land Withdrawal Boundary
m	meter
m^3	cubic meters
MP	management procedure
MPa	megapascals
Mscf	million standard cubic feet
NRoR	North Rest of Repository
PA	Performance Assessment
PCR	planned change request
QA	quality assurance
RH	remote-handled
ROM	run-of-mine
ROMPCS	Run-Of-The-Mine Panel Closure System
SA	supplemental analysis
SNL	Sandia National Laboratories
SRoR	South Rest of Repository
THMC	thermal-hydro-mechanical-chemical
TRU	transuranic
USGS	U.S. Geological Survey
WIPP	Waste Isolation Pilot Plant
WRoR	West Rest of Repository

LIST OF PEER REVIEW PANEL MEMBERS

Ronald W. Falta, Jr., Ph.D.
Dr. Falta is a Professor of Environmental Engineering and Earth Sciences at Clemson University. He received a B.S. and an M.S. in Civil Engineering at Auburn University in 1982 and 1984, and a Ph.D. in Mineral Engineering from the University of California-Berkeley in 1990. Following a post-doctoral fellowship at the Lawrence Berkeley National Laboratory he joined the faculty at Clemson in 1992. He performs research, graduate teaching, and consulting in the areas of subsurface multiphase flow and heat transfer, contaminant transport and remediation, and hydrogeology. He was a co-developer of the Lawrence Berkeley Laboratory T2VOC module of TOUGH used to simulate thermal remediation, and he was the primary developer of the REMChlor and REMChlor-MD contaminant transport-remediation models. He received the 2020 John Hem Award from the National Groundwater Association, and the 2020 Honor Award for University Research from the American Academy of Environmental Engineers and Scientists.

Mengsu Hu, Ph.D.
Dr. Mengsu Hu is currently a research scientist in the Energy Geosciences Division at the Lawrence Berkeley National Laboratory. She received a B.Eng. in civil engineering in 2010 and a Ph.D. in geotechnical engineering in 2016. Dr. Hu's research focus is on numerical modeling of coupled thermal-hydro-mechanical-chemical (THMC) processes in the energy geosciences, including: (1) novel computational methods development such as extended finite volume method, numerical manifold method, (2) numerical modeling of microscale coupled processes for understanding fundamental mechanisms, and (3) multi-scale, long-term analysis of THMC processes in energy-geosciences applications such as nuclear waste disposal and geothermal exploitation. She is continuously broadening her research interests with her increased understanding of numerical modeling and machine learning, fundamental geosciences, and energy geosciences applications.

Edward M. Kwicklis, M.S.
Mr. Kwicklis received a B.A. in geology from Queens College of the City University of New York in 1981 and a M.S. in geology from the University of Colorado, Boulder, in 1987. He worked as a student for the U.S. Geological Survey (USGS) as a groundwater flow and transport modeler, and was hired as a full-time employee by the USGS in late 1988. Mr. Kwicklis joined Los Alamos National Laboratory (LANL) in 1999 where he played a prominent role in developing groundwater flow and transport models in a probabilistic framework. He served as chief scientist for the Yucca Flat/Climax Mine area from 2008 to 2021 and served as co-team lead for the Subsurface Flow and Transport modeling team of the Earth and Environmental Sciences Division between 2008 and 2014, supervising approximately 20 Ph.D.-level scientists during that time. Mr. Kwicklis retired from LANL in April 2021.

Carl I. Steefel, Ph.D.
Dr. Steefel is currently a senior scientist in the Energy Geosciences Division, Earth and Environmental Sciences Area at Berkeley Laboratory. He also serves as head of the Geochemistry Department. He has more than 30 years of experience in developing models for multicomponent reactive transport in porous media and applying them to topics in water-rock interaction, reactive contaminant transport, chemical weathering, isotopic exchange, and

watershed modeling. His recent work has focused on modeling of geochemical transport and electrostatic effects in clay-rich rocks. He is the principal developer of the CrunchFlow software, which won an R&D100 Award in 2017. Dr. Steefel was named an AGU Fellow in 2019.

Sherilyn C. Williams-Stroud, Ph.D., P.G.
Dr. Williams-Stroud has over 30 years of U.S. and international geological analysis experience in government working at the U.S. Geological Survey and industry, having worked for operating companies including Chevron and Occidental Oil & Gas, and for service companies, including Midland Valley and MicroSeismic Inc. She has lectured and conducted courses in structural modeling, fracture modeling, and microseismic mapping. Her specialties include structural geology, fracture modeling, stress and strain analysis, and rock fracture mechanics. Her other areas of expertise include evaporite sedimentology and geochemistry. She was the technical lead for the development of the fracture modeling and orientation analysis modules of the Petroleum Experts (formerly Midland Valley) MOVE structural modeling software and is the co-author of a patented methodology to create discrete fracture networks from microseismic event data. Dr. Williams-Stroud is currently a research scientist in the Petroleum Geology section of Energy Research and Development at the Illinois State Geological Survey, focused on analyzing and interpreting microseismic data, structural geology, and fracture data in support of energy and CO_2 sequestration activities.

John A. Thies, B.S.
Mr. Thies' 35 years of experience in nuclear projects has resulted in substantial knowledge of nuclear waste repository site characterization, design, performance assessment, permitting/ licensing, and associated waste characterization. He has managed and substantially contributed to nuclear repository regulatory and technical activities involving the Nuclear Regulatory Commission, the U.S. Environmental Protection Agency, the U.S. Department of Energy, and public utilities. He has extensive experience in the assessment of repository projects for quality, regulatory and safety compliance, and cost and schedule performance. He has experience interfacing with the United States Geological Survey, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, Sandia National Laboratories, and contractors, to effectively address the technical and management aspects of transuranic waste, spent nuclear fuel, and high-level waste as they relate to nuclear fuel processing, storage, and repository disposal.

1.0 INTRODUCTION

The U.S. Department of Energy (DOE) has developed the Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico for the disposal of transuranic (TRU) wastes generated by defense programs. In May of 1998, the U.S. Environmental Protection Agency (EPA) certified that the WIPP would meet the disposal standards (EPA, 1998) established in Title 40 Code of Federal Regulations (CFR) Part 191, Subparts B and C (EPA, 1993), thereby allowing the WIPP to begin waste disposal operations. The certification was based on performance assessment (PA) calculations that were included in the DOE's Compliance Certification Application (CCA) (DOE, 1996). These calculations demonstrated that the predicted releases of radionuclides to the accessible environment would not exceed those allowed by the EPA standard, given the assumptions and understanding of the disposal system at that time. The first shipment of TRU waste arrived at the WIPP on March 26, 1999.

Sandia National Laboratories (SNL) is responsible for the development, maintenance, and conduct of the WIPP PA. As part of the PA methodology included in the CCA (DOE, 1996), the DOE identified and developed conceptual models that describe the features, events, and processes (FEPs) relevant to the WIPP disposal system and its subsystems. These conceptual models were peer reviewed by the Conceptual Models Peer Review Panel and the Panel's results were approved by the EPA during the original WIPP certification (EPA, 1998).

The WIPP Land Withdrawal Act (LWA) (U.S. Congress 1996) requires the DOE to submit documentation of continued compliance with the EPA's final disposal regulations every five years after first receipt of TRU waste. This recertification process allows the most recent and up-to-date information to be incorporated into the WIPP PA. As such, the DOE has submitted Compliance Recertification Applications (CRAs) in March 2004, 2009, 2014, and 2019 that demonstrate continued compliance with the EPA's requirements for radioactive waste disposal. Detailed changes in the PA are tracked from one CRA to the next, and as necessary, to support WIPP long-term repository performance after final facility closure. Since the submission of CRA-2019, the following changes have been made to the PA conducted for CRA-2019. Some were changes to approved WIPP conceptual models and therefore require peer review.

(1) Actinide solubilities have been corrected (not a conceptual model change).

(2) The grid for the Salado flow model is modified to accommodate replacement panels (included in this peer review as part of the Repository Fluid Flow Conceptual Model change).

(3) The grid for computing direct brine release (DBR) is modified to account for replacement panels (included in this peer review as part of the DBR Conceptual Model change).

(4) The procedure for calculating releases due to transport through the Culebra is modified to account for the revised repository footprint due to the replacement panels (not a conceptual model change). While AP-185 suggests the Culebra release point needs to be adjusted for the new repository layout (Hansen, 2020, section 2.6, page 16), the Additional Panels Performance Assessment (APPA) summary report describes why the Culebra release point was left unchanged (Brunell et al., 2021, section 2.4.7, page 12).

(5) Repository area and volume are updated to account for replacement panels (included in this peer review as part of the Disposal System Geometry Conceptual Model change).

(6) The CCDFGF code is modified to accommodate replacement panels (not a conceptual model change).

(7) The logic for assigning panel neighbors is extended to account for replacement panels (included in this peer review as part of the Disposal System Geometry Conceptual Model change).

Sandia National Laboratories reevaluates the FEPs for each recertification, and determines if the current FEPs baseline is adequate to account for any new or proposed changes to the PA. Such changes are evaluated incrementally according to SNL Standard Procedure (SP) SP 9-4, *Performing FEPs Baseline Impact Assessments for Planned and Unplanned Changes* (Kirkes, 2016). A review of the current conceptual models was conducted to identify those affected by the APPA (Hansen, 2021). The result of this review identified three of the 24 conceptual models that were affected by the proposed change. The three changed conceptual models are: Disposal System Geometry, Repository Fluid Flow, and Direct Brine Release. Peer review of changes to conceptual models developed by the DOE for the WIPP is required by 40 CFR Part 194.27. In accordance with this requirement, the DOE Carlsbad Field Office (CBFO) conducted a peer review of the changed conceptual models required to support a planned change request (PCR) for two replacement waste panels.

This Peer Review Report documents the results of the APPA changed conceptual models peer review. It provides background information relating to the WIPP facility and includes a description of the repository; the geologic and hydrogeologic setting; and the review methodology, criteria, and the Peer Review Panel's conclusions regarding the three changed conceptual models.

2.0 BACKGROUND

The DOE was authorized in 1979 (Public Law 96-164) and funded by the Congress to develop a facility for demonstrating the safe disposal of TRU radioactive wastes resulting from national defense activities. The Land Withdrawal Act of 1992 (U.S. Congress 1992) provided additional authorization to continue the project under a stipulated statutory process. With more than 20 years of scientific investigation, public input, and regulatory oversight, the WIPP facility became the first underground repository certified and permitted to safely and permanently dispose of TRU radioactive waste from the research and production of nuclear weapons. The first shipment of TRU waste arrived at the WIPP on March 26, 1999.

2.1 WIPP Overview

The WIPP facility was constructed in southeastern New Mexico, 26 miles east of Carlsbad, on land owned by the Federal Government. Prior to October 1992, this land was administered by the U.S. Department of the Interior, Bureau of Land Management. In October 1992, Congress transferred jurisdiction of the land through the Land Withdrawal Act to the Secretary of Energy.

The site encompasses 10,240 acres in a sparsely populated area. The immediate surrounding land is used for livestock grazing, potash mining, and oil and gas production.

Surface structures and the underground repository make up the WIPP facility. The purpose of the surface structures is to provide security and safeguards, and to accommodate routine operations, administrative activities, and support further scientific studies. The underground excavation is 655 meters (m) (2150 feet) below the surface in the bedded salt of the Salado Formation. The underground excavation includes a 12-acre area in the northern part of the underground used for conducting scientific investigations and experiments in which no waste will be placed; an Operations area with equipment and maintenance facilities; an area in which the waste is emplaced for permanent disposal; and four major interconnecting tunnels that are used for ventilation and traffic.

As currently permitted, WIPP includes eight disposal panels. The DOE plans to excavate replacement panels for waste disposal. The PA performed by SNL used to quantify the long-term performance of the repository with the additional panels, the APPA, is detailed in AP-185 (Hansen, 2020). The APPA includes a proposed repository layout that includes the two replacement Panels 11 and 12, and conceptual Panels 13-19 (Panels 13-19 have not been approved by the DOE), parameter updates, and modifications to PA conceptual models needed for a PA analysis. Results found in the APPA are compared to those obtained in the CRA-2019 PA (Zeitler, 2019; Day, 2019) to assess repository performance in terms of the computational differences.

2.2 Peer Review Process

The peer review of the three changed conceptual models was initiated and sponsored by the DOE CBFO, and the entire peer review process was conducted in accordance with the DOE CBFO's Management Procedure (MP) 10.5, *Peer Review*, Rev. 10, and the APPA Peer Review Plan. The DOE CBFO delegated management of the APPA peer review to the CBFO Technical Assistance Contractor (CTAC) and the DOE CBFO approved the CTAC appointment of the peer review chairperson to guide and manage the peer review.

In addition to the chairperson, the peer review was conducted by a five-member interdisciplinary technical team having the requisite broad experience and expertise to address the range of issues associated with the ability of the WIPP to comply with the EPA release limit in 40 CFR 191.13 for the 10,000-year regulatory time frame. The peer review was conducted primarily in Carlsbad, New Mexico. The Peer Review Panel was given access to relevant background information, conceptual model descriptions, scientific reports, SNL technical briefings, input from EPA observers, and SNL staff for questions and answers. The Panel also had access to reports of prior peer reviews and was given the full cooperation of the DOE and SNL throughout the review. Representatives of the EPA, DOE, and CTAC observed the SNL technical presentations, and the Peer Review Panel's questions and deliberations during the Carlsbad meetings.

2.3 WIPP Disposal System Overview

The WIPP disposal system includes the underground repository and shaft system; the geologic host rock; and the local and regional hydrologic system. Figure 2-1 shows the WIPP boundary.



Figure 2-1. WIPP Boundary

2.3.1 Repository Setting

The WIPP surface facilities, shafts, and underground workings are shown in Figure 2-2. The WIPP repository currently includes four shafts (exhaust shaft, waste shaft, salt handling shaft, and air intake shaft), an Experimental area, an Operations area, and a waste disposal area.

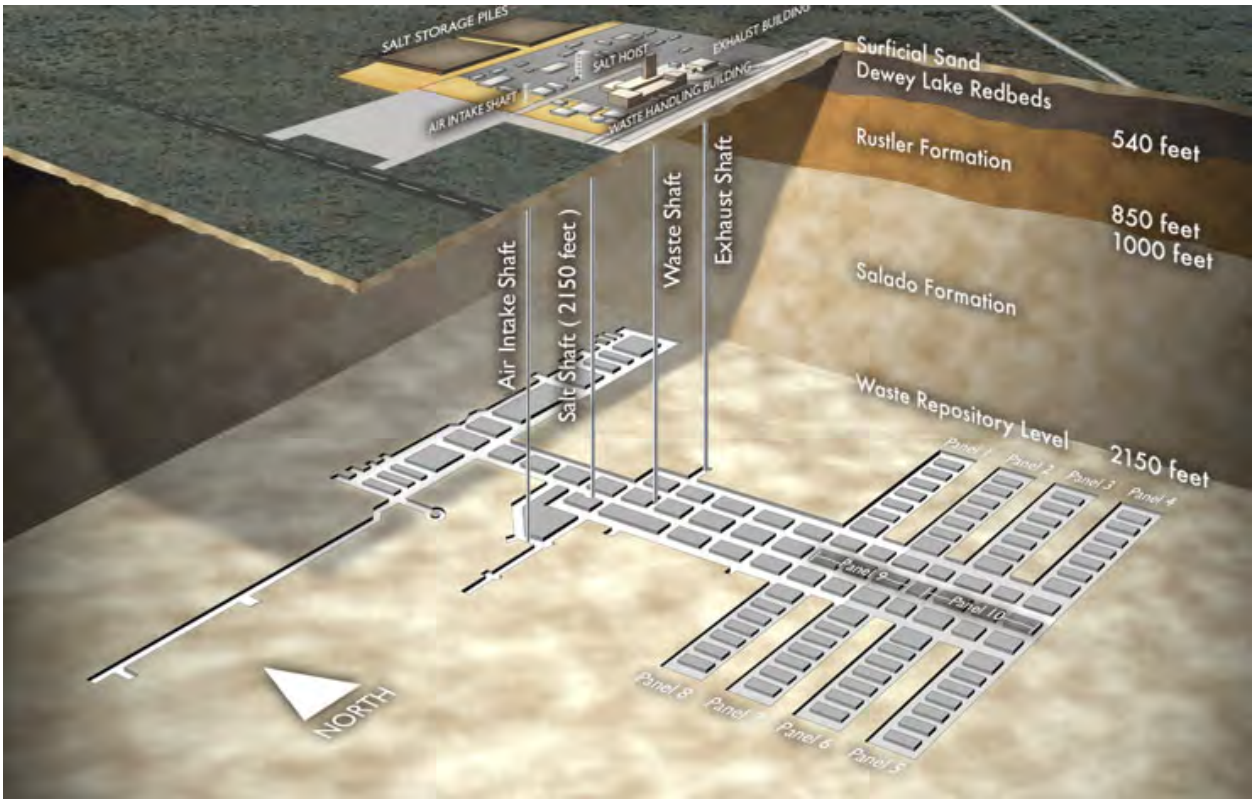


Figure 2-2. WIPP Facilities

The WIPP Repository is sited within the Salado Formation. The Salado is a bedded salt formation approximately 2,000 feet thick starting at about 1,000 feet below ground surface. The WIPP repository level is located at about the middle (2,150 feet deep) of the 2,000-feet-thick Salado Formation. There are eight permitted disposal panels, four vertical shafts, and a controlled ventilation system, with a total TRU waste volume capacity limit of 175,564 cubic meters (m^3), which was assumed to fill 10 equivalent panels. Equivalent Panels 9 and 10 were planned in the original repository layout. However, equivalent Panel 9 will not be used and Panel 10 is not yet permitted for use. Contact-handled (CH) TRU waste disposal is in waste columns on the disposal room floor, and remote-handled (RH) TRU waste disposal is in boreholes in the waste panel ribs and on the disposal room floor when packaged in shielded containers.

Approximately 40 percent (~70,800 m^3) of the total TRU (CH and RH) waste volume capacity limit authorized by Congress has been emplaced in seven disposal panels with approximately 60 percent of the WIPP LWA total TRU waste volume capacity limit remaining, as of July 2021. However, due to underutilized disposal capacity from not using some disposal rooms in Panel 1 and Panel 7, and not using equivalent Panel 9, the DOE has planned replacement Panels 11 and

12. These two replacement panels will ensure an uninterrupted WIPP mission and continued TRU waste disposal operations. To support this approach, the DOE completed a supplemental analysis (SA) for replacement Panels 11 and 12 in March 2021 in accordance with the National Environmental Policy Act. The DOE determined that the existing Environmental Impact Statement (1997 Final SEIS-II) remains adequate. The SA became effective on April 8, 2021, and formalized the DOE's decision to excavate and use replacement Panels 11 and 12.

Although the DOE has not approved any disposal panels beyond Panel 12, SNL analyzed additional panels beyond Panel 12 for internal strategic planning purposes based on the 2019 change in the disposal volume reporting and tracking methodology and assumptions of a repository filled up to the WIPP LWA volume capacity limit of 175,564 m^3 of defense-related TRU waste. The Peer Review Panel had a discussion with the DOE and understood the replacement Panels 11 and 12 had been approved by the DOE for excavation and use and that regulatory agencies would have to review a submittal from the DOE for replacement panels. The Peer Review Panel understood that the additional panels (13-19) are conceptual, based on internal strategic planning, and are not approved by the DOE for excavation and use. The additional waste panels (numbered 13 through 19) to the west of the current repository footprint are shown in Figure 2-3. Panels 13 through 19 would be similar to the dimensions of disposal rooms in Panels 1 through 8 and Panels 11 and 12.

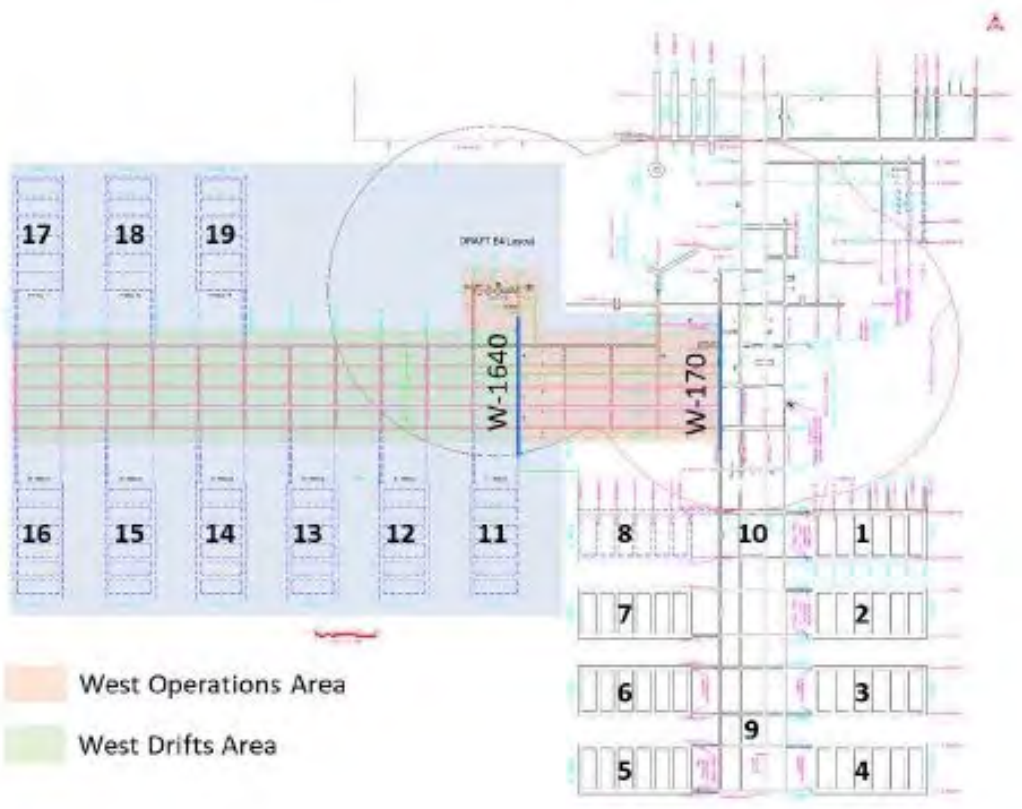


Figure 2-3. Current Repository Footprint With Conceptual Additional Waste Panels.

Panel closures for the additional panels would likely comprise 100 feet of run-of-mine (ROM) salt in the intake and exhaust drifts, the same as for the waste panels in the current repository layout. Five access drifts running east-west connect the new panels with the rest of the repository.

There are four shafts currently located in the repository north end, a salt-handling shaft, an exhaust shaft, a waste shaft, and an air intake shaft. For the CRA-2019 PA, the additional shaft (which is currently not yet excavated) was combined with the four existing shafts to form a single shaft feature in the WIPP PA models, and additional volume was added to the experimental area to account for the new access drifts for the shaft. For the APPA, the access drift volume has been moved from the experimental area to the new West Operations area. The APPA analysis uses the same TRU waste inventory estimates as the CRA-2019 PA.

2.3.2 Geologic Setting

The geologic history of southeastern New Mexico and the data collected regarding the subsurface stratigraphy at the WIPP site are important and are discussed extensively in Section 2 of the CCA and documents referenced in the CCA. The general stratigraphy at the WIPP site is presented in Figure 2-4.

The sandstones, siltstones, limestones, and shales of the Bell Canyon Formation define the first extensive, continuous, transmissive unit below the WIPP repository and provide a source of groundwater that could migrate vertically into the repository. The halite and anhydrite beds of the Castile Formation separate the Bell Canyon from the Salado, and contain pressurized brine. The brine reservoirs may be a factor in repository performance and are addressed through human intrusion scenarios. The halite-dominated Salado Formation contains the proposed repository and provides the primary natural barrier for containing radionuclides. The laterally extensive Culebra Dolomite Member of the Rustler Formation is the closest stratigraphic unit above the Salado with the potential to transport a radionuclide release to the accessible environment beyond the LWA boundary. Studies conclude that transmissivities in the Culebra vary by six orders of magnitude across the WIPP site area. Fracturing and vuggy zones account for much of the variability in the physical hydraulic properties of the Culebra.

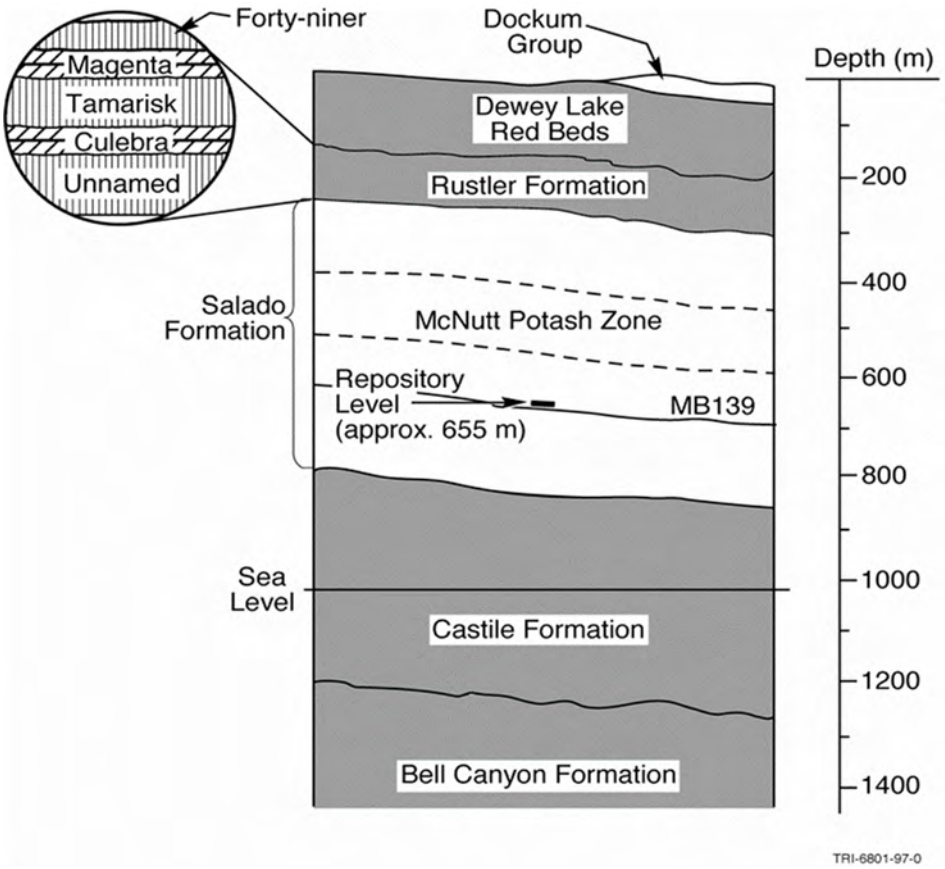


Figure 2-4. General Stratigraphy at the WIPP Site

While other stratigraphic members of the Rustler Formation, beds of anhydrite and polyhalite, clays, and other inclusions exist, the four formations and units described above define the most important components of the geologic setting for the WIPP facility.

2.3.3 Hydrologic Setting

Southeastern New Mexico is an arid-to-semiarid fringe of the Chihuahuan Desert that receives approximately 12 in (~3.5 cm) of precipitation annually.

2.3.3.1 Surface Water

The WIPP site is located within the Pecos River Basin. At its nearest point, the Pecos River flows approximately 12 miles (~19.3 km) southwest of the WIPP site boundary. There are no perennial streams at the WIPP site. Approximately 75 percent of annual precipitation results from intense, short-duration events between April and September. More than 90 percent of the mean annual precipitation is lost through evapotranspiration, and on a mean annual basis, evapotranspiration potential exceeds expected rainfall. The EPA concluded in 1989 that there were "no surface water features near the WIPP that could potentially affect repository performance in such a way as to influence the no-migration demonstration."

2.3.3.2 Groundwater

Extensive coring, logging, and testing of boreholes in the vicinity of the WIPP site has provided data for the characterization of the hydro-stratigraphy important to the WIPP site region. The deep Capitan Limestone, the Rustler-Salado contact zone near Nash Draw, and the shallower Dewey Lakes and Santa Rosa Formations are important in characterizing the general hydrogeology in the WIPP region; however, the Bell Canyon, Castile, Salado, and Rustler Formations are the units critical to the evaluation of WIPP performance.

As presented in the geologic setting, the Bell Canyon Formation is the first continuous, transmissive water-bearing unit beneath the WIPP. This formation provides a source of non-potable ground water below the WIPP repository. The Bell Canyon Formation exhibits hydraulic conductivities in the range of 10^{-7} to 10^{-12} meters per second and water pressures in the range of 12.6 to 13.3 megapascals (MPa).

The Castile Formation is of interest to site characterization as a hydrologic barrier between the Salado and Bell Canyon Formations. The Castile is predominantly low-permeability halite, which contains anhydrites with greater permeability in zones of fracture and structural deformation. Some of these fracture zones may contain over-pressure brine. The low permeable halite and high permeable anhydrites (parallel to the bedding plane) form a barrier preventing the transport of brine into the Salado Formation. The halite and anhydrite rocks of the Salado Formation are relatively impermeable, and tests have shown that flows are extremely low- to no-flow when appreciable pressure gradients are applied. The Salado contains the repository and provides the primary natural barrier for containing radionuclides.

The Magenta and Culebra Dolomite Members of the Rustler Formation are laterally extensive, transmissive, and display hydraulic characteristics sufficient for the lateral transport of radionuclides. Hydraulic conductivities in both members range over five to six orders of magnitude in the area around the WIPP site. The Magenta is generally less transmissive than the Culebra. The Culebra is the most extensive and most transmissive unit above the Salado at the WIPP site.

2.4 Peer Review Scope and Methodology

The scope of this peer review is to evaluate the adequacy of changes to the following conceptual models: Disposal System Geometry, Repository Fluid Flow, and Direct Brine Release. The APPA peer review scope is identified and described in the Peer Review Plan, DOE/CBFO-21-3629, *Additional Panels Performance Assessment (APPA) Changed Conceptual Models,* June 07, 2021.

Review of the conceptual models commenced after orientation and training of the Peer Review Panel members in accordance with MP 10.5, which included the APPA Changed Conceptual Models Peer Review Plan and other relevant information presented in the orientation.

The Peer Review Panel employed the following approaches in their overall method of accumulating and reviewing information for the reviews:

- Extensive review of referenced literature relevant to the review;
- Attendance at briefings that addressed the rationale for changes and implementation of the three changed conceptual models and other relevant aspects of the PA process;
- Issue-focused presentations with question-and-answer interactions with SNL scientists and engineers, and, at times, with the observers present at the presentations;
- Review of literature and documents referenced or submitted during the presentations, the question-and-answer sessions, and submitted by observers; and
- Formal and informal discussions among the Panel members during caucus sessions and at other times.

The Peer Review Panel received and evaluated several presentations addressing the three changed conceptual models to address whether or not they represent a reasonable view of future states of the proposed disposal system for the WIPP repository. The Peer Review Panel evaluated the three changed models in accordance with the NUREG-1297 criteria. In addition, the Panel recognized that various aspects of the models may warrant varying levels of review of their mathematical representations, computerized representations, and results. At times, individual Panel members gathered and evaluated information and shared their thoughts and findings among all of the Panel members during caucus and other meetings.

In organizing its work, the Panel established limitations on its review and the content of this report. For example, the Panel members refrained from comments on regulations, as the Panel confined its review to the three changed conceptual models as specified in the Peer Review Plan. To maintain independence, the Panel did not offer recommendations for specific methods and/or approaches to be employed in future work.

2.5 Criteria for Conceptual Model Review

The nine criteria used by the Peer Review Panel members are based on the criteria in EPA regulation 40 CFR Part 194.27, NUREG-1297, and the EPA Compliance Application Guidance. In addition, the Panel followed the guidance provided in the Peer Review Plan; the peer review procedure, MP 10.5; and that provided by the Peer Review Chairperson. The nine criteria that were used by the Peer Review Panel members are:

Information Used to Review the Conceptual Model. This is an evaluation of data and information used to review the changed conceptual models. It includes attributes of the disposal system learned by SNL during and since site characterization; insights gained from past peer reviews; information gained from exercising the models; and a review of the science and concepts that the models are based upon. It also includes pertinent information gained during operation of the repository.

Validity of Assumptions. The validity of key assumptions in the models and the application of the assumptions is assessed in terms of how they could affect the validity of the conceptual model. The review addressed the comprehensive inclusion of important FEPs, and other supporting assumptions. Examples are the assumptions that apply to drilling intrusion rates, brine

pocket volumes, and resolution of the various grids used in the mathematical representations of the conceptual models.

Alternative Interpretations. This section briefly identifies and assesses plausible alternative conceptual model changes considered, but not used by SNL, and the rationale why such alternative models were not used.

Uncertainty of Results and Consequences if Wrong. This includes an evaluation of the key uncertainties in the conceptual model changes and a discussion of the consequences if aspects of the conceptual model changes adopted were inappropriate or incompletely constrained for the site or relevant process. This is not an exhaustive evaluation, but it does raise the question, "What if the model changes are wrong?"

Appropriateness and Limitations of Method and Procedures. Based primarily on the previous four criteria, this is a simple statement of whether the individual conceptual model changes represent a reasonable approximation of the WIPP disposal system performance.

Adequacy of Application. This is an assessment of whether it appears that the conceptual model changes are being adequately applied into an acceptable overall PA system. This particular assessment does not cover the relationships among conceptual models, but rather whether the significant components of the conceptual models are appropriately implemented in support of PA.

Accuracy of Calculations. This is a statement of whether the results of performance modeling using the conceptual models within the performance system are reliable and accurate to adequately simulate the physical and chemical processes represented.

Validity of Conclusions. This is a judgment of the validity of any key conclusions that have been drawn based on results of the implementation of the conceptual models in the modeling framework. The key question here is whether or not conclusions from model implementation appropriately relates to the expected goal of assessing the long-term performance of the WIPP disposal system. This judgment requires an evaluation of output information from the total system PA.

Adequacy for Implementation. This is an overall assessment of whether the conceptual models, as implemented in the PA, represent a reasonable approximation of the actual disposal system.

3.0 CHANGED CONCEPTUAL MODELS EVALUATION

A conceptual model is a statement of how important FEPs such as fluid flow and intrusion scenarios are to be represented in WIPP PA. Conceptual models are a set of qualitative assumptions used to describe a system or subsystem for a given purpose. At a minimum, these assumptions concern the geometry and dimensionality, initial and boundary conditions, time dependence, and the nature of the relevant physical and chemical processes associated with the disposal system. The assumptions should be consistent with one another and with existing information within the context of the given purpose (DOE, 1996, Section 6.4.1).

Disposal System Geometry Conceptual Model

The Disposal System Geometry conceptual model represents the dimensionality of the engineered repository system and surrounding geologic/hydrogeologic formations for the purpose of modeling flow and transport processes. Dimensionality includes physical dimensions of length, width, and height. The Disposal System Geometry conceptual model provides the framework within which FEPs deemed important to repository performance are represented in mathematical, numerical, and computational models. Repository features represented in the Disposal System Geometry conceptual model include: the waste panels comprising the several waste rooms and pillars; drifts; panel closures; non-waste excavated areas; the shafts; and the shaft seals. Features of the geologic environment around the repository include the disturbed rock zone (DRZ), the Salado, and the anhydrite Salado interbeds. Features introduced for modeling the effect of intrusions include the borehole and borehole plugs.

Assumptions key to the Disposal System Geometry conceptual model include:

(1) The three-dimensional system can be represented by two-dimensional simplifications, in which volume is represented by assigning a thickness to each two-dimensional grid cell.

(2) Horizontal convergent or divergent flows in the rock outside of the repository can be represented by the divergent flaring of the two-dimensional grid to the north and south away from the repository.

(3) Details of features within the repository such as the waste panels, shafts, and panel closures can be represented by simplified features in the computational grid.

(4) The entire repository can be represented by the simplified floor plan used in the computational model.

(5) The effects on flow and transport of a randomly-placed intrusion borehole can be represented by modeling one intrusion at a designated location in the modeling grid.

(6) Convergent or divergent flows within the repository can be represented by the volumetric flaring of grid cells around the borehole feature.

In the computational models for flow and transport, the disposal system geometry is realized by a single computational grid with different maps of material properties. Material property maps change to represent the presence and characteristics of an intrusion borehole, as well as changes in materials over time.

The proposed replacement waste panels require new computational grids to represent the additional excavated volumes as well as the spatial relationships among repository features. These changes include:

- Blocks of grid cells to represent the additional waste panels and the associated access drifts. The group of nine additional waste panels, and the associated access drifts, are each represented by a single simplified volume. The key aspects preserved by this simplified representation include the total volumes of the additional panels and access drifts, the hydraulic connections between these volumes and the adjacent DRZ, Salado

and Salado interbeds, and the presence of panel closures separating each additional panel from the access drifts.

- Placement of the additional waste panel grid cells with the non-waste filled access drifts, operations, and experimental areas interposed between the additional waste panels and the existing waste panels. The separation reflects the expectation that any flow between the two groups of waste panels would be through the non-waste filled excavated volumes rather than through the intact Salado rock.
- The stratigraphic dip (1° southward) is applied to the grid cells representing the additional waste panels and access drifts, although in the 3D analysis these drifts are approximately orthogonal to the southward dip of the excavated repository. This is rationalized by the fact that the western drifts are fully connected with the Experimental and Observation areas.
- The center of regional flaring (a point within the repository volume) is moved to the midpoint between the regions representing the southern and western groups of waste panels. Flaring is not applied to the columns of grid cells with Salado material adjacent to the waste areas, to improve flow modeling between regions with greatly different permeability and porosity.

Aspects of the Disposal System Geometry conceptual model that are not changed to represent the additional panels include:

- A single, simplified shaft feature represents the combined volume of all shafts in the modeling grid.
- A single intrusion borehole is placed in the computational grid to represent the effects on flow and transport of any randomly-placed intrusion. The borehole is located so as to be at a low point in the stratigraphic dip.

Repository Fluid Flow Conceptual Model

The Repository Fluid Flow conceptual model is concerned with: (1) fluid flow and distribution in the waste; (2) fluid flow to and from the Salado and shafts; and (3) fluid flow between the repository and intrusion boreholes. Fluid flow in the disposal system (except for the Culebra) is conceptualized as isothermal, immiscible, multiphase flow in porous media. A residual brine saturation is defined, which is the minimum saturation at which the brine phase has a nonzero relative permeability; below this saturation, brine is immobile. Residual gas saturation in the disposal system corresponds to the gas saturation necessary to create an incipient gas-phase relative permeability; below this saturation, gas is immobile.

Disposal region fluid flow is affected by the geometrical features of the repository and surrounding rock (described by the Disposal System Geometry conceptual model), the time-dependent properties of materials, and chemical processes that generate gas and consume brine. Salado creep closure changes disposal region porosity. Depending on material properties and conditions, brine may flow into the disposal region from the DRZ or through the shaft seal materials, or during disturbed conditions, through a borehole. Brine contained in the Salado may flow to the waste disposal region because of pressure gradients created by the excavation. Brine flow into the repository may be reduced as repository pressure increases, and brine may be

expelled from the repository if pressure in the repository exceeds brine pressure in the immediately surrounding rock, borehole, or shaft.

The waste and surrounding geologic materials are represented as isotropic and homogeneous. Except for the DRZ, anhydrite marker beds, and waste, each material is assumed to have a constant permeability and porosity, although the value may be uncertain in the performance assessment. For the DRZ and the anhydrite marker beds, permeability and porosity are time-dependent in response to pressure-driven fracturing, as described by the Salado Interbeds conceptual model.

The waste material porosity is time-dependent in response to consolidation by creep closure of the excavated volume. As described by the Creep Closure conceptual model, closure of excavated volumes and consolidation of emplaced waste are expected in response to deviatoric stresses. Closure and consolidation can be resisted by waste strength and pressure in the repository.

For all solid materials except the anhydrite marker beds, capillary pressure and relative permeability are assumed to be well-described by the model of Brooks and Corey (DOE, 2019, Appendix PA Section PA-4.2.1). For the anhydrite marker beds, the model for capillary pressure and relative permeability is regarded as uncertain, and either the model of Brooks and Corey or that of van Genuchten and Parker are assumed to apply.

As described by the Gas Generation conceptual model, gas may be generated by a number of reactions. Gas may flow away from the repository into lower pressure areas, which may include the DRZ, the interbeds, the shafts, or an intrusion borehole. Gas flow into intact, halite-rich rock is not expected because of the expected high threshold pressure of halite. Wicking (the retention of brine in a capillary fringe) is accounted for nonwetting phase entry in the gas generation models. Puddling (the capture of brine in isolated pockets of waste caused by waste heterogeneity) is neglected (Vaughn et al., 1995). Gas composition is expected to be dominated by H_2, and gas is represented as a homogeneous material with properties of H_2. Brine is also assumed to be a homogeneous fluid, with pressure-dependent density.

There are no changes to the Repository Fluid Flow conceptual model per se, as a consequence of the proposed additional panels. However, due to changes in the Disposal System Geometry conceptual model and the intimate connection between the Repository Fluid Flow and Disposal System Geometry conceptual models, the Repository Fluid Flow conceptual model is considered as affected by the proposed additional panels. The numerical and computational models, which implement the Repository Fluid Flow conceptual model, are changed by use of a new grid, which represents the volume of the new panels and the separation of the new panels from existing repository areas. The processes of two-phase flow, gas generation, and creep closure are not affected in their conceptual, mathematical, numerical, or computational forms.

Direct Brine Release Conceptual Model

The Direct Brine Release conceptual model refers to the scenario that brine containing actinides may flow from the waste panels up a borehole to the surface during drilling. The boreholes are assumed to be cased from the ground surface to the lower Rustler before entering the Salado;

thus, brine flowing up the borehole during drilling would reach the surface, but not enter the Culebra or the other permeable horizons above the Salado. Direct brine release to the surface can occur when two conditions are met: 1) brine saturation in the intruded waste panel exceeds the residual brine saturation, and 2) pressure in the intruded waste panels is greater than the pressure at the base of the column of drilling mud. Drillers in the Delaware Basin use a salt-saturated mud with a specific gravity of about 1.23 while drilling through the Salado. This corresponds to a fluid static pressure of approximately 8 MPa at the repository horizon.

Direct brine releases are assumed to endure from 3 to 4.5 days. In cases where low flow is encountered, it is conservatively assumed that the driller does not notice that an over-pressurized zone has been encountered and does not take action to mitigate this condition. In this case it is assumed that direct brine release stops when the driller cases the hole after reaching the base of the salt section. This process is assumed to take 3 days from the time that the repository is intercepted. In other cases where control of the well is lost and mitigative actions must take place, fluid flow to the surface during drilling is assumed to cease within 4.5 days after penetration of the repository (Kirkes, 2007).

Implementation of the Direct Brine Release conceptual model involves two domains joined at a common boundary: a repository domain and a wellbore domain. The repository area from which fluid flow to a borehole can occur during direct brine release is assumed to be the rooms and drifts of waste panels, room pillars, panel closures, and the DRZ. Because local-scale, short-duration flow is important, the geometry of the waste panels is considered important and the repository features are represented in a near-horizontal, two-dimensional geometry parallel to the repository horizon, with a 1° dip from north to south. It is assumed that the flow interactions with the Salado other than the pillars and DRZ are not important during direct brine release.

Flow in the repository domain is modeled consistent with the Repository Fluid Flow conceptual model, i.e., isothermal, immiscible two-phase (brine and gas) flow in porous media. Materials are assigned properties consistent with the implementation of the Repository Fluid Flow conceptual model. Pillars are assumed to have the properties of the intact halite. Initial conditions (i.e., pressure and saturation) and time-dependent properties (e.g., waste porosity) are taken from the repository fluid flow simulations for each grid region at the time of the modeled intrusion.

No flow across the boundaries of the repository model domain is assumed, due to the short duration of the direct brine release. Brine and gas can exit from the repository modeling domain at the modeled borehole to the surface. It is possible that a direct brine release could occur from a panel that is connected by a previously-drilled, abandoned borehole to a brine reservoir in the Castile. In this case, flow directly between the two boreholes, analogous to the E1E2 scenario for long-term performance, may contribute to the total brine released. The direct brine release for this scenario is calculated with a constant-pressure, flowing injection well placed as a boundary condition in the modeling grid.

Flow from the repository domain into the wellbore domain is assumed to be represented by two-phase, locally radial flow in a material with uniform saturation. From these assumptions, a productivity index is derived from Darcy's law. The portion of the wellbore domain intersecting the repository domain is conceptualized as a cylindrical cavity with effective radius determined

by the solids removed by cuttings, cavings, and spall. The productivity index accounts for the geometrical relationship between the wellbore and the numerical grid block containing the wellbore.

Flow within the wellbore is conceptualized as two-phase vertical flow in the annulus between the wellbore sides and the drill string. The complex physics of this flow are assumed to be represented by the model developed by Poettmann and Carpenter (DOE, 2019, Appendix PA Section PA-4.8.6). Gas is represented by the properties of H_2. Pressure at the interface between the repository and wellbore domains is conceptualized as the flowing bottom-hole pressure at the base of the column of drilling fluid, which is determined by the solution of the Poettmann-Carpenter equations with atmospheric pressure at the top of the borehole. The direct brine flow is calculated as the product of the productivity index and the pressure difference between grid block pressure and the flowing bottom-hole pressure.

A borehole could penetrate the repository anywhere. For simplification, the implementation of the Direct Brine Release conceptual model assumes that calculation of direct brine release at several defined locations and a select set of times provides results that are representative of the possible variation in direct brine releases.

In the conceptual model for direct brine release, several other assumptions are made that relate to other conceptual models. The processes of direct solids release from cuttings, cavings (Cuttings and Cavings conceptual model), and spall (Spallings conceptual model) are treated separately, although the Direct Brine Release conceptual model does account for the effects on fluid flow of solids removal (spall) near the well bore. Although direct brine release would affect the pressure and saturation in the repository, it is assumed that these effects are negligible over the long-term because of their transient and local nature, and they are not accounted for in the Repository Fluid Flow conceptual model. This assumption simplifies modeling because it allows detailed consideration of direct brine release over a short time period, without having to couple the results of these calculations back into the disposal system simulations.

Although the mathematical model that implements the Direct Brine Release conceptual model is not affected, the implementation of that mathematical model (e.g., computational grid) is affected by the conceptual additional waste panels. Hansen (2021) provides a summary description of all 24 conceptual models and explains why the other 21 conceptual models are not changed for the APPA.

4.0 CONCLUSIONS OF THE PEER REVIEW PANEL

The Peer Review Panel reviewed the three changed conceptual models in detail, including the assumptions and scientific information used as the basis to change the models, and they considered alternative models, the areas of uncertainty associated with the models, adequacy of the models, accuracy of the models, and the validity of the conclusions reached. The Panel also made an assessment of the information used to change the models and whether the conceptual models are adequate for implementation in the PA.

Each of the three conceptual models was reviewed individually and in the context of the overall WIPP PA. The review evaluated the structure of the conceptual models and the mathematics that are used to embody the models in code. The review included an assessment of the reasonableness of outputs based on sensitivity to parameter inputs.

The APPA analysis uses the same inventory as the CRA-2019 PA; a FEPs assessment was conducted that identified a total of 30 FEPs that are potentially affected by the proposed changes to the repository; and changes were incorporated relative to the CRA-2019 PA. Changes were made to the computational grid and associated material maps used by the BRAGFLO code (King, 2021a). The grid for calculating direct brine releases was adjusted to create a new panel group with a new representative borehole that was used to estimate DBR volumes from intrusions into the proposed additional waste panels. The DBR grid for the APPA retains the geometry used in the CRA-2019 PA with 10 notional panels. The 10-panel representation in the DBR grid differs from the 19-panel proposed footprint, so the interpretation of each panel also differs in the APPA compared to the CRA-2019 PA (Hansen, 2020). The CCDFGF code simulates random sequences of drilling intrusions. For the APPA analysis, the CCDFGF and PRECCDFGF codes were modified from those used for the CRA-2019 PA (Brunell, et al., 2021).

With the above changes noted, the basic structure of the APPA remains the same as for the CRA-2019 PA (https://wipp.energy.gov/library/CRA/CRA%202019/index.html). For each vector of sampled values of uncertain parameters, many 10,000-year futures are randomly generated. Each future comprises a sequence of simulated drilling and mining intrusions. For each intrusion, direct releases are tabulated using output from the PA computer models, and over the course of the entire future, releases through the Salado and Culebra formations to the land withdrawal boundary are recorded using output from the Salado and Culebra transport computer models.

The calculation of a single complementary cumulative distribution function (CCDF) curve is accomplished by randomly sampling, using Latin Hypercube Sampling, across uncertain PA parameters and then using Monte Carlo sampling techniques to sample stochastic variables (e.g., drilling intrusion time, drilling location, whether pressurized brine is hit or not, etc.). A single CCDF curve represents 10,000 possible multi-intrusion future conditions (expressed as probability and consequence or normalized releases) that could occur during the 10,000-year regulatory time period. For PA, 100 CCDFs are generated, and since each CCDF represents 10,000 possible futures, the generation of 100 CCDFs equal 1,000,000 possible multi-intrusion and normalized release futures. Then three replicates of the 100 CCDFs are generated to comply with the EPA requirements in 40 CFR 194.34 (f).

The CCDFGF code generates the random futures and estimates the CCDFs. The quantitative measure of long-term repository compliance to the EPA release limits is a comparison of the overall mean CCDF for total normalized releases with the EPA containment requirements in 40 CFR 191.13(a). A detailed definition of PA conceptual structure is found in Appendix PA of CRA-2019 (DOE, 2019).

4.1 Disposal System Geometry

The Disposal System Geometry conceptual model expresses the dimensionality of the engineered system and surrounding geologic/hydrogeologic formations. The addition of new repository waste panels and associated drifts necessitate changes to the BRAGFLO (brine and gas flow) grid, which is a change in this conceptual model.

With the addition of Panels 11 to 19 on the west, there are several important issues associated with the geometry that need to be addressed:

(1) The layout to represent the new (11-19) panels to rigorously account for their volumes and dimensions so that flow features such as the hydraulic gradient can be captured;

(2) The connection between the old (1-10) and the new (11-19) panels, which is particularly important for capturing the flux exchange between these panels;

(3) Potential borehole intrusions into the new repository waste Panels 11-19;

(4) Appropriate and adequate consideration of Panel 9, where no waste is planned to be placed due to the events in 2014; and

(5) The logic for assigning panel neighbors is extended to account for additional panels.

Calculations of Salado flow and DBR need different numerical grid resolution. The former can use a grid with a lower resolution; for example, an extended version of a lumped flared 2D grid that has been used in the past (e.g., Day, 2019). But the latter requires finer resolution in order to account for localized flow around an intruding borehole. Because of these differences, a careful design of grids for both Salado flow and DBR calculation is essential to evaluate the flow and transport and the resulting potential brine release, in a conservative manner.

APPA Salado Flow Grid

The determination of Salado flow grids for the PA involves several steps of comparison between alternative approaches.

A natural approach for incorporating the new panels is to use a grid system that is independent of the original grid. Previously, Day investigated the possibility of adding a separate New West repository grid system to account for new panels, which would be independent from the original repository corresponding to Panels 1-10 (named Old South repository). However, there are two limitations to this approach:

(1) This approach with two grid systems to represent the old and new repositories assumes little or no communication between these two repositories.

(2) The study also found that the simulations were sensitive to the flaring approach used for the far-field Salado applied to the grid cells in contact with the excavated regions of the repository.

Alternatively, Day built an integrated grid to study communication between the two repository areas. Using this approach, the grid from the south area was mirrored to the north to represent

the new west area—i.e., the new west area is lumped into the extension to the north of the existing repository. As a result, two representative boreholes and two shafts were included. Day compared the results between the separate grid approach and the integrated grid approach, focusing on brine pressure and brine saturation in the waste panel. Based on the comparisons, Day suggested to use an integrated grid approach that considers the communication between the south and west panel areas. In addition, conserving the volume of the intact Salado adjacent to excavated cells and far-field flaring starting in the next column outside the Salado grid cells was suggested.

However, there were two important factors that were not considered by Day, as noted in King (2021a):

(1) The west repository is assumed to have exactly the same layout and connectivity as the south repository, and the abandoned panels closures around Panel 9 are not considered, as panel closures in the new west panels are planned;

(2) The mirroring of a 1° dip to the south creates a 1° dip to the north in the west repository, resulting in a high point and hydraulic gradients in both directions.

To overcome these issues, a grid system including two boreholes and two shafts was proposed by King with a constant dip from the north (west) to the south. These two boreholes represent potential intrusions in both the south and the west groups of panels.

With potential intrusions in two boreholes, the number of scenarios becomes 11 (S1, S2-S6 considering both the south and west panels). With three replicates of 100 vectors in the PA, the total required number of vectors times the number of scenarios becomes 3300, compared with 1800 for a single borehole intrusion. Thus, an effective step is to investigate whether the two-borehole intrusion can be simplified as a single borehole intrusion. It requires an answer to the question: Can a single borehole intrusion represent the flow (brine pressure and saturation) in the intruded panel and in panels that are in a different part of the repository?

Investigating an E1 intrusion at 350 years in both boreholes, King (2021b) found that:

(1) West intrusions result in lower brine pressure and brine saturation than south intrusions in the intruded waste panel.

(2) The adjacent panel to the west intrusion (the West Rest of Repository [WRoR]) has a lower mean brine pressure and similar brine saturation compared with a panel adjacent to the south intrusion (the North Rest of Repository [NRoR]). Therefore, it was concluded that using a single borehole intrusion in the south can represent the borehole in the west slightly conservatively in terms of release. Based on these considerations, two boreholes (one each in the south and west) are represented by a single borehole in the south. In addition, all five vertical shafts (four shafts in the south and the new fifth shaft in the west) are combined into a single shaft representation, and this shaft was relocated between the Experimental area and West Operations area.

For Panel 9, three different scenarios with no waste emplaced in Panel 9 were investigated. Based on comparisons of different scenarios with or without waste in Panel 9, it was found that

considering Panel 9 with waste was a slightly conservative assumption with little impact on PA results. Panel 9 is assumed to contain waste in the APPA.

An effort that was made to reduce computational costs was to reduce the distance to the grid boundary. The approach was tested by using a smaller distance to the boundary and comparing the results of brine pressure and saturation in the waste panel, and the volume of brine flow up the borehole. It was concluded that "moving the grid boundary from 20,000 m to 10,000 m beyond the Land Withdrawal Boundary (LWB) has little effect on the output metrics that drive releases in PA." Thus, the distance to the grid boundary is reduced from 20,000 m (which was used in the CRA-2019) to 10,000 m in the new grid used in the APPA.

In order to represent the structures of interest with a coarse grid without compromising the accuracy of flow calculation, a flaring algorithm was implemented to apply "adaptive" lengths of grid in both north-south (x) and z direction (as shown in Figure 4-1). It is interesting to note that because the x-z plane involves lumping in the south repository and unbending in the west repository, the z direction refers to the horizontal direction perpendicular to the 2-D grid. The general principle is to represent converging/diverging flows in the x dimension while maintaining rock volumes in the z dimension.

Figure 4-1, shows a Peer Review Panel-prepared plot of the spacings in the x and z directions (noted as Δx and Δz, respectively) in order to give a visual explanation of the flared grid. Figure 4-1a shows the APPA grid provided by SNL. Figure 4-1b shows the Δx of the grid and the Δx within the LWB with an enlarged view. Figure 4-1c shows Δz and the Δz within a domain, including the repository area, and one column shown outside each side of the repository with an enlarged view.

To capture potential high-gradient flow adjacent to the borehole in the south panel, a locally flared grid is applied in both x and z directions, which function as a local refinement in the south panel.

For all the waste panels, the lengths of the South Rest of Repository (SRoR), NRoR, and WRoR in the x dimension are the same, i.e., equal to the length of a standard waste panel. Whereas, the differences in the z direction represent different numbers of panels. For example, in the WRoR there are 9 new panels included; therefore, larger values of Δz are used for WRoR compared with the SRoR and NRoR.

For the panel closures, the south Operations area, the experimental area, the shaft (representing the volume of five shafts), the west Operations area, and west drifts, Δx is generally set to account for the distances between areas and/or possible shortest flow paths, and Δz is set for presenting volume.

In terms of the area outside the repository, one column outside each side of the repository in the x direction remains the similar dimension in order to capture the contrast of material properties. Different ratios of spacing increase in the x direction are applied in order to accommodate the distance from the repository to the LWB, and the distance from the LWB to the outer left and right boundaries. Accordingly, increase of Δz is set to maintain volumes.

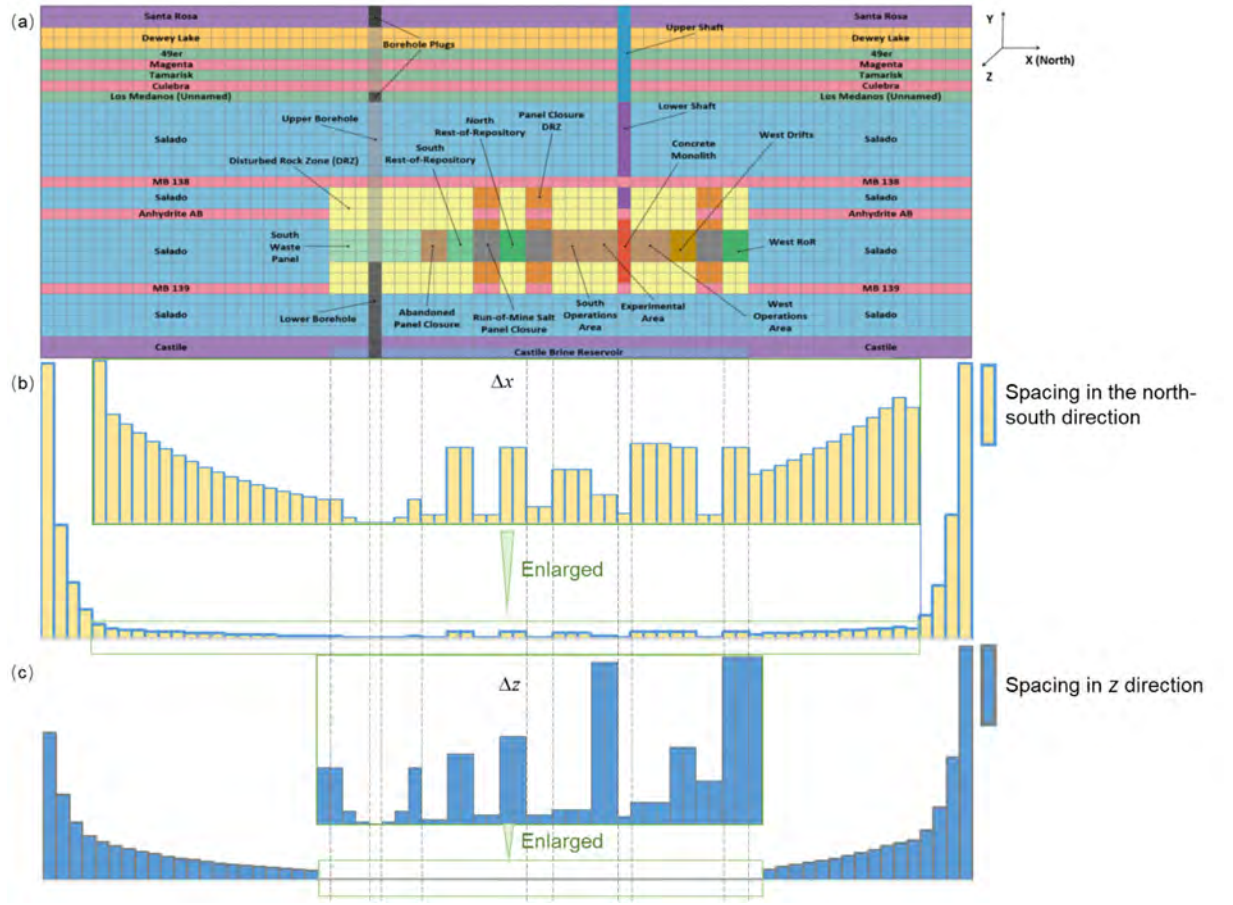


Figure 4-1. APPA Grid for Salado Flow Modeling: (a) overall layout, (b) grid spacings in the north-south direction, and (c) grid spacings in the z direction.

The grid system as shown in Figure 4-1 is used as the final configuration for the BRAGFLO simulations presented in the APPA. This grid system includes a single borehole in the south and a representative shaft, Panel 9, with waste combined with the SRoR, and a 1° dip from the north to the south. This grid also considers the west Operations area, the west drift, and the WRoR, and additional panel closures between the west drift and the WRoR.

APPA DBR Grid

DBR calculations require a grid with a higher resolution than the Salado flow model in order to calculate the short-term (days) volumetric flux to an intruding borehole. Because flux is a function of the first derivative of hydraulic head, the calculations are more sensitive to grid spacing, and a more refined grid is developed for the DBR calculations. In previous CRA-2019 calculations, a near-field grid in the region of the waste panels was used for calculating DBR from the original 10 panels.

The DBR grid only includes the area immediately surrounding the waste panels (a much smaller volume than the full-scale volume in the Salado flow model), and the outer boundary is one of no-flow. In general, boundary effects could be important to consider, but the extreme permeability contrast between the intruded waste panels and the intact halite combined with the

short duration (3-4.5 days) of a DBR greatly reduce the impact of the outer boundary condition. The volume-averaged brine pressure and saturation from the Salado flow calculation are used as the initial condition to carry out the near-field DBR calculation.

The DBR model is used to construct a lookup table of release volumes for each parameter vector using a scenario (S1-DBR through S5-DBR) combined with a future intrusion time chosen from the scenario, and an intrusion location. For an initial intrusion, the location could be "lower," "middle," or "upper" if it occurs in panels 1-10, or it could be "other" if it occurs in panels 11-19. For a second intrusion, the location used in the DBR model depends on its relationship with the first intrusion. If the second intrusion occurs in the same panel, the lower (same) well location is used. If it occurs in a panel that is not separated from the first intrusion (panels 3, 4, 5, 6, and 9) the middle (connected) well location is used. If the second intrusion occurs in a panel in the same part of the repository (south or west), but is separated from the first intrusion by a panel closure, then the upper (adjacent) well location is used. If the second intrusion occurs in a panel in a different part of the repository, it is represented by the other (nonadjacent) well location.

For the APPA model with additional panels in the west, King used the same grid layout as in the CRA-2019. The changes that were made in that grid are: (1) the grid of the NRoR in the DBR simulation is lumped from two sections into one section with half of its original volume, and (2) the WRoR is added on the top section (Figure 4-2). This lumping of panels was justified by King (2021c) by the localized nature of the pressure and saturation fields during a 3-4.5-day-long DBR event, that results in very little communication across a panel closure. King (2021c) further demonstrated the reasonableness of the APPA lumping approach by comparing those results to one computed using two separate numerical grids for the south and west parts of the repository. The two-grid approach preserved the volume relationships of the two parts of the repository, but produced results essentially the same as the simpler combined approach used in the APPA.

The random sampling used by the CCDFGF program to determine future borehole intrusion locations is not affected by this change, which only impacts the flow calculation from a given DBR scenario. As the CCDFGF computes a possible future for a vector, it determines the time and location of intrusions into a waste panel. If there was a previous intrusion, it also determines the relationship of the new intrusion with the previous intrusion. From this determination, the results compiled in the DBR lookup table are interpolated with respect to time from the corresponding scenario (S1-DBR–S5-DBR) and well location (same, connected, adjacent, or nonadjacent).

Based on the limited flow communication across panel closures during a short DBR event, and on the comparison with the two-grid approach, the Peer Review Panel agrees that it is reasonable to use the single DBR grid with representative areas for the SRoR/NRoR and the WRoR.

Another issue that is associated with calculation of volumetric flux of brine release is that the computed flow from the intruding well can be mesh-dependent. Based on experience, a refined mesh is often required in order to accurately capture the high gradient and flux into a wellbore. At the request of the Peer Review Panel, King (2021e) conducted supplementary numerical simulations with a refined grid where the single column of grid cells that made up a room with

a wellbore intrusion in the APPA grid was split into three columns of grid cells with the wellbore intrusion placed in the center column (highlighted in red rectangles in Figure 4-2). The comparison between the original and refined APPA DBR grids is shown in Figure 4-2. The concern with the initial numerical grid was that the waste areas between halite pillars were only represented by a single grid block. The numerical formulation for the pressure dependent well sink term used to compute the DBR flow rate assumes a radial flow into the sink grid block, which is not possible due to the halite pillars.

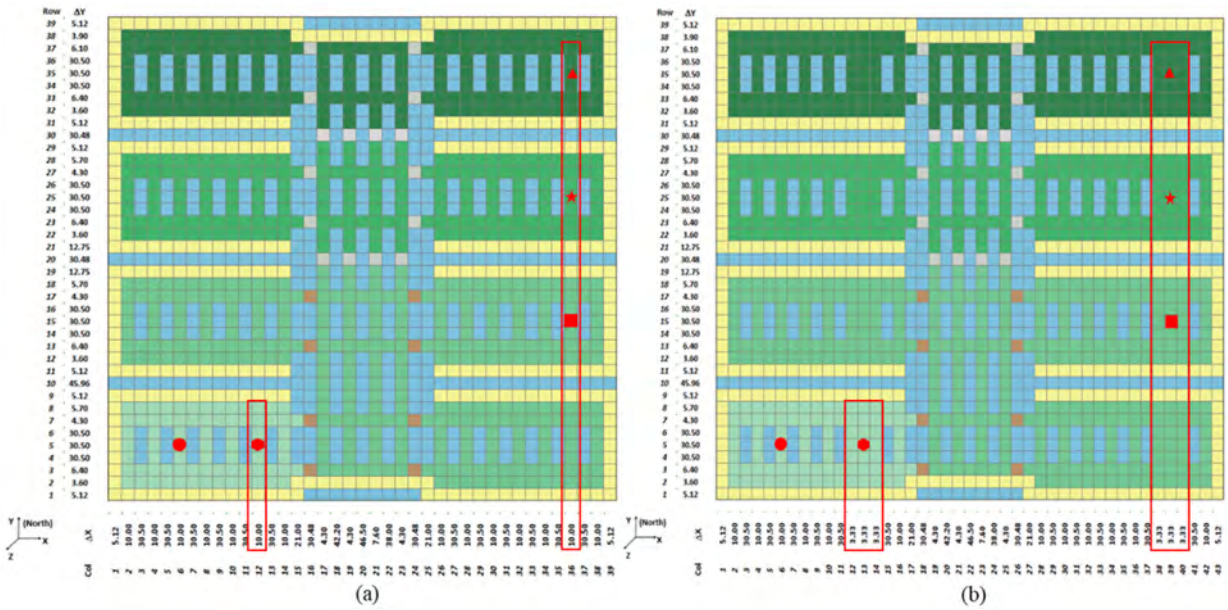


Figure 4-2. APPA BRAGFLO grids for DBR calculation: (a) original and (b) refined grid. The red rectangles refer to the regions that have refined grids, i.e., each single column of grid cells that made up a room with a wellbore intrusion has been split to three columns of grid cells.

The conclusion of comparing the original and refined grids for DBR calculations is that the refined grid with waste material surrounding the intruded grid cell tends to produce slightly larger DBR volumes than the unrefined grid. This is explained by: (1) the refined grid allowing for a more radial flow to enter the producing grid block, and (2) the refined grid providing a higher-order resolution near a wellbore to capture potential high gradients of pressure near the wellbore, which may not be fully captured by the unrefined grid. The slightly larger DBR volumes lead to slightly larger DBR releases. The slightly larger DBR releases result in a shift to the right in the mean DBR CCDF at lower probabilities, but the effect is small enough to be considered negligible.

In summary, the DBR grid uses the original design for the Waste Panel and SRoR from CRA-2019, lumps the original two rows of grids for NRoR into one, and adds WRoR on the top. New neighbor relationships have been developed in order to simplify borehole intrusion and brine release in any location while considering all the possibilities of borehole intrusion in each panel group. A comparison between a single-column and refined grids has been conducted, resulting in a slight increase of DBR releases that is considered insignificant.

Validity of Assumptions

APPA Salado Flow Grid

There are several assumptions in the Salado flow grid:

(1) A 2D flared grid can be used to reasonably approximate a 3D grid;

(2) Instead of using a full-scale grid with explicit representation of all the repositories with all of the waste panels, a lumped grid is used;

(3) A 1° dip from the north (WRoR) all the way from north to south is assumed;

(4) Panel 9 is assumed to contain waste; and

(5) Borehole intrusion is only represented in the Waste Panel.

For Assumption (1), the validity and effectiveness have been shown in previous simulations (Such as in CRA-2019 PA). In addition, the comparison of results incorporating the new panels between the 2D BRAGFLO and the 3D PFLOTRAN results corroborate the assumption as being reasonable.

For Assumption (2), King (2021a) has carefully compared the lumped results with those that were calculated by the separate grid approach and it was shown that the lumped approach, though not fully representing the geometry, can adequately represent the communication between the Old South and the New West repositories.

For Assumption (3), the 1° dip from the north all the way to the south would over-estimate the flow to the south. But the 1° dip is equivalent to a gradient of elevation head (as a component of hydraulic gradient) of 0.017, which is relatively small compared with the gradient of brine and gas. King (2021a) stated the advantage of applying this 1° dip is the dip forces a low point in the repository representation to allow an intrusion to be modeled in a worst-case event of being down-dip from the rest of the repository. As noted in the Salado Flow section, the multiple closures between the north and south end also limit the flow from north to south, and thus the importance of this 1° dip is limited.

For Assumption (4), King (2021a) concluded that modeling Panel 9 with waste will tend to move waste down dip and increase gas generation, leading to relatively conservative results. An advantage of modeling Panel 9 with waste is that panel 9 then can be combined with the SRoR, without additional gridding effort to represent Panel 9 independently in the Salado flow calculations.

For Assumption (5), King (2021a) concluded that representing west intrusions with south intrusions will tend to produce higher brine pressures and saturations for releases leading to relatively conservative results. The advantage of assuming a single borehole intrusion instead of both in the south and west is that the computational cost can be dramatically reduced. This approach, being conservative and efficient, is reasonable.

Thus, these assumptions made in the Salado flow grid are reasonable, leading to conservative but reasonable model results.

APPA DBR Grid

In the DBR grid for the additional panels, there are several assumptions:

(1) Use of a full-scale grid is not necessary, and a near-field grid of the repository area is sufficient for DBR calculations;

(2) Use of independent grids with full representation of both existing and new (west) repository areas is not necessary, and a lumped grid with the same layout as CRA-2019 is sufficient;

(3) The volume-averaged brine pressure and saturation from Salado flow calculations transferred to the DBR calculations as initial conditions are reasonable conditions for each DBR scenario calculations; and

(4) The assumed specific location(s) of borehole intrusions in each panel group are reasonable representations of possible intrusion scenarios. If not using a flared grid (i.e., a uniform grid with the same Δx and Δz is applied anywhere), then a much larger number of grids will be needed to account for the flow features and localized high-gradients (such as near the wellbore). So far, such a flaring algorithm of the grids has been optimized to use possibly the least grid to represent all the structures, volumes of the repositories, panel closures and shafts, and possible high hydraulic gradients (e.g., near the borehole).

For Assumption (1), the near-field grid may have boundary effects because the DBR grid only includes the area of immediately surrounding the waste panels (a much smaller volume than the full-scale volume in the Salado flow model). However, the Salado flow calculations at a larger scale provide the initial conditions for the DBR simulations so that the DBR simulations with a smaller volume can be well-constrained. The extreme permeability contrast between the intruded waste panels and the intact halite combined with the short duration (3-4.5 days) of a DBR greatly reduce the impact of the outer boundary condition.

For Assumption (2), the lumped layout is reasonable, since the results are consistent with those that are calculated by a two-grid full-volume approach (DBRX) under different scenarios (King, 2021c).

For Assumption (3), the DBR grid has a higher resolution than the Salado flow grid. This assumption is reasonable as all the potentially high pressures from the Salado flow grid are mapped and captured in the DBR grid, considering that the waste panels are lumped into generalized areas in the Salado flow calculations and details of panel layout are not considered.

For Assumption (4), the specified locations are the Middle, Upper, and Other intrusions located close to the eastern boundaries, and the Lower intrusion located in Panel 5. This assumption is made with slight adjustments from CRA-2019, where three drilling locations were considered. These adjustments are: (1) the Upper intrusion is moved from Panel 10 to Panel 2, and (2) a new (Other) intrusion location is added at the WRoR. The location of the APPA Upper, and Other intrusions close to the eastern boundaries of the panels could have a small influence on the flow due to boundary effects. This possible boundary influence is expected to be minimal due to the large contrast in permeability between the waste material in the panel and the panel closure, and the intact halite around the panel. During a DBR intrusion, the Upper and Other panels tend to

behave like closed compartments, and the temporary pressure decline inside the panel is relatively uniform throughout the panel.

Alternate Interpretations

APPA Salado Flow Grid

Several alternatives were considered during the development of the APPA Salado flow grid. These are:

(1) Two independent grids for the old and the new west repositories: As they do not represent the communication between these two areas, a single integrated grid was finally used.

(2) Two representative intrusion locations, one in both the south and the west repositories: Because the representation of the west intrusions with the south intrusions results in prediction of more conservative results of brine pressure and saturation and can dramatically save computational cost, a single intrusion in the waste panel was applied.

(3) A larger distance to grid boundary than 10,000 m beyond the LWB. That was tested by using a shorter distance and comparing the results of brine pressure and saturation in the waste panel and the volume of brine flow up the borehole. It was concluded that moving the grid boundary from 20,000 m to 10,000 m beyond the LWB has little effect on the output metrics that drive releases in APPA. Thus, the distance to the grid is reduced from 20,000 m to 10,000 m in the new grid.

(4) If not using a flared grid (i.e., a uniform grid with the same Δx and Δz is applied everywhere), then a much larger number of grids will be needed to account for the flow features and localized high-gradients (such as near the wellbore). So far, such a flaring algorithm of the grids has been optimized to use possibly the least number of grid blocks to represent the structures, volumes, panel closures and shafts, and possible high hydraulic gradients (e.g., near the borehole).

(5) Modeling Panel 9 without waste (compared to modeling Panel 9 with waste). King (2021a) concluded that modeling Panel 9 with waste will tend to move waste down dip and increase gas generation, leading to relatively conservative results. An advantage of modeling Panel 9 with waste is that Panel 9 then can be combined with the SRoR, without additional gridding effort.

An alternative approach for gridding is to use a full-scale grid with explicit representations of all the structures, as was done in the PFLOTRAN simulations. However, the agreement of Salado flow results by BRAGFLO and PFLOTRAN built confidence in using such a lumped representation with proper flaring and coarser grid, all of which were needed to keep the computational cost reasonable for the APPA analysis.

APPA DBR Grid

One alternative that has been considered is to use the two DBR grids with full volume for the old (Panels 1-10) and the new (Panels 11-19) repositories. The results were compared to the APPA DBR results. It was concluded that the comparison showed little difference between the full volume model and the APPA DBR model.

In addition, a local refinement around the intruded wellbores from the DBR grid was tested and the resulting differences were very minor (i.e., negligible).

Uncertainty of Results and Consequences, if Incorrect

The major uncertainty of this gridding system is when and where intrusion occurs in both Salado flow and DBR grids. By considering a scenario of single borehole intrusion in the lowermost waste panel of the Salado flow model, a more conservative estimate of brine pressure and saturation is obtained. As a result, all scenarios of intrusions in the four groups of the panels occurring at different times and their interaction with conservative locations of the wells (close to the non-flux outer boundaries) tend to give an overall conservative prediction of DBR release.

Appropriateness and Limitations of Methodology and Procedures

The assumptions can be justified, and the current Salado flow and DBR grids designs have been carefully compared with the alternative approaches step-by-step. Thus, the Panel concludes that the methodology and procedures are appropriate. It is worth mentioning that the current methodology and procedures of constructing grids have been used in previous WIPP PA calculations. The change associated with accounting for the additional panels does not alter the basic methodology and procedures from those used in the previous grid construction.

Adequacy of Application

The assumptions and simplifications (the unbending of the new west repository into a linear repository that can be modeled using a 2D approach) are acceptable. The current design of the Salado flow and DBR grids used in the APPA have been carefully compared with the alternative approaches and the changed conceptual model has been found to be adequate for its intended application.

Accuracy of Calculations

Given the assumptions and uncertainties, the calculations of Salado flow and DBR are both corroborated with alternative approaches.

For Salado flow calculations, comparisons were made between the 2D BRAGFLO and 3D PFLOTRAN grids. The results of brine pressure, brine saturation, and brine flow up the borehole calculated by the 2D flared BRAGFLO grid show minor deviations from those calculated by the 3D PFLOTRAN. The corroboration of the 2D BRAGFLO model using the 3D geometry incorporated into PFLOTRAN indicates that the 2D BRAGFLO approach used in the APPA is adequate for the purpose of estimating releases from the disposal system.

For DBR calculations, an alternative two-grid approach that preserved the waste area volume was compared to the APPA DBR results. The comparison showed little difference between these two grids. Additionally, grid refinement was applied to the areas of the Lower, Middle, Upper, and Other wellbores. The results were compared with the unrefined APPA grid. The refined grid tends to predict slightly larger DBR volumes, resulting in slightly larger DBR releases than predicted by the unrefined DBR grids. As DBRs dominate the low probability portion of the total release curve, this grid refinement has resulted in a slight increase in total releases at low

probabilities. But these changes are shown to be very minor. The comparisons between the two-grid approaches as well as a refined grid both support the APPA DBR calculations.

Validity of Conclusions

Assumptions are well justified. The current design of the APPA Salado flow and DBR grids have been carefully compared with alternative approaches and the conclusions that were drawn are reasonable and acceptable.

Adequacy of Requirements and Criteria in Accordance with Approved Technical and Quality Assurance (QA) Requirements and the Applicable Peer Review Plan(s)

This peer review was conducted according to the requirements of 40 CFR §194.27, which states that peer reviews must follow the guidelines of NUREG-1297, *Peer Review for High-Level Nuclear Waste Repositories*. The requirements were implemented in the DOE CBFO's MP 10.5. These requirements and criteria are adequate and in accordance with the approved technical and QA requirements imposed by applicable plans and procedures.

Conclusions Reached by the Peer Review Panel

The development of numerical grids for the APPA Repository Fluid Flow and DBR calculations was carefully conducted using reasonable assumptions and simplifications that resulted in conservative estimates of the brine pressure, saturation, and DBR release. The comparisons of results with PFLOTRAN for Salado Flow and with two-grid approach and refined-grid approach for DBR calculation both show the system grids used in the APPA analysis are adequate.

4.2 Repository Fluid Flow

The Repository Fluid Flow conceptual model addresses: (1) fluid distribution in the waste, (2) fluid flow to-and-from the Salado Formation and shafts, and (3) fluid flow between the repository and intrusion boreholes. These three issues can be time-dependent over the long term as a result of complex coupled hydro-chemical-mechanical processes. These include creep induced changes of porosity and permeability, and borehole intrusions potentially occurring hundreds of years afterwards. The Repository Fluid Flow conceptual model is a complex description of simultaneous, interacting hydrologic, chemical, geomechanical, engineering design, and human intrusion scenarios. The effects can be described separately, but require numerical modeling to identify the combined, integrated outcome. The processes impacting repository fluid flow include brine inflow rates, within repository flow of brine and gas, halite creep rates, gas generation from anoxic iron corrosion, microbial degradation, and brine radiolysis. The computer (computational) model accepts inputs from other related computer models and provides numerical results of pressures, flow rates, and flow directions for brine and gas within the excavated areas of the Salado Formation. The Repository Fluid Flow model also produces outputs that are used by other models; for example, transport of radionuclides by the NUTS module.

The key elements of the repository layout pertaining to the Repository Fluid Flow conceptual model are the waste disposal area (the waste panels and access drifts), the panel closures, the shaft pillar access drifts area, the northern Experimental area, the shafts, the WIPP site

characterization boreholes in the vicinity of the repository, and any future inadvertent human intrusion boreholes that are modeled to penetrate the repository at selected times and random locations.

The representation of brine and gas flow used in the BRAGFLO model for the Salado Formation for the WIPP APPA required few conceptual model changes relative to the BRAGFLO model used in the CRA-2019 PA. The most significant changes in the WIPP APPA BRAGFLO model involved changes in the geometry of the BRAGFLO grid due to the inclusion of future Panels 11-19 in the currently undeveloped western part of the repository. The character of the waste streams to be included in Panels 11-19 is assumed to be identical to the waste streams already characterized and emplaced in Panels 1-8. It should be noted that because of its very low permeability under undisturbed conditions, the halite of the Salado Formation does not allow extensive flow of either gas or brine beyond the disturbed areas associated with the repository, except possibly when gas pressures exceed the strength of the anhydrite beds embedded in the Salado Formation and create fractures. However, flow may occur in the disturbed areas, where the excavation has provided potential flow pathways for both brine and gas and where the flow is not interrupted by closures.

The main impact of decisions regarding how to model gas and brine flow within the disturbed area near the repository is on two subsets of FEPs that SNL classifies as "release mechanisms" within PA. Both release mechanisms are associated with inadvertent intrusions due to drilling: (1) spalling of waste into boreholes that penetrate the repository; and (2) direct release of radionuclide-bearing brine into and up the intruding boreholes. The spalling of waste into the intruding boreholes increases with increasing fluid pressures in the Salado Formation, and the release of contaminated brine into the borehole as calculated in the DBR model depends directly on the brine pressures and saturations calculated in the BRAGFLO model for the Salado Formation at the time and location of the intrusion. Another aspect of repository performance that can be important at high probabilities is the release of contaminated brine into the boreholes, leading to contamination of the overlying Culebra Formation. Brine pressures and saturations, in turn, depend on gas (H_2) generation from iron corrosion, cellulose degradation, and brine radiolysis, dip of the repository floor, time-dependent rock properties assumed for the DRZ and anhydrite marker beds adjacent to the open drifts and panel closures, as well as assumed ROM salt consolidation rates in the waste-panel rooms (e.g., EPA, 2017). The latter is important because the creep rate of the halite determines the efficacy of the closures that are planned.

Because none of the unchanged aspects of the CRA-2019 BRAGFLO Repository Fluid Flow model are within the scope of this APPA Changed Conceptual Models Peer Review, the comments presented below pertain to the changed geometry in the APPA BRAGFLO model that resulted from the inclusion of waste Panels 11-19 in the revised BRAGFLO grid. Some observations can be made based on the known repository layout in 3D, and how these can be related to the 2D BRAGFLO model used in the PA. As noted, brine pressures and gas saturation are taken from the Repository Fluid Flow model when an intrusion occurs, so the distribution of these parameters over the extent of the repository can make a difference. Thus, even without contaminant transport (not considered formally in this review), flow of brine and gas can have an impact and it is important to understand how this occurs. The issue of how to handle the 1° dip from north to south of the repository has been much discussed. This is one of the features of the

system that contributes to gravity-driven brine flow from north to south, and thus both brine pressure and gas saturation in individual panels. In theory, this should be fully accounted for in a rigorous 3D treatment as was carried out with PFLOTRAN.

Even making use of PFLOTRAN, an examination of the impact of the closures is useful. This issue was raised by EPA observers, who argued that contaminated brine was not present in the Experimental and Operations areas in the original CRA-2019 model, but now with the inclusion of the western panels, it is asserted that there would be contaminated brine in those locations that should be accounted for. While it is true that the western drifts are fully connected with the Experimental and Operations areas (Figure 4-3), Zeitler (2021) noted that panel closures consisting of Run-Of-Mine Panel Closure System (ROMPCS) would impede flow of contaminated brine into these connected areas. And, it could be argued, if contaminated brine from the western waste panels does flow into the Experimental and Operations areas, radionuclide concentrations are likely to be low because any contaminated brine would be largely diluted by uncontaminated brine that also made its way into the areas from the DRZ above the excavated areas. The important role of the closures was highlighted during the peer review in a "simulation movie" provided by Seth King, the set of snapshots over time clearly showed how brine flow from north to south is limited or eliminated by the ROMPCS (Figure 4-4). The brine in individual waste panels is thus largely derived from the DRZ above, and brine and gas saturations are modified over time by interactions with overlying, and in some cases, underlying formations. Because of the ROMPCS in place, flow between various waste-bearing sections of the excavated repository will be minor and likely even negligible.

From Figure 4-3, it is apparent that brine pressures and gas saturations will be impacted by the open areas within the repository to the extent that the closures function as expected, producing a very low permeability in as little as 50 to 100 years. Note, in agreement with the comments of Todd Zeitler, the brine and gas flow in the western panels is unlikely to make its way into the west access drifts (which are not themselves closed off from the Experimental and Operations areas). Panels 1, 2, 7, and 8 are effectively isolated from both the Experimental and Operations areas, but also from the western panels and associated access drift. They are also isolated by the closure between the S-2520 and S-2570 cross drifts related to Panels 3, 4, 5, and 6.

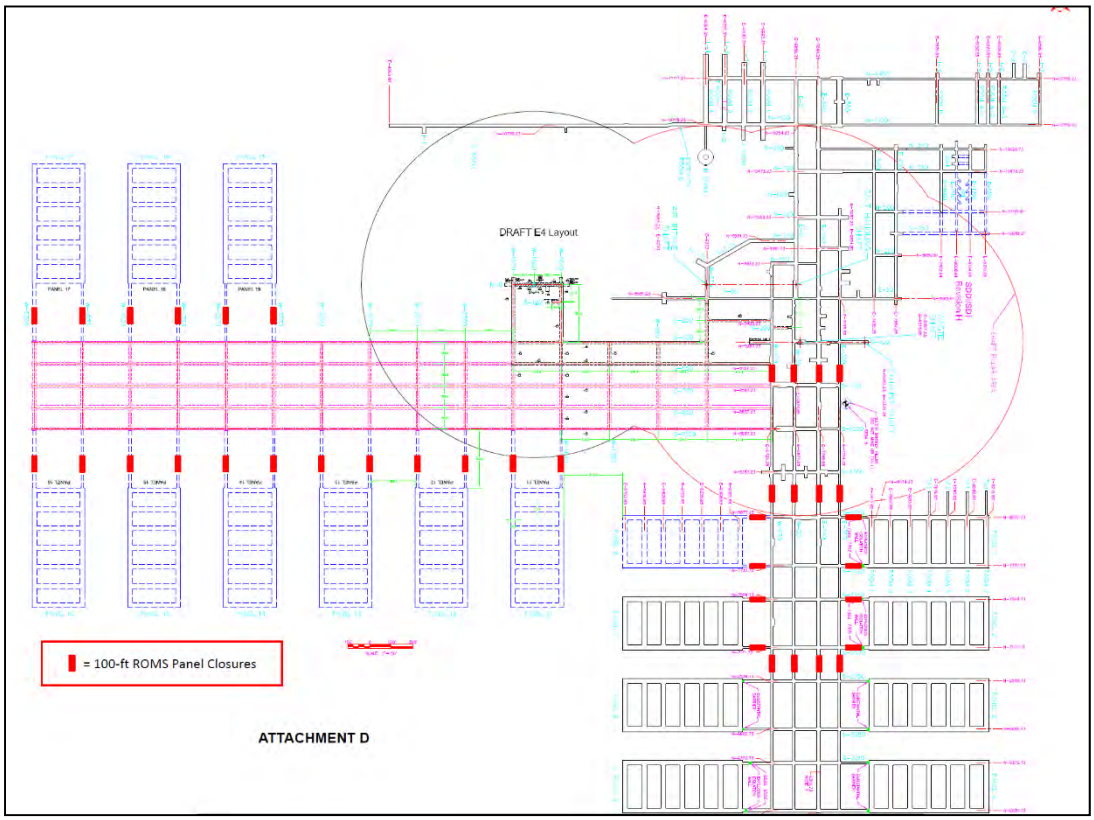


Figure 4-3. Conceptual repository layout showing the conceptual locations of the run-of-mine panel closures (red bars) in the western area.

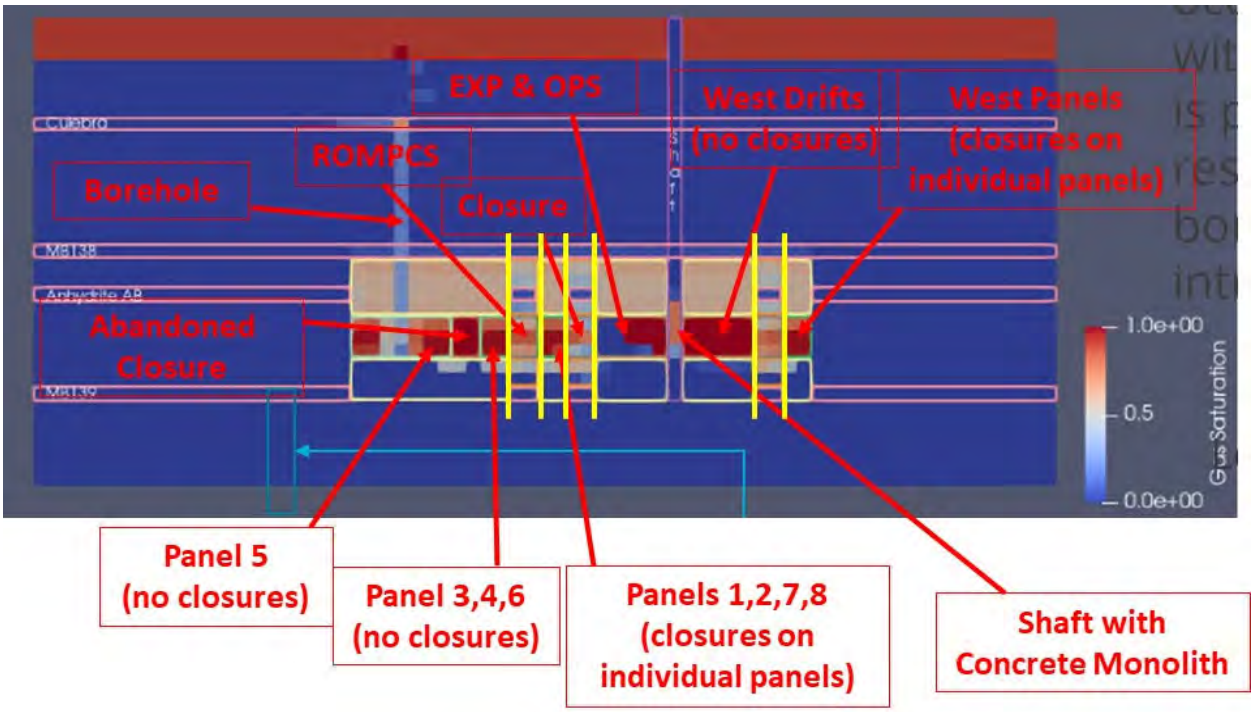


Figure 4-4. Example of Salado flow simulation using 2D BRAGFLO (Seth King, personal communication, 2021).

However, some down-dip flow probably occurs between areas not isolated by the ROMPCS, as illustrated by the accumulation of brine up-dip from closures isolating panels 1, 2, 7, and 8 from the Experimental and Operations areas in the central part of Figure 4-4 (high brine saturation is inferred from low gas saturation [blue] region in this area). The figure also shows the flow of gas up through the borehole penetrating Waste Panel 5 towards the overlying Culebra formation, as inferred from the higher gas saturation in the borehole compared with the surrounding rock. (The reader should note that the vertical yellow lines added by the Peer Review Panel are not to scale, but are simply intended to show known panel closures [ROMPCS] in the BRAGFLO model.)

If the panel closures function as expected, the ROMPCS has the effect of turning the 3D repository, including both its disturbed (excavated) zones and the overlying DRZ, into a series of cuboidal, semi-isolated regions. Compartmentalization of the repository by the ROMPCS limits lateral flow within the repository and makes the need to represent it in a 3D model less significant than it would have been had the ROMPCS been absent. These conclusions were made more quantitative with the use of the 3D PFLOTRAN code, as described further below.

The highly schematic representation of the repository elements in the 2D BRAGFLO grid either with or without Panels 11-19 included would normally make evaluation of this model difficult; however, the recent development of a truly 3D representation of the future expanded repository using the highly parallelized PFLOTRAN code provided an independent basis for evaluating the abstractions that were necessary when using the 2D BRAGFLO code (Figure 4-5).

The favorable comparisons of the distributions of gas saturation and brine pressure calculated for different repository features with the 2D BRAGFLO and 3D PFLOTRAN models supports the conclusion that the simplifications in the 2D BRAGFLO model are adequate to approximate the gas and brine flow system behavior. Gas saturation and brine pressure provided appropriate metrics for comparing the two models, since these were shown to have a dominant impact on spalling and direct brine release volumes, both of which were shown to be processes contributing significantly to overall radionuclide release during the regulatory period. PFLOTRAN does not simulate the actual flow into the borehole(s) that connect with the overlying Culebra Formation, but the brine and gas pressures that contribute to this process are calculated as a function of time. The more detailed 3D PFLOTRAN model also provided corroboration that the lumping of waste panels into generalized repository areas in the 2D BRAGFLO model did not overlook the significant variations among pressures and saturations within individual panels. The 3D PFLOTRAN model also established that locating a single representative waste panel in Panel 5 in the southern, down-dip end of the repository was an appropriately conservative assumption.



Figure 4-5. Mapping of features in the PFLOTRAN grid onto the BRAGFLO grid.

Validity of Assumptions

The primary assumption employed in the APPA that was not included in the CRA-2019 PA is that the new L-shaped repository layout that results when the western waste-panels (11-19) are added can be "unfolded" and projected onto a modified 2D BRAGFLO grid. And, that the unfolding can be implemented without sacrificing the ability of the model to accurately represent gas saturations and brine pressures, which affect radionuclide releases associated with flow to the overlying Culebra Formation through borehole(s), waste spalling, and direct brine releases, if and when the repository is penetrated by an intrusion borehole. The relatively low impact of the 3D geometry is apparent from the fact that panel closures limit lateral migration of brine and gas within the repository, so the effects of the added western panels is likely to be largely a result of the increased footprint of the repository. The assumption was corroborated by comparing gas saturations and brine pressures in different repository areas calculated from the modified 2D BRAGFLO model with gas saturations and brine pressures calculated with the 3D PFLOTRAN model. The successful comparison supports the representation of the L-shaped repository layout in the 2D BRAGFLO grid used in the APPA analysis.

A second significant assumption in the APPA performance assessment is that it is not necessary to consider borehole intrusion scenarios in the Experimental and Operations areas because they lack solid waste and the panel closures in place and/or planned will significantly limit the flow of brine from adjacent waste panels. As noted by Todd Zeitler in his response to a query/comment from the EPA,

> "…the justification for not including boreholes into these areas in PA compliance calculations has not previously been tied to the regional dip applied in the Salado flow grid, but instead relied on the: 1) lack of potential releases due to cuttings, cavings, or spallings due to no solid waste in those areas; 2) relatively low volume of contaminated brine that is expected to migrate through the panel closures into those areas from the waste disposal area; and 3) the dilution of radionuclide concentrations in the contaminated brine from mixing with uncontaminated brine in those areas (Wilson et al., 1996, DOE 2015). The expectation of low brine migration across panel closures is attributed to the low permeability of the run-of-mine panel closures (ROMPCS) (DOE 2014 Appendix PA, EPA 2017)."

The Peer Review Panel considers these arguments to be reasonable assuming the ROMPCS behave as expected.

Alternate Interpretations

An alternate interpretation is that the 2D BRAGFLO grid cannot adequately represent important three-dimensional processes affecting the flow of gas and brine near the expanded repository. This was demonstrated not to be the case by the successful comparison of the 2D BRAGFLO and 3D PFLOTRAN models. A second alternative conceptual model that investigated the use of two independent 2D BRAGFLO models–one investigating the original 10 waste emplacement panels and the second investigating the western waste emplacement panels–was found to be unsatisfactory because it neglected flow interactions between the two areas.

If it is assumed that the ROMPCS is more permeable than expected, or if the DRZ above the panel closures remains permeable for longer than expected, some contaminated brine from the western panels could find its way into the Experimental and Operations areas. However, the Peer Review Panel does not believe that the inclusion of the DBR scenario for the Experimental and Operations areas is necessary because cuttings and cavings have typically dominated radionuclide releases when borehole intrusions occur and radionuclide concentrations in the Experimental and Operations areas are expected to be much lower than in the waste panels, as noted in the quote from T. Zeitler presented above.

Uncertainty of Results and Consequences, if Incorrect

The highly abstract nature of the 2D BRAGFLO model would ordinarily make it difficult to characterize the uncertainty or error associated with the dimensionality and other simplifications of the model. What the 2D BRAGFLO model captures, however, is the isolation of various compartments within the repository as a result of the placement of closures (or ROMPCS). In addition, the successful comparison of the gas saturations and brine pressures generated by the 2D BRAGFLO model with those of the high-fidelity 3D PFLOTRAN model suggests that those uncertainties and the potential errors in the BRAGFLO model are acceptably small, especially in light of the much larger uncertainty of outcomes that result from the random sampling of uncertain model parameters.

If contaminated brine from the western waste panels does reach the Experimental and Operations areas because the ROMPCS does not perform as expected, ignoring borehole intrusion scenarios in the Experimental and Operations areas could result in an underestimation of radionuclide release. However, expected dilution of contaminated brine by uncontaminated brine is expected to make DBR contributions from these areas to overall radionuclide release relatively small compared to brine in the waste panel areas where waste cuttings and spalling also contribute to radionuclide release.

Appropriateness and Limitations of Methodology and Procedures

The APPA analysis appropriately includes FEPs that could potentially affect radionuclide releases either to the ground surface or to subsurface areas beyond the LWB. Most model parameters are randomly sampled from parameter distributions developed from experimental or observational data collected from the WIPP site (EPA, 2017). Since it is known that the physical system will evolve due to salt creep and gas generation, many of the sampled model parameters are time-dependent. Salt creep affects both the performance of the closures (ROMPCS) and the inflow of brine into individual panels from the overlying DRZ. Gas generation rates affect the pressurization of the system, which can affect direct brine release, but also flow through the borehole into the overlying Culebra formation.

Three replicate sets of 100 randomly sampled parameter vectors are generated in a way that preserves the correlations among parameters or time-dependencies associated with the physical processes. For each parameter vector, 10,000 alternative futures are considered in which drilling intrusions are randomly distributed in time and space. The impact of the drilling intrusion in terms of the release of radioactivity from direct brine release is determined by interpolation of results from pre-calculated drilling intrusion scenarios using the gas saturation and brine pressures calculated by the BRAGFLO model. The 10,000 different alternative futures allow the creation of a complementary cumulative distribution function for each parameter vector that covers a range of probabilities between 1 and 10^4. The mean normalized radioactive release (in EPA units) is calculated for each of the three replicates by averaging the radioactive releases at a given probability across parameter vectors and comparing the mean to the regulatory limits specified by the EPA in 40 CFR 194. The process is repeated for each of the 3 replicates of 100 parameter vectors to help characterize the statistical uncertainty in the mean release curves. The methodology is adequate to address the EPA safety criteria that govern operation of the WIPP facility (less than a 0.1 probability that more than one EPA unit [10^{-4} of the total radioactive inventory at closure, in Curies] and less than a 0.001 probability that ten or more EPA units will be released over the next 10,000 years). The WIPP-specific regulatory requirements listed in 40 CFR 194 do not stipulate limits on radioactive exposure to individuals, aqueous radionuclide concentrations, or the timing of the releases.

Adequacy of Application

The adequacy of the 2D BRAGFLO model for representing an expanded repository footprint that includes future waste emplacement Panels 11-19 in the currently undeveloped western part of the repository area, along with existing waste Panels 1-10, was corroborated using a high-resolution 3D PFLOTRAN model. In the PFLOTRAN model, known spatial relationships among the panels

and dip of the repository floor (approximately 1º S) were preserved exactly, and variability in gas saturations and brine pressures in waste panels that were lumped together in the 2D BRAGFLO model could be examined to determine if important differences among panels were being overlooked in the BRAGFLO model. The consistent means and ranges in gas saturations and brine pressures calculated by the BRAGFLO and PFLOTRAN models, along with the relative uniformity of mean gas saturations and brine pressures among panels that were averaged together in the simpler BRAGFLO model, demonstrates the adequacy of the BRAGFLO results.

Accuracy of Calculations

The accuracy of the calculations depends not only on the numerical accuracy of the BRAGFLO code, but also on the representation and accuracy of the many FEPs in the APPA that could affect radionuclide releases, and on the assumption that rock properties used in the CRA-2019 PA for waste Panels 1-10 do not change in the undeveloped western part of the repository area included in the APPA. The representation of FEPs did not change between the APPA and CRA-2019 PA models, so the sub-models and their parameters are not part of this review. However, given the probabilistic nature of both the CRA-2019 PA and the APPA analyses and the abstracted nature of the FEPs that need to be captured in a stochastic framework, it is reasonable to expect trade-offs occurred between model accuracy and the computational efficiency necessary to consider uncertainty in parameter space. It is also expected that if and when the area that will host the western panels is developed, any significant changes in the stratigraphy and rock properties relative to the existing waste panel areas will be characterized and updates to parameters in future PA analyses will be made. Lastly, it is not expected that numerical accuracy of the BRAGFLO code is a significant issue in the APPA analysis, especially in light of the large variations in model output that result from uncertainty in the input parameters, and the dominance of FEPs unrelated to BRAGFLO involving human intrusion scenarios on overall releases from the repository. The latest BRAGFLO user manual (Day, 2019) describes options for controlling the time-step size and numerical accuracy of the calculations. Information provided to the Peer Review Panel by SNL staff (King, LaForce, and Feng, 2021) describes how convergence tolerances, time-step controls, and solver options were set to ensure numerical accuracy, and how departures from the optimal parameters were made in the relatively rare instances when the BRAGFLO solutions failed to converge.

Validity of Conclusions

The successful comparison between the flared 2D BRAGFLO and 3D PFLOTRAN flow model results for gas saturation, brine pressure, and flow up or down intrusion boreholes under different intrusion scenarios demonstrated that the unbending of the repository in the flared 2D BRAGFLO model was an acceptable simplification of the actual repository geometry. Given the isolation of the various compartments within the repository by the ROMPCS, this conclusion might have been reached even without a comparison with a fully 3D model, particularly since panel volumes and distances were preserved rigorously in the 2D BRAGFLO model. A comparison of the more detailed variability in gas saturations and brine pressures in different panels calculated with PFLOTRAN with the lumped responses for different repository areas calculated by BRAGFLO further demonstrated that the lumping of panels in the BRAGFLO model did not neglect any significant variability among individual waste panels. The overall conclusion that the simpler

flared 2D BRAGFLO model used in the APPA analyses is adequate for calculating radionuclide releases from an expanded repository that includes future waste panels 11-19 is supported by the BRAGFLO-PFLOTRAN comparison.

Adequacy of Requirements and Criteria in Accordance with Approved Technical and QA Requirements and the Applicable Peer Review Plan(s)

The peer review of the APPA Changed Repository Fluid Flow conceptual model was conducted according to the requirements of 40 CFR §194.27, which states that peer reviews must follow the guidelines of NUREG 1297, *Peer Review for High-Level Nuclear Waste Repositories.* The requirements were implemented in the DOE CBFO's MP 10.5. These requirements and criteria are adequate and in accordance with the approved technical and QA requirements imposed by applicable plans and procedures.

Conclusions Reached by the Peer Review Panel

The overall conclusion reached by the APPA Changed Conceptual Models Peer Review Panel is that the flared 2D BRAGFLO model used in the APPA is adequate for calculating radionuclide releases from existing waste emplacement Panels 1-10 and potential future waste emplacement Panels 11-19 in the currently undeveloped western area of the repository.

This above statement is subject to the following constraints:

(1) The nature of the waste stream in Panels 11-19 does not significantly differ from that already emplaced in Panels 1-10, and

(2) The hydro stratigraphy and rock properties in the relatively unexplored western repository area are similar those that exist in the vicinity of Panels 1-10.

It is expected that any changes in the waste stream or in the rock properties in the western repository area would be reflected in future PAs when these become better understood.

4.3 Direct Brine Release

Direct Brine Release refers to the probability that brine containing actinides may flow from the waste panels up a borehole to the surface during an inadvertent human intrusion drilling event. In general, the important features of the DBR grid are retained in the APPA DBR grid; however, the change to modeling only a subsection of the waste area is a shift in the conceptual model.

A DBR requires conditions of sufficient repository brine pressure and saturation. For a DBR to occur, the brine pressure in the intruded waste panel would need to exceed 8 MPa, which is the static pressure exerted by a column of drilling fluid at the repository depth (Bethune, 2019). The brine saturation in the intruded waste panel would also need to be above the residual brine saturation for the brine to be mobile and flow up the borehole. Direct brine releases are an important part of the overall PA because they dominate the CCDF total actinide release at the lower probability/higher release range.

A DBR is simulated in the PA as a short-term event lasting between 3 and 4.5 days, depending on the computed gas flow rate up the borehole. If the computed gas flow rate is less than 100 Mscf/day (2832 m^3/d) the brine release is terminated after 3 days; otherwise, the brine release continues for a total of 4.5 days (King, 2021c). The brine volume released during a DBR is calculated using the BRAGFLO-DBR model, which is separate from the BRAGFLO Salado Flow model. This modeling approach is appropriate due to the much shorter time period of interest in a DBR event (days) compared to the overall Salado Flow behavior (10,000 years), and due to the higher spatial resolution needed to resolve brine and gas flow near the intruding wellbore. The BRAGFLO-DBR model is linked to the BRAGFLO Salado Flow model by using the relevant BRAGFLO Salado Flow model pressures and brine saturations as initial conditions for a given scenario.

The methodology used to simulate DBRs in the APPA is similar to that used in previous performance assessments, going back to 1996 (Stoelzel and O'Brien, 1996). The BRAGFLO-DBR model uses a 2D near horizontal model with 1° dip from north to south. Past BRAGFLO-DBR models have used a model domain that was slightly larger than the waste Panels 1-10 in the repository, and the model was scaled to match the repository volume in the waste area (Stoelzel and O'Brien, 1996; Bethune, 2019). These previous BRAGFLO-DBR models have discretized the waste area including the salt pillars, rooms, panel seals, and passageways. A DRZ borders each waste panel, with a no-flow boundary extending around the exterior of the model. These features of the DBR numerical grid are retained in the APPA DBR grid; however, a conceptual model change has been made to account for new waste areas while using a numerical grid that is similar to past BRAGFLO-DBR grids. Figure 4-6 shows the APPA BRAGFLO-DBR grid.

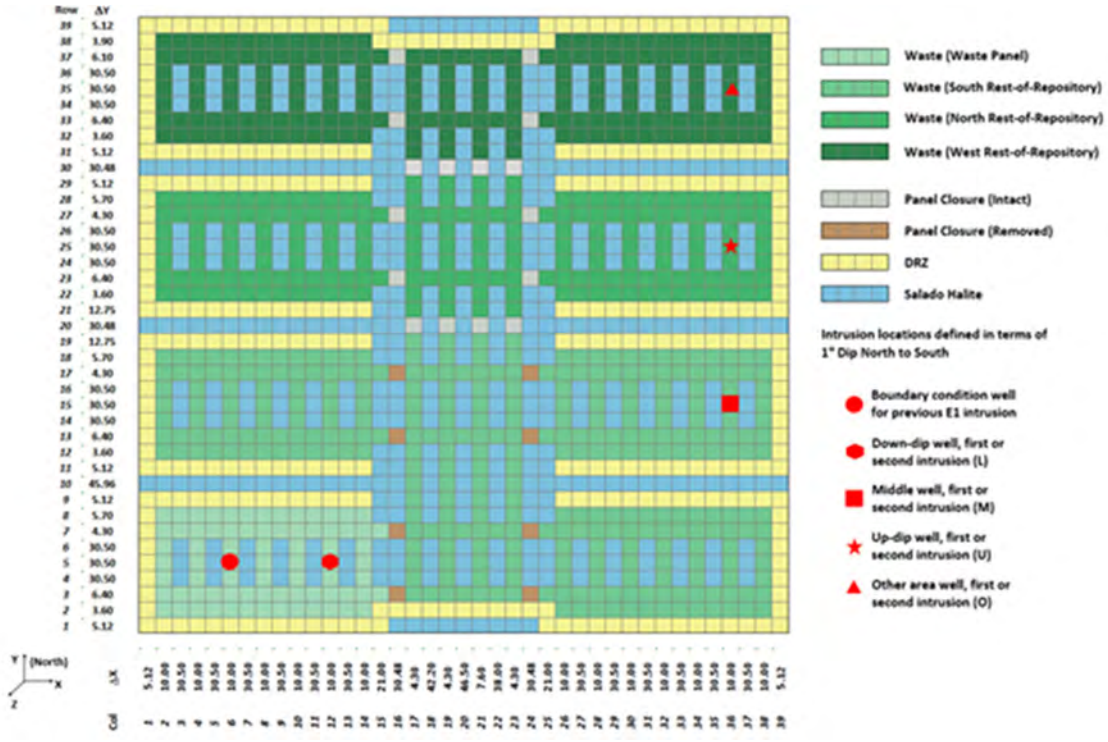


Figure 4-6. APPA BRAGFLO-DBR numerical grid

The DBR modeling process uses one of five BRAGFLO Salado Flow model scenarios to provide initial (and in some cases well boundary) conditions in the waste panels. Scenario S1-DBR is an undisturbed repository with a DBR model intrusion at 100, 350, 1,000, 3,000, 5,000, or 10,000 years. This scenario generally does not result in many non-zero brine releases. Scenario S2-DBR simulates an initial E1 intrusion that encounters a pressurized brine reservoir at 350 years (BRAGFLO-Salado Flow model) followed by a DBR model intrusion at 550, 750, 2,000, 4,000, or 10,000 years. Scenario S3-DBR is similar to S2-DBR, but the E1 intrusion occurs at 1,000 years, and the subsequent DBR model intrusion occurs at 1,200, 1,400, 3,000, 5,000, or 10,000 years. The S4-DBR and S5-DBR scenarios involve an E2 intrusion that does not encounter a pressurized brine pocket, followed by a subsequent DBR intrusion. The S4-DBR and S5-DBR scenarios do not result in a high probability of a non-zero DBR release. The S2-DBR and S3-DBR scenarios are far more likely to produce non-zero brine releases than the other scenarios, and the mean volume of the non-zero brine releases is larger than the other scenarios (Bethune, 2019; King, 2021d).

For scenario S1-DBR in the APPA, a single intrusion (DBR) occurs in one of the 19 panels. For scenarios S2-DBR − S5-DBR, an initial E1 or E2 type intrusion randomly occurs in one of the 19 panels. In these scenarios, a second DBR intrusion occurs randomly in one of the 19 panels. This second intrusion may occur in the same panel as the initial E1 or E2 intrusion. If the initial E1 or E2 intrusion occurred in panels 3, 4, 5, 6, or 9, then a subsequent DBR intrusion into one of these panels (but not the same panel) is characterized as a “Connected” intrusion (Table 4-1). If the second intrusion is not in the same or a connected panel, but in the same repository area (either south Panels 1-10 or west Panels 11-19), then it is characterized as an “Adjacent” intrusion (Table 4-1). If the second intrusion occurs in a different repository area, then it is characterized as an “Other” intrusion. Once the DBR intrusions have been classified as “Same,” “Connected,” “Adjacent,” or “Other,” the BRAGFLO-DBR simulation is performed using set representative locations for each of these categories of intrusions.

Table 4-1 – Panel neighbors in the APPA, from Hansen (2020)

Intruded Panel	Intrusion Probability	Connected Panels	Adjacent Panels
1	0.053662264	-	2 through 10
2	0.053662264	-	1, 3 through 10
3	0.053662264	4, 5, 6, 9	1, 2, 7, 8, 10
4	0.053662264	3, 5, 6, 9	1, 2, 7, 8, 10
5	0.053662264	3, 4, 6, 9	1, 2, 7, 8, 10
6	0.053662264	3, 4, 5, 9	1, 2, 7, 8, 10
7	0.053662264	-	1 – 6, 8, 9, 10
8	0.053662264	-	1 – 7, 9, 10
9	0.042154636	3, 4, 5, 6	1, 2, 7, 8, 10
10	0.045586876	-	1 through 9
11	0.053662264	-	12 – 19
12	0.053662264	-	11, 13 – 19
13	0.053662264	-	11 – 12, 14 – 19
14	0.053662264	-	11 – 13, 15 – 19
15	0.053662264	-	11 – 14, 16 – 19
16	0.053662264	-	11 – 15, 17 – 19
17	0.053662264	-	11 – 16, 18 – 19
18	0.053662264	-	11 – 17, 19
19	0.053662264	-	11 – 18

The APPA BRAGLFO DBR model considers borehole intrusions in one of five locations, as illustrated in Figure 4-3. The lower left borehole (red circle) is a boundary condition well used to simulate the effect of a previous E1 or E2 intrusion for modeling scenarios S2-S5. The borehole immediately to the right of the boundary condition well (red hexagon) is known as the down-dip or lower well for scenario S1, and it is used for an intrusion into the same panel as the initial E1 or E2 intrusion for scenarios S2 through S5.

The lower right borehole (red square) is called the middle well for scenario S1, and it is used for a second intrusion into a connected panel for scenarios S2 through S5. The borehole location shown by the red star represents an up-dip, or upper intrusion location for scenario S1, and it is used in scenarios S2 through S5 to represent a second intrusion into a panel that is adjacent to the initial E1 or E2 intrusion. The upper right borehole location (red triangle) is referred to as an "Other" location for an initial intrusion in scenario S1, and it is used to represent a second intrusion in scenarios S2 through S4 into a panel that is nonadjacent to the panel where the initial E1 or E2 intrusion occurred. Nonadjacent means that the second intrusion is not in the same group of panels (1-10 or 11-19) as the initial intrusion.

The most recent CRA to receive regulatory approval is the 2014 CRA (CRA-2014). The CRA-2014 used a BRAGFLO-DBR numerical grid similar to the APPA grid (Figure 4-3), but Panels 1-10 were explicitly represented in the model, with intact panel closures separating each waste panel from other areas. The 2014 radiological incident at the repository later resulted in an

operational decision to not emplace panel closures in panels 3, 4, 5, and 6 (the lowest 4 panels in Figure 4-3).

The 2014 BRAGFLO-DBR model was modified for the 2019 CRA (CRA-2019) to reflect the absence of the panel closures in Panels 3, 4, 5, and 6. That modification of the CRA-2014 approach is also used in the APPA DBR model. The primary effect of removing the panel closures is that now Panels 3, 4, 5, 6, and 9 are hydraulically connected to each other. In the event of an E1 intrusion into any one of these five panels, pressurized brine from the underlying brine reservoir in the Castile formation could increase the brine pressure and saturation in all these connected panels. The larger number of connected panels increases the chances that a subsequent borehole intrusion would encounter a pressurized panel with high brine saturation, leading to a DBR. The larger volume of the pressurized zone also leads to larger DBR releases for a subsequent borehole intrusion into the same panel as the initial E1 intrusion.

DBR results presented by Bethume (2019) show that removal of the panel closures in CRA-2019 leads to a higher non-zero brine release vector fraction, and to higher mean non-zero brine volumes compared to CRA-2014. This occurs in the two E1 intrusion scenarios S2 and S3, for second intrusions in the same and in adjacent panels. The increase in the fraction of non-zero brine releases for second intrusions in the same panel are relatively small, but the mean brine volume is substantially larger in CRA-2019. This increase in the DBR brine volume is likely due to the larger repository volume that is pressurized and connected to the representative well in Panel 5. The direct brine release is essentially a depressurization of the intruded panel, with little communication with other panels unless they are connected. The decision to place the representative E1 well in Panel 5, and to use this panel for subsequent DBR intrusions into the same panel, appears to be conservative due to the larger pressurized volume of the connected panels compared to a single panel that is isolated by panel closures.

There was a large increase in the fraction of vectors with non-zero brine release rates between CRA-2019 and CRA-2014 for second intrusions into the middle borehole location. In CRA-2014, the middle location is isolated from the E1 intrusion in Panel 5 by panel closures, while in CRA-2019, the middle location is now connected to Panel 5. Second intrusions into connected panels tend to act in a way that is like a second intrusion into the same panel as the initial intrusion, leading to more frequent and larger DBR occurrence and brine volume.

The APPA BRAGFLO-DBR model grid is similar to the CRA-2019 and previous DBR grids, but conceptually it takes a different approach. The APPA DBR grid now represents not only the original Panels 1-10, but also the additional Panels 11-19 in the west area. Past DBR grids modeled the entire waste volume, but in the APPA, only part of the extended repository area (panels 11-19) is included, and represented by two panels, and waste Panels 1, 2, 7, 8, and 10 have been consolidated into two panels. Referring to Figure 4-3, the bottom 19 rows of the DBR model remain unchanged from the CRA-2019 model. Rows 20-30 now represent the NRoR, or Panels 1, 2, 7, 8, and 10. This area is separated by panel closures (row 30) from the remaining rows 30-39, which represent the WRoR, or Panels 11-19. The lower (same) and middle (connected) representative DBR intrusion locations remain the same as in the CRA-2019 model, but the upper (adjacent) intrusion location has been moved from Panel 10 to column 36 near the eastern part of the panel. A new (other) DBR intrusion location has been added near the north

end of the model to represent initial DBR intrusions into the WRoR, or second intrusions into a panel that is nonadjacent to a previous E1 or E2 intrusion.

This conceptual change to the DBR modeling approach appears to be reasonable and adequate given the short duration of DBR events, which result in little hydraulic communication across panel closures. King (2021c) presented an alternative DBR modeling approach for the APPA where two DBR grids are used. With this approach, the first grid represents the current repository Panels 1-10 as in the CRA-2019. The additional 9 panels in the west repository area are simulated using a separate grid that explicitly represents the panel geometries including panel closures and drifts. These models preserve the volume relationships of the two repository areas, and the two grids were not connected to each other. The two-grid approach was compared to the APPA and showed little difference. A comparison of the release volume frequency for all non-zero releases shows practically identical results over the range of release volume. Based on this comparison, and on the characteristics of a DBR, the geometrical approach used in the APPA is reasonable.

The APPA DBR results are similar to the CRA-2019 results. The APPA has more DBR events with brine volumes less than 40 m^3 than the CRA-2019. This difference is attributed to the additional category of "other" releases from nonadjacent panels, and to the general increase in brine saturation in most areas of the repository from the BRAGFLO Salado Flow model (King, 2021c, d). The increased brine saturation increases the probability of exceeding the residual brine saturation necessary for a DBR. The mean and maximum DBR volumes from the APPA are somewhat lower than from the CRA-2019. King (2021c, d) attributes this decreased volume to lower maximum pressures in the repository from the APPA Salado Flow model. Overall, the new conceptualization used in the APPA to simulate direct brine releases is reasonable, and consistent with past PA approaches.

Validity of Assumptions

The main assumption made in the APPA that was not a part of previous CRA-2019 PA is that the new west part of the repository (Panels 11-19) can be represented in a single DBR grid without preserving volume relationships. While this is a departure from past conceptual approaches, the short duration of a DBR event limits its influence mainly to a single panel, or to a group of panels that are connected to each other. The validity of this assumption was demonstrated by simulations using a two-model approach with separate models for the 10-panel south repository and the 9-panel west repository. The results from that study were practically indistinguishable from the APPA DBR results.

Alternate Interpretations

An alternate interpretation is that the APPA conceptualization used in the DBR model cannot reliably represent the 9-panel west repository. This alternate interpretation was shown to not be true by the successful comparison of the APPA DBR results with a two-model approach that simulated both the 10-panel south repository and the 9-panel west repository.

Uncertainty of Results and Consequences, if Incorrect

In general, the important features of the DBR grid from past performance assessments are retained in the APPA DBR grid. The change to modeling only a subsection of the waste area is a shift in the conceptual model. The effects of a DBR on the flow, pressure, and brine saturation are limited to a single waste panel, or group of connected waste panels, due to the short duration of the DBR event. Any influence from adjacent or nonadjacent waste panels that are separated by panel closures is expected to be minor, so the uncertainty of results and consequences of this change in the conceptual model, if incorrect, are not expected to be significant.

Appropriateness and Limitations of Methodology and Procedures

The methodology and procedures used in the APPA follow from BRAGFLO-DBR modeling approaches that have been used in multiple performance assessments since 1996. These use reasonable and accepted numerical approaches for calculating flow from a well using a productivity index well deliverability model within a multiphase flow model. The change in the conceptual model used for the APPA DBR calculation does not alter the basic methodology and procedures from those used in the previous performance assessments. The methodology is adequate to address the EPA safety criteria that govern operation of the WIPP facility.

Adequacy of Application

The approximations used in the APPA BRAGFLO-DBR model are adequate for this application. Unlike previous DBR models, which simulated the full volume of the waste panels, the APPA uses a different conceptual approach, where only some of the waste panels are directly simulated. This is justified by the short time scale of a DBR where pressures and brine saturations are mainly affected in the intruded waste panel itself, or in nearby connected panels. A comparison of the APPA approach with a two-model approach that simulated the full volume of the waste panels showed little difference between the two approaches.

Accuracy of Calculations

The accuracy of the calculations depends on the numerical accuracy of the solution process in the BRAGFLO code, and on the spatial and temporal discretization. The latest BRAGFLO user manual (Day, 2019) describes options for controlling the time-step size and numerical accuracy of the calculations. Information provided to the Peer Review Panel by SNL staff (King, LaForce, and Feng, 2021) describes how convergence tolerances, time-step controls, and solver options were set to ensure numerical accuracy, and how departures from the optimal parameters were made in the relatively rare instances when the BRAGFLO solutions failed to converge.

At the request of the Peer Review Panel, King (2021e) performed an analysis of refining the numerical grid around the intruding wellbore. The results produced using the finer numerical grid were close to the APPA results. The fraction of vectors with non-zero releases was identical between the two sets of simulations, and there were only minor differences in the mean brine volumes released. This comparison shows that the grid resolution used in the APPA is adequate with respect to the accuracy of calculations.

Validity of Conclusions

The successful comparison of the two-model DBR simulation approach to the APPA approach demonstrates the DBR conceptual model used in the APPA for direct brine releases is acceptable. Overall, the results of the APPA have relatively small changes from the previous CRA-2019 DBR evaluation. The APPA has more small non-zero DBR releases than the CRA-2019 analysis, due in part to the additional repository area, and due in part to higher brine saturations in the repository predicted by the BRAGFLO Salado Flow model. The APPA has fewer large brine releases compared to the CRA-2019 due to lower maximum pressures in the APPA BRAGFLO Salado Flow model.

Adequacy of Requirements and Criteria in Accordance with Approved Technical and QA Requirements and the Applicable Peer Review Plan(s)

The peer review of the APPA Changed Direct Brine Release conceptual model was conducted according to the requirements of 40 CFR §194.27, which states that peer reviews must follow the guidelines of NUREG 1297, *Peer Review for High-Level Nuclear Waste Repositories.* The requirements were implemented in the DOE CBFO's MP 10.5. These requirements and criteria are adequate and in accordance with the approved technical and QA requirements imposed by applicable plans and procedures.

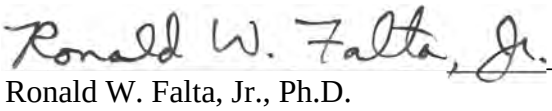
Conclusions Reached by the Peer Review Panel

The conclusion reached by the APPA Conceptual Models Change Peer Review Panel is that the APPA representation of the waste panels in the DBR model is adequate for calculating radionuclide releases from direct brine releases from existing waste Panels 1-10, and from potential future waste Panels 11-19. Although the APPA model does not explicitly represent all the panels, it has been demonstrated that it represents them in a way that preserves the probability and impact of first and second intrusions into any waste panel.

5.0 DISSENTING VIEWS

There are no dissenting views expressed by members of the Peer Review Panel.

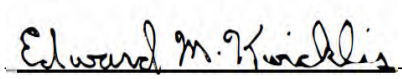
6.0 SIGNATURES OF PEER REVIEW PANEL MEMBERS



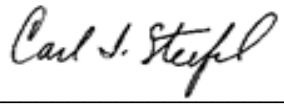
Ronald W. Falta, Jr., Ph.D. — 12/1/2021 Date



Mengsu Hu, Ph.D. — 12/1/2021 Date



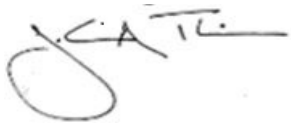
Edward M. Kwicklis, M.S. — 12/1/2021 Date



Carl I. Steefel, Ph.D. — 12/1/2021 Date



Sherilyn C. Williams-Stroud, Ph.D., P.G. — 11/30/2021 Date



John A. Thies, B.S. — 11/30/2021 Date

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8.0 LIST OF APPENDICES

Appendix A - Peer Review Panel Chairperson Qualification Documents

Appendix B - Peer Review Plan and Peer Review Procedure

Appendix C - Peer Review Panel Member Qualification and Selection Documentation

Appendix D - Acquisition Documents - (North Wind declined the Peer Review Panel Chairperson’s request for redacted copies of the pertinent acquisition documents)

Waste Isolation Pilot Plant
Additional Panels Performance Assessment
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December 2021

APPENDIX A

Peer Review Panel Chairperson Qualification Documents

Context

John Thies served as the Chairperson for the APPA Changed Conceptual Models Peer Review. He was selected based on his qualifications and experience. He has verifiable technical credentials and experience in the management of peer reviews, modeling, and performance assessment. He has not been involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed, and he is not influenced by funding considerations, which ensures his impartially related to the work reviewed. As the Peer review chairperson Mr. Thies confirmed that the peer review evaluation considered relevant data, models, and methods, and that the evaluation was conducted objectively and without bias.

Mr. Thies has 30+ years of experience managing and contributing to large nuclear projects. His experience spans a range of technical and management activities including nuclear safety, security and environmental compliance; design and construction; and decommissioning and waste management. He has a successful history of completing projects on schedule and within budget. He has worked with the Nuclear Regulatory Commission (NRC); Environmental Protection Agency (EPA); multiple Department of Energy (DOE) organizations, including Environmental Management (EM) and the National Nuclear Security Administration (NNSA); the U.S. Navy; and multiple state governments. Mr. Thies has extensive experience in the assessment of projects for quality, regulatory, and safety compliance; operational readiness; and cost and schedule performance. He has worked with Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), and Sandia National Laboratories (SNL) on technical projects addressing new technology applications, nuclear waste management, and strategic materials production. He has demonstrated success working with both management and technical staff on complex projects involving stringent quality assurance, tight budgets, multiple government and public interfaces, and aggressive schedules.

2008 to Present, Consultant, Various Locations

- Serves as a subject matter expert for nuclear projects.

1996 to 2008, Founder and President of Time Solutions Corp (TSC), Albuquerque, NM

- Worked with government and industry to resolve technical issues involving nuclear safety, security, quality, cost, and schedule performance.
- Served as Program Manager for two blanket purchase agreements (BPAs); one being for Technical, Engineering and Professional Services (TEPS) and the other being for Management, Organizational, and Administrative (MOA) Services supporting the NNSA.
- Managed independent technical reviews (in accordance with NUREG 1298) of the field and laboratory data assembled by SNL to support the Waste Isolation Pilot Plant (WIPP) compliance certification application (CCA) submittal to the EPA. Managed peer reviews of the site waste isolation performance models. As WIPP Peer Review Manager, his responsibilities included hiring and managing subject matter experts from academia and industry to serve as peer reviewers for the recertification of WIPP (in accordance with NUREG 1297). Mr. Thies was under contract to the Department of Energy via the WIPP Carlsbad Technical Assistance Contractor (CTAC) and interfaced with the EPA, State of New Mexico, National Academy of Sciences, DOE National Laboratories, and concerned citizens to successfully complete the reviews on schedule in a highly regulated environment.
- Evaluated DOE technical and management alternatives at various DOE facilities.

- Served on external independent review (EIR) teams for the DOE evaluating cost, schedule, and technical performance of large DOE nuclear projects.
- Supported the Pantex Plant by performing hazard assessments, dispositioning USQs for nuclear operations, and performing safety analyses. Qualified as a Pantex certified safety analyst.
- Supported LANL with implementation of several large nuclear projects. Qualified as a LANL certified safety analyst.
- Supported SNL in the areas of Price Anderson and Nuclear Quality Assurance (NQA-1 and QC-1).

1994 to 1996, Consultant, Albuquerque, NM

- Assisted ICF Kaiser at LANL with preparation of a plutonium salt distillation conceptual design report for Rocky Flats. Assisted Fluor Daniel Hanford (FDH) with the Plutonium Reclamation Facility (PRF) explosion incident response by managing all aspects of the project from technical safety evaluations to quality assurance and records management. As a result of his work on PRF, he supported the FDH Price Anderson Amendments Act (PAAA) response to EH-10 and he served as one of the principal authors of the FDH site-wide quality improvement plan.

1992 to 1994, Advanced Sciences Inc. (ASI), Albuquerque, NM

- Served as Project Manager for the Technical Assistance Contract for the WIPP Site.

1988 to 1992, MAC Technical Services Company, Richland, WA and Albuquerque, NM

- Assisted SNL with the development of the DOE National Transuranic Nuclear Waste Disposition Program.

1986 to 1988, Westinghouse Hanford Company, Richland, WA

- Served as Program Manager of the Hanford Solid Nuclear Waste Program Office.
- Served as Program Manager for the Systems Integration Program Office for the Basalt Waste Isolation Program (BWIP).

1978 to 1986, Rockwell Hanford Operations, Richland, WA

- Served as Department Manager for the BWIP Performance Assessment Department.
- Served as Project Manager for the Plutonium Finishing Plant (PFP) Safety Upgrades Project.
- Served as Group Manager for the Atomic Vapor Laser Isotope Separation (AVLIS) Systems Engineering and Integration.
- Served as Hanford Site contractor liaison supporting nuclear related NEPA compliance and waste management activities.

After leaving the U.S. Navy in 1975, Mr. Thies earned a Bachelor of Science degree in engineering-physics with a minor in mathematics from Fort Lewis College.

Environmental Compliance

- Mr. Thies served as the coordinator for the Hanford Defense Waste Environmental Impact Statement (HDW-EIS).
- Mr. Thies served as program manager for the Resource Conservation and Recovery Act Part B hazardous waste permit for the Hanford solid nuclear waste burial grounds. He interfaced with state and federal agencies, the WIPP Project, and other DOE sites and contractors to establish environmental compliance actions, budgets, and schedules to meet emerging EPA and Washington State environmental requirements.

Nuclear Safety

- Mr. Thies Mr. Thies worked with Dr. Edward Deutsch to revitalize the largest university research reactor in the United States to bring it into safety, security, and operational compliance with Nuclear Regulatory Commission requirements. MURR serves as a key U.S. nuclear research facility and as a producer of critical radio-pharmaceuticals. Mr. Thies and Dr. Deutsch focused on upgrading the physical plant safety systems and the reactor core neutron flux barrel; improvements in operating procedures, and training for operations personnel. All improvements and upgrades were completed within budget and on schedule. Mr. Thies recruited a deputy reactor plant manager for MURR. The facility is now known as a world class nuclear facility. Mr. Thies is a United States Navy qualified nuclear reactor electrical operator, engineering laboratory technician, and radiological controls monitor.
- Mr. Thies worked at the DOE Pantex Plant and LANL where he supported documentation of nuclear facility safety analysis, performed hazard assessments, and revised Authorization Basis (AB) documentation. He performed unreviewed safety question evaluations/determinations (USQE/D) (10 CFR 5059) to support nuclear explosives and nuclear material operations. He supported LANL with implementation of nuclear materials production and he is very familiar with the DOE Documented Safety Analysis and the proposed changes. He also supported the LANL EIS.
- Mr. Thies' support to Pantex and LANL required engineering expertise and knowledge of DOE AB requirements to develop and revise the DSAs; Hazard Analysis Reports (HARs), Safety Analysis Reports (SAR) and the Technical Safety Requirements (TSRs) to support the AB for facility operations. Additionally, his work required expert knowledge and experience in hazard identification, mathematical analyses, and the assessment of risk. Mr. Thies performed technical reviews, presented AB change packages to government representatives, and prepared source-term calculations and safety analyses. Mr. Thies is a certified safety analyst at both LANL and Pantex.

Nuclear Waste Management and Spent Nuclear Fuel

The following summarizes Mr. Thies' experience with nuclear waste repositories and associated waste characterization and disposal:

- Served as an independent expert for the review of Sacramento Municipal Utility District's Hardened SAFSTOR Program at the Rancho Seco Nuclear Site.
- Served as independent expert for the Army Corps of Engineers critical assessment of the Idaho National Engineering and Environmental Laboratory's (INEEL) transuranic (TRU) waste management program. Part of this review was an assessment of the Waste Isolation Pilot Plant's readiness to receive TRU waste as scheduled.
- Served as independent expert for the Army Corps of Engineers critical assessment of the INEEL high-level waste management program.
- Served as independent reviewer for the Army Corps of Engineers critical assessment of the WIPP.
- Served as subject matter expert for the WIPP waste certification readiness assessment at Hanford.
- Served as subject matter expert for the WIPP waste certification readiness assessment at LANL.
- Served as the WIPP Independent Data Review Manager for the quality assurance review of all natural barriers, engineered systems, waste characterization, waste form, and disposal room

data. These reviews were conducted in accordance with NQA-1, 2, and 3 criteria and NUREG 1298. They included review of the technical protocols used to gather and use the data.

- Served as the WIPP Peer Review Manager for qualification of all of the natural barriers, engineered systems, waste characterization, waste form, and disposal room data that could not be qualified by an approved QA program; all of the Project's Performance Assessment conceptual models; and the passive institutional controls that the Project planned to implement in support of the Compliance Certification Application (CCA) to the EPA, i.e., their license. Mr. Thies served as Peer Review Manager for the following WIPP conceptual models.
- Served as a peer reviewer for Her Majesties Inspectorate of Pollution to review Phase Two of the NIREX performance assessment for the Sellafield nuclear repository.
- Served as the Program Manager for the WIPP technical assistance contract. Provided technical and management support to the DOE. Mr. Thies was responsible for supporting DOE with all aspects of program performance including interactions with other government Departments and the public. He managed 115 administrative and technical staff providing support to the DOE WIPP Project. He assisted DOE with the development and implementation of the National TRU Waste Integration Office and was a key contributor to the strategic planning, performance assessment, and systems evaluation processes for the WIPP Project.
- Conducted audits and overviews of DOE and contractor nuclear quality assurance programs and assisted with development of design control programs.
- Planned, authorized, and controlled work scope, budgets, and schedules for technical Performance Assessment (PA), safety, systems engineering, and project planning and scheduling for site characterization phase of the Basalt Waste Isolation Project (BWIP).
- Managed a 63-member technical staff that analyzed waste isolation performance of the Basalt Waste Isolation Project. The Performance Assessment Department was responsible for determining whether the proposed repository met all applicable safety and waste isolation regulatory requirements.
- Established a system to document and qualify 113 scientific and engineering Performance Assessment computer codes to meet NUREG 0856 requirements.
- Interfaced with the DOE and national laboratories to provide input to national and international Performance Assessment planning.
- Supported development of the Spent Nuclear Fuel and High-level Waste Transportation Requirements Document for OCRWM.
- Supported Sandia National Laboratories as part of the DOE's technical advisor team with the licensing strategy for the Yucca Mountain Project.

Memo to Peer Review File
April 2021

The purpose of this memo is to address the process used to select the Peer Review Panel chairperson for the additional panels PA (APPA) Changed Conceptual Models peer review.

In accordance with the regulatory requirements specified in 40 CFR Part 191 and the criteria for the implementation of those requirements, as specified in 40 CFR Part 194, DOE is conducting a Peer Review Waste Isolation Pilot Plant (WIPP) compliance certification application. 40 CFR Part 194 provides further criteria for the utilization of peer reviews for the confirmation and determination of completeness and accuracy of data and other information.

To accomplish the requirements of the peer review and to aid the peer review panel with preparation of the peer review report, a chairperson has been selected as a technical chairperson for the remainder of the peer review.

The process used to identify and select the chairperson was to identify an individual with a clear understanding of the issues, and the leadership and interpersonal skills to coordinate and ensure that the peer review meets its technical, administrative, and regulatory repuirements. The following were used as selection criteria:

- Demonstrated grasp of the technical issues.
- Ability to focus technical evaluation and constructive technical discussion.
- Leadership and interpersonal skills.
- Ability to identify panel members individual technical expertise.
- Ability to see and understand the WIPP PA.
- Ability to comply with applicable procedural requirements.
- Excellent organizational skills.

Justification for selecting John Thies as the APPA Changed Conceptual Models Peer Review Chairperson.

- Mr. Thies has demonstrated his ability to lead and participate in peer reviews.
- He has demonstrated his ability to work as a constructive member of a highly-technical team.
- He has a broad understanding of WIPP and its associated PA.
- Mr. Thies displays good interpersonal skills which enable him to guide the panel toward consensus. This will greatly benefit the panel with preparation of a draft and final peer review report.
- Mr. Thies has displayed good organizational skills and his ability to operate within the administrative and procedural requirements imposed on the peer review process.

Tim Runyon
CTAC
03/21/21

DOE F 1325.8

United States Government **Department of Energy**

memorandum

Carlsbad Field Office
Carlsbad, New Mexico 88221

DATE: June 9, 2021

REPLY TO ATTN OF: CBFO:OEP:MRB:MC:21-0227:UFC 5486.00

SUBJECT: Peer Review Chairperson Identification and Qualification Documentation

TO: John A. Thies, APPA Changed Conceptual Models Peer Review Chairperson

The purpose of this memo is to review and concur with the process used to select the chairperson for the Additional Panels Performance Assessment (APPA) Changed Conceptual Models peer review panel.

Containment of transuranic (TRU) waste at the Waste Isolation Pilot Plant (WIPP) facility after final WIPP facility closure is regulated by the U.S. Environmental Protection Agency (EPA) according to the regulations set forth in Title 40 of the Code of Federal Regulations (CFR), Part 191, Subparts B and C. The Department of Energy (DOE) demonstrates compliance with the containment requirements in 40 CFR Part 191.13(a) according to the Certification Criteria in Title 40 CFR Part 194 by means of Performance Assessment (PA) calculations performed by Sandia National Laboratories (SNL). The WIPP PA conceptual models are used to support the repository recertification process that occurs at five-year intervals following the receipt of the first waste shipment at the site in 1999. The conceptual models are maintained and updated with new information, when needed, as part of an ongoing process. Improved information regarding important WIPP features, events, and processes can result in refinements and modifications to PA computer models and/or the parameters used in them. Planned changes to the repository and/or the components therein also result in updates to WIPP PA models.

The WIPP PA methodology uses conceptual models that represent specific features of the disposal system. The EPA regulations at 40 CFR 194.23(a)(3)(v) require that PA conceptual models be peer reviewed consistent with 40 CFR 194.27, and 24 conceptual models were peer reviewed for the original Compliance Certification Application (DOE, 1996). Historically, the EPA has also required that any "significant" changes to previously peer-reviewed conceptual models again be peer reviewed prior to approval and incorporation into the next PA compliance calculation. A PA is required to demonstrate, with a reasonable expectation, that the WIPP disposal system complies with the EPA Containment Requirements in 40 CFR 191.13(a). With regards to reasonable expectation for a PA, EPA states the following in 40 CFR 191.13(b) "Because of the long time period involved and the nature of the events and processes of interest, there will inevitably be substantial uncertainties in projecting disposal system performance. Proof of the future performance of a disposal system is not to be had in the ordinary sense of the word in situations that deal with much shorter time frames. Instead, what is required is a reasonable expectation, on the basis of the record before the implementing agency, that compliance with 40 CFR 191.13 (a) will be achieved."

The APPA uses many of the same conceptual and mathematical models for PA as were used for the Compliance Recertification Application (CRA-2019) (DOE, 2019); however, the numerical calculations will be performed using a revised grid that accounts for additional panels. In accordance with the regulatory requirements specified in 40 CFR Part 191 and the criteria for the implementation of those requirements, DOE is conducting a Peer Review (PR) to evaluate three conceptual models for use in supporting the WIPP PA.

The PR is a documented, critical review performed by peers who are independent of the work being reviewed. The peers' independence from the work being reviewed means that the peer: a) was not involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed; and b) to the extent practical, has sufficient freedom from funding considerations to assure the work is impartially reviewed.

To accomplish the requirements of the APPA Changed Conceptual Models peer review and to aid the peer review panel with preparation of the peer review report, a chairperson has been selected by the Carlsbad Technical Assistance Contractor (CTAC). The process used to identify and select the peer review panel chairperson was to identify an individual with a clear understanding of the regulatory requirements and technical issues; and an individual with the leadership and interpersonal skills to chair the panel. The following were used as selection criteria:

- Demonstrated understanding of the technical issues
- Ability to focus technical evaluation and constructive technical discussion
- Leadership and interpersonal skills
- Ability to draw upon other panel members individual technical expertise as required to support the review
- Ability to understand the relevant data and information
- Ability to comply with regulatory and procedural requirements
- Organizational skills

Justification for selecting John Thies as the peer review panel chairperson:

- Mr. Thies has demonstrated his ability to lead technical evaluations associated with WIPP conceptual models and performance assessments.
- He has demonstrated his ability to work as a constructive member of a highly technical team.
- He has a broad understanding of WIPP technical issues beyond those associated with this peer review. This allows him to serve as an integrator across a broad range of WIPP related issues.
- He is a capable manager able to draw upon the specific expertise of the other panel members as necessary to ensure the coupling and interactions between the pertinent issues, i.e., he understands the regulatory and physical environment that WIPP operates within.
- Mr. Thies displays good interpersonal skills which enables him to guide the panel toward consensus. This will greatly benefit the panel with preparation of a draft and final peer review report.
- Mr. Thies has displayed good organizational skills and his ability to operate within the administrative and procedural requirements imposed upon the peer review process.

I have reviewed the peer review chairperson identification and qualification documentation submitted to me by CTAC (see attachment) and I concur with the selection of John Thies as the APPA Changed Conceptual Models peer review chairperson.

Michael Brown Digitally signed by Michael Brown
Date: 2021.06.09 14:54:30 -06'00'

Michael R. Brown, Director
Office of Environmental Protection

Attachment

cc: w/attachment

A. Ward, CBFO	*ED
G. Basabilvazo, CBFO	ED
M. Conroy, CTAC	ED
V. Bynum, CTAC	ED
T. Runyon, CTAC	ED

APPA Peer Review File
CBFO M&RC
*ED denotes electronic distribution

Waste Isolation Pilot Plant
Additional Panels Performance Assessment
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APPENDIX B

Peer Review Plan and Peer Review Procedure

U.S. Department of Energy Carlsbad Field Office,
Additional Panels Performance Assessment (APPA) Changed Conceptual Models Peer Review Plan,
DOE/CBFO-21-3629, Rev. 0, July 2021

CBFO MP 10.5, *Peer Review*, Rev. 10, October 2018

U. S. Department of Energy
Carlsbad Field Office

Additional Panels Performance Assessment (APPA)
Changed Conceptual Models
Peer Review Plan

DOE/CBFO-21-3629

Revision 0

Effective: June 07, 2021

U. S. Department of Energy
Carlsbad Field Office

Additional Panels Performance Assessment (APPA)
Changed Conceptual Models
Peer Review Plan

DOE/CBFO-21-3629

Revision 0

Effective: June 07, 2021

Approved by: /Signature of File/ 06-03-2021
Michael R. Brown Date
Director, Office of Environmental Protection

CHANGE HISTORY SUMMARY

Revision Number	Description of Changes
0	Initial issue.

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ACRONYMS AND ABBREVIATIONS

APPA	Additional Panels Performance Assessment
CBFO	DOE Carlsbad Field Office
CCDF	complementary cumulative distribution function
CFR	Code of Federal Regulations
CRA	Compliance Recertification Application
DBR	Direct Brine Release
DOE	U. S. Department of Energy
EPA	U. S. Environmental Protection Agency
MP	Management Procedure
NRC	Nuclear Regulatory Commission
OEP	CBFO Office of Environmental Protection
OQA	CBFO Office of Quality Assurance
PA	Performance Assessment
QA	Quality Assurance
QL	Quality Level
SME	Subject Matter Expert
SNL	Sandia National Laboratories
TBD	To Be Determined
WIPP	Waste Isolation Pilot Plant

DEFINITIONS

Computational Model – The computational model is the implementation of the mathematical model (see definition of mathematical model below). Implementation may be through analytical or numerical means. Often the analytical solution is numerically evaluated (for example, numerical integration or evaluation of complex functions); hence, both solution techniques are typically coded on a computer. Consequently, the computational model is often called a computer model.

Conceptual Model – Qualitative assumptions used to describe a system or subsystem for a given purpose. At a minimum, these assumptions concern the geometry and dimensionality of the system, initial and boundary conditions, time dependence, and the nature of the relevant physical and chemical processes. A conceptual model incorporates the relevant features, events, and process at the site. The assumptions should be consistent with one another and with existing information within the context of the given purpose. Conceptual models are translated into mathematical models.

Independence – Members of the peer review group should be independent of the original work to be reviewed. Independence in this case means that the peer: (1) was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed, and (2) to the extent practical, has sufficient freedom from funding considerations to assure the work is impartially reviewed.

Mathematical Model – Mathematical models are developed to represent features, events, and processes at the site. The conceptual models provide the context within which these mathematical models must operate and define the processes they must characterize. The mathematical models are predictive in the sense that, once provided with the known or assumed properties of the system and possible perturbations to the system, they predict the response of the system. The processes represented by these mathematical models include fluid flow, mechanical deformation, radionuclide transport in ground water, and removal of waste through intruding boreholes.

Numerical Model – Numerical models are developed to provide approximations of mathematical model solutions because most mathematical models do not have closed-form solutions. The complexity of the repository system requires the use of computer codes to solve the numerical models. The implementation of the numerical model in the computer code with specific initial and boundary conditions and parameter values is generally referred to as the computational model.

Peer – A person having technical expertise in the subject matter, to be reviewed, that is at least equivalent to that needed for the original work.

Peer Review – A documented, critical review performed by peers who are independent of the work being reviewed. A peer review is an in-depth critique of assumptions, calculations, extrapolations, alternate interpretations, methodology, and acceptance criteria employed, and of conclusions drawn in the original work. It will assess the adequacy of the original work and determine its acceptability for use per 40 Code of Federal Regulations (CFR) Part 194.

Peer Review Chairperson – An individual designated by the U. S. Department of Energy (DOE) Carlsbad Field Office (CBFO) Deputy Manager, CBFO Director of the Office of Environmental Protection (OEP) or designee to provide technical leadership to the peer review panel, and to determine the manner in which the required peer review evaluations and reporting are conducted.

Peer Review Observers – Representatives of regulatory entities, stakeholders, CBFO, and CBFO participant organizations with the expressed need to observe the peer review process.

Peer Review Observer Protocol – Documented instructions given to the peer review observers, by the peer review chairperson, on interaction with the peer review panel.

Peer Review Panel – An assembly of peers representing an appropriate spectrum of knowledge and experience in the subject matter to be reviewed.

Peer Review Plan – Documents the scope of the peer review, describes the work to be reviewed, the intended use of the work, the size and composition of the peer review panel, and methods used for the specific peer review.

Peer Review Procedure – CBFO Management Procedure (MP) 10.5, Revision (Rev.) 10, *Peer Review*, which documents responsibilities and methods for conducting a peer review. Meets the criteria established in NUREG-1297.

Peer Review Report – In-depth documentation of the proceedings and findings of a peer review signed by each peer review panel member.

1.0 INTRODUCTION

The Waste Isolation Pilot Plant (WIPP), located in southeastern New Mexico, has been developed by the U. S. Department of Energy (DOE) for the geologic (deep underground) disposal of defense-related transuranic (TRU) waste. Containment of TRU waste at the WIPP facility after final WIPP facility closure is regulated by the U. S. Environmental Protection Agency (EPA) according to the regulations set forth in Title 40 of the Code of Federal Regulations (CFR), Part 191, Subparts B and C.

The DOE demonstrates compliance with the containment requirements in 40 CFR Part 191.13(a) according to the Certification Criteria in 40 CFR Part 194 by means of performance assessment (PA) calculations performed by Sandia National Laboratories (SNL). The WIPP PA calculations estimate the probability and consequence of potential radionuclide releases from the repository to the accessible environment for a regulatory period of 10,000 years after facility closure. The WIPP PA conceptual models are used to support the repository recertification process that occurs at five-year intervals following the receipt of the first waste shipment at the site in 1999.

The conceptual models are maintained and updated with new information, when needed, as part of an ongoing process. Improved information regarding important WIPP features, events, and processes can result in refinements and modifications to PA computer models and/or the parameters used in them. Significant changes to the repository and/or the components therein also result in updates to WIPP PA models.

This Peer Review Plan presents the scope of the Additional Panels Performance Assessment (APPA) Changed Conceptual Models peer review; a description of the work to be reviewed; and the intended use of the work in PA. The Plan presents the composition of the peer review panel and the methods that they will use to document observations, comments, and conclusions. A schedule of key peer review activities, including completion of the peer review report, and the frequency of status reports is also presented.

NOTE: **The health and safety of the Federal workforce and the public is the highest priority of the DOE Carlsbad Field Office (CBFO). All work on the WIPP Project is subject to the requirements of the *CBFO COVID-19 Workplace Safety Plan*. The *CBFO COVID-19 Workplace Safety Plan* is required reading for all WIPP Project participants, and will be included in the orientation materials provided to the peer review panel members.**

2.0 BACKGROUND

The WIPP PA methodology uses conceptual models that represent features, events, and processes pertinent to the disposal system. EPA regulations at 40 CFR 194.23(a)(3)(v) require that PA conceptual models be peer reviewed consistent with 40 CFR 194.27, and 24 conceptual models were peer reviewed for the original Compliance Certification Application (DOE, 1996). Historically, the EPA has also required that any “significant” changes to previously peer-reviewed conceptual models again be peer reviewed prior to approval and incorporation into the next PA compliance calculation.

A PA is required to demonstrate, with a reasonable expectation, that the WIPP disposal system complies with the EPA Containment Requirements in 40 CFR 191.13(a). In regards to reasonable expectation for a PA, the EPA states the following in 40 CFR 191.13(b), "Because of the long time period involved and the nature of the events and processes of interest, there will inevitably be substantial uncertainties in projecting disposal system performance. Proof of the future performance of a disposal system is not to be had in the ordinary sense of the word in situations that deal with much shorter time frames. Instead, what is required is a reasonable expectation, on the basis of the record before the implementing agency, that compliance with § 191.13 (a) will be achieved."

The APPA uses many of the same conceptual and mathematical models for PA as were used for the 2019 Compliance Recertification Application (CRA-2019) (DOE, 2019); however, the numerical calculations will be performed using a revised grid that accounts for additional panels.

3.0 PURPOSE

The purpose of this peer review plan is to describe the scope of the APPA conceptual models peer review, and to describe the approach that the peer review panel will use for conducting the peer review. Implementation of this plan is meant to result in an unbiased, independent critical review of the revised representation of the Disposal System Geometry, Repository Fluid Flow, and Direct Brine Release (DBR) conceptual models.

4.0 SCOPE AND DESCRIPTION OF WORK TO BE REVIEWED

The scope of this peer review is to evaluate the adequacy of changes to the following conceptual models: Disposal System Geometry, Repository Fluid Flow, and Direct Brine Release.

4.1 Description of Work to be Reviewed

Disposal System Geometry - The Disposal System Geometry conceptual model expresses the dimensionality of the engineered system and surrounding geologic/hydrogeologic formations. The addition of new repository waste panels and associated drifts necessitate changes to the BRAGFLO (brine and gas flow) (ERMS 570275, DOE, 2019) grid, which is a change in this conceptual model.

Repository Fluid Flow - The Repository Fluid Flow conceptual model addresses: (1) fluid distribution in the waste, (2) long-term fluid flow to-and-from the Salado Formation and shafts, and (3) long-term fluid flow between the repository and intrusion boreholes. The Repository Fluid Flow conceptual model is a complex description of simultaneous, interacting hydrologic, chemical, geomechanical, engineering design, and human intrusion scenarios. The effects can be described separately, but require numerical modeling to identify the combined, integrated outcome. The processes controlling repository fluid flow include brine inflow rates, halite creep rates, gas generation from anoxic iron corrosion, microbial degradation, and brine radiolysis. The computer (computational) model accepts inputs from other related computer models and provides numerical results of pressures, flow rates, and flow directions for brine and gas within the excavated areas of the Salado formation.

The key elements of the repository layout, pertaining to the Repository Fluid Flow conceptual model, are the waste disposal area (the waste panels and access drifts), the panel closures, the shaft pillar access drifts area, the northern experimental area, the shafts, the WIPP site characterization boreholes in the vicinity of the repository, and any future inadvertent human intrusion boreholes that are modeled to penetrate the repository at random times and random locations.

Direct Brine Release - Direct Brine Release refers to the probability that brine containing actinides may flow from the waste panels up a borehole to the surface during an inadvertent human intrusion drilling event. In general, the important features of the DBR grid are retained in the APPA DBR grid; however, the change to modeling only a subsection of the waste area is a shift in the conceptual model.

4.2 Summary Description of the Structure of the Performance Assessment

The basic structure of the APPA remains the same as for the CRA-2019 (https://wipp.energy.gov/library/CRA/CRA%202019/index.html). For each vector of sampled values of uncertain parameters, many 10,000-yr. futures are randomly generated. Each future comprises a sequence of simulated drilling and mining intrusions. For each intrusion, direct releases are tabulated using output from the PA computer models, and over the course of the entire future, releases through the Salado and Culebra formations to the land withdrawal boundary are recorded using output from the Salado and Culebra transport computer models.

The calculation of a single complimentary cumulative distribution function (CCDF) curve is accomplished by randomly sampling, by use of Latin Hypercube Sampling, across uncertain PA parameters and then use of Monte Carlo sampling techniques to sample stochastic variables (e.g., drilling intrusion time, drilling location, whether pressurized brine is hit or not, etc.). A single CCDF curve represents 10,000 possible multi-intrusion future conditions (expressed as probability and consequence or normalized releases) that could occur during the 10,000-year regulatory time period. For PA, 100 CCDFs are generated, and since each CCDF represents 10,000 possible futures, the generation of 100 CCDFs equal 1,000,000 possible multi-intrusion and normalized release futures. Then 3 replicates of the 100 CCDFs are generated to comply with the EPA requirements in 40 CFR 194.34 (f).

The code CCDFGF (DOE, 2019) generates the random futures and estimates the CCDFs. The quantitative measure of long-term repository compliance to the EPA release limits is a comparison of the overall mean CCDF for total normalized releases with the EPA containment requirements in 40 CFR 191.13(a). A detailed definition of this conceptual structure is found in Appendix PA of CRA-2019 (DOE, 2019).

5.0 PEER REVIEW PLANNING AND IMPLEMENTATION

The APPA Changed Conceptual Models Peer Review will be conducted using a rigorous, procedure-controlled process in accordance with NUREG-1297, *Peer Review for High-Level Nuclear Waste Repositories* (NRC, 1988). The DOE CBFO Management Procedure (MP) 10.5, *Peer Review*, was prepared specifically for conducting peer reviews in accordance to NUREG-1297. CBFO procedure MP 10.5, Rev. 10, will be used to implement this Peer Review Plan.

Adherence to CBFO MP 10.5, Rev. 10, requires the peer review to be a documented, critical review performed by qualified peers who are independent of the original work being reviewed, and that the peer review panel submits a formal written report of the peer review findings and conclusions.

5.1 Peer Review Panel Member Orientation

The peer review chairperson will ensure that all peer review panel members have received adequate orientation prior to performing their assigned work. Orientation will take the form of reading assignments, briefings, and chairperson instruction. The chairperson will document the content of the orientation. The chairperson will facilitate the orientation and provide material for assigned reading, including the following:

- 40 CFR Part 191, *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes* (applicable sections)
- 40 CFR Part 194, *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations* (applicable sections)
- NUREG-1297, *Peer Review for High-Level Nuclear Waste Repositories* (applicable sections)
- DOE/CBFO-94-1012, *Quality Assurance Program Document* (current revision), Sections 1.1.2.5, and 5.4
- CBFO MP 10.5, *Peer Review*, Rev. 10
- Applicable Peer Review Plan
- The peer review process, including the administrative requirements.
- A brief summary of the peer review technical subject matter, which may include a briefing by the subject matter expert (SME) responsible for the study being reviewed.
- The *CBFO* Covid-*19 Workplace Safety Plan*

Attendance at orientation will be documented on a Peer Review Panel Orientation Form (CBFO Form 10.5-4) and will be maintained as a record. CBFO forms are located on the CBFO Forms/Templates page on the Intranet (https://bellview/cbfo/forms-templates.html).

5.2 Observer Protocol

The peer review chairperson will maintain the observer protocol during the peer review process. Observers are not active participants in the peer review process. Observer communication with peer review panel members during formal panel sessions is disallowed unless requested by a panel member or prior approval is obtained from the peer review chairperson. The chairperson is responsible for the conduct of the peer review and will maintain administrative control of the peer review process.

The peer review chairperson will ensure that all observers are introduced in the pre-review meeting and initial review sessions. Prior to starting a panel session, the chairperson will provide a brief introduction, summary of review objectives, and expectations for observer conduct.

Observers may submit questions in writing to the peer review chairperson during breaks or other designated times unless otherwise requested by peer review panel members or approved by the chairperson. Observers will limit questions to issues directly related to the information/data being reviewed. Observer questions and peer review panel responses will be addressed only if prior approval is obtained from the peer review chairperson, and the approved questions are documented on the Observer Inquiry Form (CBFO Form 10.5-5). The completed form will be maintained as a record.

Observers shall be allowed to receive, upon request to the peer review chairperson, copies of any information provided to the peer review panel during the peer review process. Such requests for information shall be documented. Observers are permitted to submit to the peer review panel relevant information that is within the scope of the peer review. The information must first be provided to the chairperson, for approval and documentation as a record, before it is submitted to the peer review panel.

Authorization for observers to attend peer review panel caucus meetings shall be obtained through the chairperson prior to admittance.

5.3 Composition of the Peer Review Panel

The peer review panel will be composed of five individuals who possess the subject matter technical expertise to a degree that is at least equivalent to that needed for the original work. Panel members will be independent of the work being reviewed, which means that they have not been involved as participants, supervisors, technical reviewers, or advisors in the work being reviewed, and, to the extent practical, have sufficient freedom from funding considerations to ensure that the work is impartially reviewed. The panel will include individuals who have expertise in modeling subsurface flow and transport, a general knowledge of geologic disposal systems, and familiarity with the use of PA to meet regulatory requirements.

5.4 Training, Approach, and Methods

The peer review panel will employ the following approach in their overall method of conducting and accumulating information for the reviews:

- Extensive review of referenced literature relevant to the review;
- Attendance at briefings on conceptual models and relevant aspects of the PA process;
- Issue focused presentations with question-and-answer sessions with SNL SMEs;
- Review of literature and documents referenced during the question-and-answer sessions; and
- Formal and informal discussions among the panel members.

Prior to the commencement of the peer review, the panel will receive and review background and orientation documents that are pertinent to the conduct of the peer. The peer review chairperson will discuss the contents of the documents and answer questions the panel may have regarding the conduct of the peer review. Each panel member will certify that they have read and understand the contents of the background and orientation documents.

The panel will meet (either in-person or via teleconference) and be presented technical material to review and attend briefings by SNL staff. The panel will caucus after each such meeting and caucus notes will be recorded. The peer review panel will use CBFO MP 10.5, Rev. 10, and the criteria in NUREG-1297 as a guide for their review.

The panel will engage in formal interaction with SNL staff to present and discuss their observations and findings. The panel's interactions with SNL staff will be documented in a draft report that will be circulated for review and comment. When comments are dispositioned, a final report will be prepared and submitted to the CBFO.

Panel members will not review or offer comments on regulations. The panel will confine its review to the three conceptual models identified in this Peer Review Plan. Also, to maintain independence, the panel will not offer recommendations for specific methods and/or approaches to be employed in future work.

Peer review panel members will interact to ensure that sufficient consideration is given to interdisciplinary and coupled data and information. Each peer review panel member will support the peer review chairperson in the preparation of the peer review report with regard to their specific review areas. The chairperson will provide technical leadership to the peer review panel members, and determine the manner in which the required peer review evaluations and reporting are conducted. If necessary, the chairperson will delegate the assignments of specific review tasks and activities among peer review panel members.

Based upon the data and information relevant to changes in the conceptual models, the panel will evaluate the three conceptual models with respect to whether or not they represent a reasonable view of future states of the proposed disposal system for the WIPP repository. The panel will evaluate the conceptual models in accordance with MP 10.5, Rev. 10, and the NUREG-1297 criteria. In addition, the panel may wish to review the PA results using the changed conceptual and related computational models.

The peer review chairperson will provide coordination between the peer review panel members and supporting organization to ensure effective flow of information and logistic/technical support to the peer review effort. The chairperson will provide the CBFO Deputy Manager, OEP Director, and Office of Quality Assurance (OQA) Director with periodic progress reports on the status of the peer review, as specified within the peer review plan. The peer review chairperson will also ensure that all required forms and documentation are complete prior to the start of the peer review process.

When peer review activities are conducted, the peer review chairperson will schedule and conduct daily caucuses of the peer review panel to address issues, concerns, questions, and conflicts. Written caucus minutes will be developed and maintained as records. Authorization

for observers to attend the caucus meetings will be obtained through the peer review chairperson prior to admittance.

5.5 Criteria for Conceptual Model Review

The criteria used by the peer review panel members are based on the criteria in EPA regulation 40 CFR Part 194.27, NUREG-1297, and the CBFO procedure, MP 10.5, Rev. 10.

1. **Information Used to Review Changes in Conceptual Model.** This is an evaluation of data and information used to change the conceptual models and sub-models. It includes attributes of the disposal system learned by SNL during site characterization activities, exercising the models, and a review of the science and concepts that the models are based upon. It also includes information gained during the operation of the repository.
2. **Validity of Assumptions.** The validity of key assumptions in the model and its application is assessed in terms of how they could affect the usefulness of the conceptual model. The **review** should address the comprehensive inclusion of important features, events, processes, and other key assumptions. An example is the mathematical method chosen to develop the model grid.
3. **Alternative Interpretations.** This section should identify and assess plausible alternative conceptual models or sub-models considered by SNL but not used, and the rationale of why such alternative models were not used.
4. **Uncertainty of Results and Consequences if Wrong.** This will include an evaluation of the key **uncertainties** in the selected conceptual models and the discussion of the consequences if aspects of the conceptual model chosen were inappropriate or incompletely constrained for the site or process. This is not an exhaustive evaluation, but it does raise the question, "What if the model is wrong?"
5. **Appropriateness and Limitations of Method and Procedures.** Based primarily on the previous **four** criteria, this is a simple evaluation of whether the individual conceptual models, process models, and sub-models represent a reasonable approximation of the actual disposal system elements.
6. **Adequacy of Application.** This is an assessment of whether individual conceptual models appear to be adequately applied into an acceptable overall performance assessment system. This particular assessment does not cover the relationships among conceptual models, but rather whether the significant components of the individual conceptual models are appropriately implemented in support of PA. For example, are the various geometrical systems and representations of the conceptual models adequately applied within the performance modeling system, or do there appear to be discontinuities between the conceptual model and its application? Also, are there alterations of important key assumptions between the conceptual model and its implementation in performance modeling?
7. **Accuracy of Calculations.** This is a statement of whether the results of performance modeling using the conceptual model within the performance system are reliable and

accurate to reasonably represent the long-term physical and chemical processes of the repository.

8. **Validity of Conclusions.** This is a judgment of the validity of any key conclusions that have been drawn based on results of the implementation of the conceptual models in the modeling framework. The key question is whether or not conclusions from model implementations appropriately relate to the expected goal of assessing the long-term performance of the disposal system. This judgment requires an evaluation of output information from the total system PA.
9. **Adequacy of Requirements, Criteria, and Implementation.** An evaluation in accordance with approved technical and quality assurance (QA) requirements and the applicable peer review plan.

5.6 Peer Review Daily Caucus

The peer review chairperson will schedule and conduct caucuses of the peer review panel following meetings to address issues, concerns, questions, and conflicts. The chairperson will ensure that written caucus minutes are developed, and will initial the minutes to signify that they have been reviewed to represent the work of the peer review panel. The chairperson will ensure that caucus minutes are maintained as records.

6.0 SCHEDULE TO COMPLETE THE PEER REVIEW REPORT

Attachment I presents a schedule of peer review activities. This schedule will serve as the baseline schedule from which requested schedule deviations will be evaluated and approved, if necessary. Revisions to the baseline schedule will not require revision to this plan, but must be approved by the Peer Review Chairperson. The schedule will be used as the basis for weekly status reports.

6.1 Frequency of Status reports and Deliverables

The peer review chairperson will provide status reports addressing peer review progress against the schedule weekly, or as requested by the CBFO OEP Director. The CBFO will communicate and work with the peer review chairperson to provide timely information to the panel. A final peer review report will be delivered to the CBFO OEP Director by December 31, 2021.

7.0 PEER REVIEW REPORT

A written peer review report will be prepared under the direction of the peer review chairperson and will meet the following requirements outlined in MP 10.5, Rev. 10:

- Describe the scope of work that was reviewed.
- Describe the conclusions reached by the peer review panel.
- Provide additional statements by the peer review panel members reflecting dissenting views or additional comments, as appropriate.

- List the peer review panel members and provide acceptability information (i.e., technical qualifications and independence) for each member.
- Pertinent review results and conclusions reached by the peer review panel.
- Individual statements by the peer review panel members, reflecting dissenting views or additional comments, as appropriate.
- Signature of the peer review chairperson and each peer review panel member.

The peer review report will also include the following appendices:

A. Peer review chairperson qualification documentation.

B. Peer review plan(s), including peer review procedure(s).

C. Peer review panel member qualification and selection documentation, including:

   1. Verification of education/employment documentation.
   2. Determination of peer review panel member independence documentation.
   3. Justification/decision related to peer review panel selection.

D. Acquisition documents (beginning with request for peer review from the CBFO Office of Business Operations through peer review panel member service provider contracting documentation).

8.0 QUALITY ASSURANCE

The work associated with the APPA Changed Conceptual Models Peer Review has been assigned a Quality Level (QL) 1 determination in that it involves:

- Measurements of geological, ground water, meteorological, and topographical characteristics in compliance with 40 CFR 194.
- Computations, computer codes, models, and methods to demonstrate compliance with 40 CFR 194.
- Procedures to support the applications for certification and recertification in accordance with 40 CFR 194.

To ensure the QL1 requirements are met, the peer review process will be conducted and documented in a controlled manner and in compliance with the DOE/CBFO-94-1012, *Quality Assurance Program Document*, and CBFO MP 10.5, Rev. 10. The CBFO OQA Director may appoint a QA observer to attend the peer review orientation and peer review meetings. The CBFO OQA Director may schedule assessments and audits of the peer review process and records prior to completion of the review.

9.0 RECORDS MANAGEMENT

Records will be retained by the peer review chairperson (or designee) until completion of the peer review process. Upon completion of the peer review process, the peer review chairperson will transfer the records to the responsible CBFO Deputy Manager, CBFO OEP Director, or designee.

The records to be retained include:

- Peer review plan(s)
- Peer review procedure(s)
- Service acquisition documents
- Peer review panel member education/employment documentation (CBFO Form 10.5-1, Peer Review Panel Member Verification of Education/Employment Form)
- Peer review panel member independence documentation (CBFO Form 10.5-2, Determination of Peer Review Panel Member Independence Form)
- Peer review panel selection justification
- Peer review panel member service provider contracting documentation
- Observer inquiry forms (CBFO Form 10.5-5, Observer Inquiry Form)
- Peer review chairperson qualification documentation
- Peer review panel member selection documentation (CBFO Form 10.5-3, Peer Review Panel Selection Justification/Decision Form)
- Peer review panel orientation documentation and attendance form (CBFO Form 10.5-4, Peer Review Panel Orientation Form)
- Written minutes of meetings, deliberations, and activities
- Peer review report

10.0 REFERENCES

1. 40 Code of Federal Regulations, Part 191, *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes*
2. 40 Code of Federal Regulations, Part 194, *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations*
3. Carlsbad Field Office Covid-19 Workplace Safety Plan
4. Carlsbad Field Office Management Procedure (MP) 10.5, Peer Review Revision 10
5. Carlsbad Field Office Quality Assurance Program Document, DOE/CBFO-94-1012, Sections 1.1.2.5 and 5.4
6. DOE, 1996. U. S. Department of Energy (DOE), DOE/CAO-1996-2184, Title 40 CFR Part 191, Compliance Certification Application for the Waste Isolation Pilot Plant, 1996
7. DOE, 2019. U. S. Department of Energy (DOE), DOE/WIPP-19-3609, Title 40 CFR Part 191, *Compliance Recertification Application for the Waste Isolation Pilot Plant*, 2019
8. NRC, 1988. Nuclear Regulatory Commission (NRC), NUREG-1297, *Peer Review for High-Level Nuclear Waste Repositories*, 1988

Attachment I

Peer Review Schedule

Submit Draft Peer Review Plan	TBD
Identification and Contract with Peer Review Panel Members	TBD
Draft Peer Review Panel Orientation and Training Session	TBD
SNL Present Peer Review Panel Orientation and Training Session	TBD
Conduct Peer Review Panel interaction with SNL	TBD
Prepare Draft Peer Review Report	TBD
Prepare and Deliver Final Peer Review Report	TBD
Formally Transfer Peer Review Records Package	TBD

U.S. Department of Energy
Carlsbad Field Office

MANAGEMENT PROCEDURE

CBFO MP 10.5, Rev. 10

Effective: October 1, 2018

SUBJECT: PEER REVIEW

Procedure Approver: /signature on file/ Date: 09/18/2018
Michael R. Brown

CHANGE HISTORY

REVISION	REASON FOR REVISION
9	• Updated “Office of Regulatory Compliance” to “Environmental Protection Division”. • Update “Officer Director” to Assistant Manager”. • Redefined “Independence”. • Added “expert judgments” in addition to “technical reviews” in Section 5.1. • Referenced “NUREG-1297” in Section 5.1 Peer Review Process to indicate the origin of the section. • Revised Section 5.3.1.F for clarification. • Revised Section 5.2.2 to reflect the change in 5.3.1.F. • Added a sentence in Section 6.1.3 to clarify that the QA records generated are identified as “lifetime” QA records based on QAPD. • Added the following statement to 6.4.2.C to clarify what the report should contain at a minimum, “The conclusion shall include the final analysis and evaluation results of Section 6.2.2 consented by the peer review panel members”. • Revised Attachment I Section 2.1.1 regarding the alternate Peer Review Panel Member to “If a group member cannot finish or fulfill the review process, the committee will determine the need for a replacement. Should a replacement be needed, the new nominee will undergo the qualification and selection process in accordance with Sections 2.2 and 2.3”. • Clarified the Education section in Attachment II in nominee’s education verification and evaluation. • Numerous editorial and formatting changes.
10	• Complete rewrite of procedure. No change bars present. • Migrated procedure to the new MP template to meet procedural requirements (CBFO MP 4.1, Rev. 13). • Deleted “Date Issued” section in “Change History” from Revision 9 to be in compliance with template and procedure requirements (CBFO MP 4.1, Rev. 13). • Addressed the new CBFO organization titles from the latest CBFO restructuring. • Incorporated Interim Change Notice #1. • Added definitions. • Revised the Attachment example forms and CBFO Forms 10.5-1, 10.5-2, 10.5-3, 10.5-4, and 10.5-5 to meet procedural requirements (CBFO MP 4.1, Rev. 13).

1.0 PURPOSE

This management procedure (MP) defines the responsibilities, requirements, and methodologies to be used for the performance of peer reviews conducted for the Carlsbad Field Office (CBFO) in support of the Waste Isolation Pilot Plant (WIPP). This procedure was developed in accordance with and implements the guidance in NUREG-1297, *Peer Review for High-Level Nuclear Waste Repositories* (refer to Attachment I, Typical WIPP Protocol for Implementation of NUREG-1297 Peer Review Process).

2.0 SCOPE

This procedure applies to the performance of peer reviews described in Code of Federal Regulations (CFR) Title 40 Part 194 (40 CFR Part 194), and conducted under the authority of the CBFO. Per the criteria of 40 CFR §194.27(a), peer reviews may be used to support conceptual models; waste characterization analyses, as required in §194.24(b); and engineered barrier evaluation, as required in §194.44. This procedure supersedes CBFO MP 10.5, Revision 9.

3.0 REFERENCES AND DEFINITIONS

3.1 References

3.1.1 40 CFR Part 191, *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes*

3.1.2 40 CFR Part 194, *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations*

3.1.3 DOE/CBFO-94-1012, *Quality Assurance Program Document* (QAPD)

3.1.4 CBFO MP 4.1, *Preparation and Maintenance of CBFO Procedures*

3.1.5 CBFO MP 4.2, *Document Review and Approval*

3.1.6 CBFO MP 4.9, *Quality Assurance Records*

3.1.7 NUREG-1297, *Peer Review for High-Level Nuclear Waste Repositories*

3.2 Definitions

3.2.1 **Independence** – Members of the peer review group should be independent of the original work to be reviewed. Independence in this case means that the peer: (1) was not involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed, and (2) to the extent practical, has sufficient freedom from funding considerations to assure the work is impartially reviewed.

3.2.2 **Peer** – A person having technical expertise in the subject matter, to be reviewed, that is at least equivalent to that needed for the original work.

3.2.3 **Peer Review** – A documented, critical review performed by peers who are independent of the work being reviewed. A peer review is an in-depth critique of assumptions, calculations, extrapolations, alternate interpretations, methodology and acceptance criteria employed, and of conclusions drawn in the original work. It will assess the adequacy of the original work, and determine its acceptability for use per 40 CFR Part 194.

3.2.4 **Peer Review Chairperson** – An individual designated by the CBFO Deputy Manager, CBFO Director of the Office of Environmental Protection (OEP) or designee to provide technical leadership to the peer review panel, and to determine the manner in which the required peer review evaluations and reporting are conducted.

3.2.5 **Peer Review Observers –** Representatives of regulatory entities, stakeholders, CBFO, and CBFO participant organizations with the express need to observe the peer review process.

3.2.6 **Peer Review Observer Protocol –** Documented instructions given to the peer review observers, by the peer review chairperson, on interaction with the peer review panel.

3.2.7 **Peer Review Panel** – An assembly of peers representing an appropriate spectrum of knowledge and experience in the subject matter to be reviewed.

3.2.8 **Peer Review Plan** – Documents the scope of the peer review, describes the work to be reviewed, the intended use of the work, the size and composition of the peer review panel, and methods used for the specific peer review.

3.2.9 **Peer Review Procedure** – Documents responsibilities and methods for conducting a peer review. Meets the criteria established in NUREG-1297 and in Attachment I of this procedure.

3.2.10 **Peer Review Report** – In-depth documentation of the proceedings and findings of a peer review signed by each peer review panel member.

3.2.11 **Service Provider** – The organization selected by the CBFO Office of Business Operations to solicit and contract peer review panel members.

4.0 RESPONSIBILITIES

4.1 CBFO Deputy Manager, CBFO Director of OEP or Designee

4.1.1 Request CBFO Office of Business Operations to acquire a service provider to solicit and contract peer review panel members to conduct a peer review consistent with this procedure.

4.1.2 Ensure information and data required to support the peer review are assembled and complete.

4.1.3 Ensure appropriate CBFO staff, in accordance with CBFO MP 4.2*, Document Review and Approval,* review the service provider peer review procedure and peer review plan as needed.

4.1.4 Provide the required interfaces to ensure effective flow of information and logistic support for the peer review process.

4.1.5 Ensure necessary communications, including regulatory reporting requirements, with the U.S. Environmental Protection Agency, the New Mexico Environment Department, and other interested stakeholders.

4.2 CBFO Office of Quality Assurance (OQA) Director or Designee

Responsible for the overall assessment of the peer review process.

5.0 PROCEDURE

5.1 Peer Review Process

The peer review, which meets the criteria established in NUREG-1297, shall be used as a management tool to achieve confidence in the validity of certain technical and programmatic judgments. A peer review process provides assurance in cases where scientific uncertainties and ambiguities exist, but technical and programmatic judgments and decisions still must be made. In general, peer reviews are used to achieve defensible consensus. Peer reviews shall not be used as a substitute for readily collectable data. Conclusions based on inadequate or limited data cannot be improved by subjecting those conclusions to the peer review process. Peer reviews shall not be confused with technical reviews or expert judgments.

5.2 Peer Review Process Initiation

NOTE: The latest revisions of CBFO Forms 10.5-1, 10.5-2, 10.5-3, 10.5-4, and 10.5-5 are accessible in fillable format on the CBFO "Forms/Templates" page on the CBFO home page via the Intranet, http://bellview/cbfo/forms-templates.html.

5.2.1 Upon request for a peer review per the criteria of 40 CFR §194.27, the CBFO Deputy Manager, or CBFO OEP Director, shall request the CBFO Office of Business Operations to prepare an acquisition action that requires service providers to perform the following actions:

A. Develop and submit to the CBFO Deputy Manager, CBFO OEP Director or designee a peer review plan that specifies the scope of the peer review to be conducted, a schedule for peer review activities, and delivery of the final peer review report.

B. Determine whether to develop a new peer review procedure, or use Attachment I of CBFO MP 10.5 as the procedure for the peer review. For a new procedure, develop and submit a procedure that incorporates the NUREG-1297 requirements and CBFO Forms 10.5-1, 10.5-2, 10.5-3, 10.5-4, and 10.5-5 (refer to Attachments II through VI examples) to the CBFO Deputy Manager, CBFO OEP Director or designee for CBFO review in accordance with CBFO MP 4.2. If Attachment I of CBFO MP 10.5 is used as the procedure for conducting the peer review, then no further action is required.

C. Submit the identification and qualification documentation of the nominated individual selected as peer review panel chairperson for concurrence by the responsible CBFO Deputy Manager, CBFO OEP Director or designee prior to initiation of the peer review process.

D. Submit all quality assurance (QA) records generated by the peer review to the CBFO Deputy Manager, CBFO OEP Director or designee.

5.3 Peer Review Process Support

5.3.1 The CBFO Deputy Manager, CBFO OEP Director or designee shall:

A. Evaluate the qualifications of the candidates for peer review chairperson submitted by the service provider, and communicate concurrence or non-concurrence until a peer review chairperson is selected.

B. Verify that information and data required to support the peer review are assembled, completed, and provided to the peer review chairperson.

C. Process requests for information, including any additional information required by the peer review panel, in a timely manner.

D. Provide required interfaces to ensure effective flow of information and logistics support for the peer review process.

E. Initiate the CBFO document review process if changes are made to the peer review plan that will affect the implementation of this procedure.

F. Ensure CBFO reviews the changes to CBFO MP 10.5 (Attachment I included) or alternate service provider peer review procedures in accordance with CBFO MP 4.2.

5.3.2 The CBFO Deputy Manager, CBFO OEP Director or designee will serve as the interface with internal and external observers and will coordinate logistics between the peer review chairperson and observers.

5.3.3 The CBFO Deputy Manager, CBFO OEP Director or designee will review and approve/disapprove requests for information from observers as deemed appropriate.

5.4 Peer Review Process Conclusion

5.4.1 The CBFO Deputy Manager, CBFO OEP Director or designee shall review the final peer review report and any supplemental information for impacts and further actions required.

5.4.2 The CBFO Deputy Manager, CBFO Director or designee shall notify the affected organizations (if any) and the appropriate regulatory agencies of the conclusions of the peer review.

5.5 Quality Assurance Assessments

5.5.1 The CBFO OQA Director shall assess the peer review process to ensure that it conforms to this procedure.

5.5.2 The CBFO OQA Director shall present any assessment findings to the responsible CBFO Deputy Manager, CBFO OEP Director or designee; who in turn, submits them to the peer review chairperson for resolution.

5.5.3 The CBFO OQA Director shall review the resolution of any findings to ensure that they include an assessment of the impact of the findings on completed and ongoing peer reviews, as applicable.

5.5.4 Attendance requests for individuals performing peer review QA oversight activities must be coordinated through the peer review chairperson.

6.0 RECORDS

6.1 QA Records

6.1.1 Upon completion of the peer review process and receipt of the QA records from the peer review chairperson, the CBFO Deputy Manager, CBFO OEP Director or designee, with the assistance of the CBFO OQA Director or designee, shall verify that the following documents are assessed for completeness and retained as appendices to the peer review report:

A. Peer review panel chairperson qualification documentation.

B. Peer review plan(s) including peer review procedures (identify if different from Attachment I of CBFO MP 10.5).

C. Peer review panel member qualification and selection documentation including:

- Verification of education/employment documentation (CBFO Form 10.5-1.
- Determination of peer review panel member independence documentation (CBFO Form 10.5-2).
- Justification/decision related to peer review panel selection (CBFO Form 10.5-3).

D. Acquisition documents (beginning with request for peer review from CBFO Office of Business Operations through peer review panel member service provider contracting documentation).

E. Peer review panel orientation documentation and attendance form(s) (CBFO Form 10.5-4).

F. Written minutes of meetings, deliberations, and activities.

G. Observer inquiry forms and/or relevant information that is within the scope of the peer review submitted by an observer to the panel (CBFO Form 10.5-5).

6.1.2 Upon the completion of the verification that appropriate QA records were provided, the CBFO Deputy Manager, CBFO OEP Director or designee shall process the QA records in accordance with CBFO MP 4.9, *Quality Assurance Records.*

6.1.3 In accordance with the CBFO QAPD, records used for repository permitting or certification shall be classified as “lifetime” QA records. Lifetime QA records shall be retained and preserved in an acceptable condition for the operating life of the WIPP.

NOTE: The latest revisions of CBFO Forms 10.5-1, 10.5-2, 10.5-3, 10.5-4, and 10.5-5 are accessible in fillable format on the CBFO "Forms/Templates" page on the CBFO home page via the Intranet. Attachments II through VI (listed below) are examples and are not intended for use.

7.0 ATTACHMENTS

Attachment I. Typical WIPP Protocol for Implementation of NUREG-1297 Peer Review Process

Attachment II. Example of CBFO Form 10.5-1, *Peer Review Panel Member Verification of Education/Employment Form*

Attachment III. Example of CBFO Form 10.5-2, *Determination of Peer Review Panel Member Independence Form*

Attachment IV. Example of CBFO Form 10.5-3, *Peer Review Panel Selection Justification/Decision Form*

Attachment V. Example of CBFO Form 10.5-4, *Peer Review Panel Orientation Form*

Attachment VI. Example of CBFO Form 10.5-5, *Observer Inquiry Form*

Typical WIPP Protocol for Implementation of NUREG-1297 Peer Review Process

NOTE: Refer to Section 3.2 of CBFO MP 10.5 for definitions of terms.

A1.0 Establishment of the Peer Review Panel Chairperson

1.1 The service provider shall document the selection of peer review panel chairperson who will select the peer review panel members.

A2.0 Selection of Peer Review Panel Members

2.1 Peer Review Panel Size and Composition

2.1.1 Peer review panel size and composition shall be determined by the peer review chairperson. The peer review chairperson may utilize technical advisors to assist in the selection process. If a panel member cannot finish or fulfill the review process, the peer review chairperson will determine the need for a replacement. Should a replacement be needed, the new nominee will undergo the qualification and selection process in accordance with Sections 2.2 and 2.3.

2.1.2 The number of peers comprising a peer review panel varies with the complexity of the work to be reviewed, its importance in meeting safety or waste isolation performance goals, the number of technical disciplines involved, the degree to which uncertainties in the data or technical approach exist, and the extent to which differing viewpoints are held within the applicable technical and scientific community concerning the issues under review. The Peer review chairperson is required to confirm that the peer review evaluation did consider relevant data, models, and methods, and that the evaluation was conducted objectively and without bias.

2.1.3 The collective technical expertise and qualifications of peer review panel members shall span the issues, and areas involved in the work to be reviewed, including any differing bodies of scientific thought. Technical areas more central to the work to be reviewed shall receive proportionally more representation on the peer review panel. The peer review panel should represent the major schools of scientific thought. The potential for technical or organizational partiality shall be minimized by the formation of a balanced peer review panel.

2.2 Peer Review Panel Member Qualifications

2.2.1 The acceptability of any peer review panel member is based on technical qualifications and independence, both of which shall be satisfied.

2.2.2 The requirement for technical qualifications of a panel member shall be satisfied by meeting all of the following:

A. Recognized and verifiable technical qualifications at least equivalent to those needed for the original work under review (the primary consideration in the selection process) in the technical area the panel member has been selected to cover. The technical qualifications of each panel member and of the peer review panel as a whole, shall relate to the importance of the subject matter to be reviewed.

B. The peer review chairperson shall ensure that the education and pertinent experience of each panel member is verified and documented on CBFO Form 10.5-1, *Peer Review Panel Member Verification of Education/Employment Form* (refer to Attachment II example).

2.2.3 The requirement for independence shall be satisfied by meeting all of the following:

A. Peer review panel members shall be independent of the original work to be reviewed.

B. Due to the U.S. Department of Energy's (DOE's) extensive effort in the waste management area, the unavailability of other technical expertise in certain areas, and the possibility of reducing the technical qualifications of the reviewers in order to maintain total independence, it may not be possible to exclude all DOE or DOE contractor personnel from participating in a peer review. In cases where total independence requirements cannot be met, a documented rationale as to why someone of equivalent technical qualifications and greater independence, if applicable, was not selected shall be documented in a memo to be filed and included in the QA record package.

C. The peer review panel member shall document the rationale for independence on a *Determination of Peer Review Panel Member Independence Form (*CBFO Form 10.5-2) (refer to Attachment III example). The documented rationale shall be reviewed, verified, and approved by the peer review chairperson. The form shall be maintained as a QA record.

2.3 Peer Review Panel Selection

2.3.1 The peer review chairperson shall eliminate potential peer review panel members from consideration based on the following criteria: (1) equally or more qualified individuals are available, (2) the candidate is not available, and/or (3) the candidate has a potential or perceived organizational conflict of interest.

2.3.2 The peer review chairperson shall document the rationale for selection and non-selection of peer review panel members on a *Peer Review Panel Selection Justification/Decision Form* (CBFO Form 10.5-3) (refer to Attachment IV example). This form shall be maintained as a QA record.

2.3.3 The peer review chairperson shall ensure the services of the selected peer review panel members are retained. Service acquisition documents are to be included with the QA records.

2.3.4 If an appointed peer review panel member is unable to continue as a standing member, the member shall formally resign. The peer review chairperson will select an alternate member in accordance with the applicable sections of this protocol, or opt to continue the peer review with the remaining panel members, as appropriate. The basis for the decision shall be formally documented.

A3.0 Peer Review Panel Member Orientation

3.1 The peer review chairperson shall ensure that all peer review panel members have received adequate orientation prior to performing their assigned work. Orientation may take the form of reading assignments, briefings, or classroom training, as appropriate. Orientation shall be documented as to content and scope.

3.2 At a minimum, assigned reading or orientation shall be facilitated by the peer review chairperson, and shall include the applicable sections of the following:

3.2.1 40 CFR Part 191, *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes.*

3.2.2 40 CFR Part 194, *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations.*

3.2.3 NUREG-1297, *Peer Review for High-Level Nuclear Waste Repositories.*

3.2.4 DOE/CBFO-94-1012, *Quality Assurance Program Document*, sections 1.1, 2.5, and 5.4.

3.2.5 CBFO MP 10.5, *Peer Review.*

3.2.6 Applicable Peer Review Plan.

3.2.7 Peer Review Procedure.

3.2.8 The peer review process, including the administrative requirements.

3.2.9 A brief summary of the peer review technical subject matter, which may include a briefing by the scientist or engineer responsible for the study being reviewed.

3.3 Attendance at orientation shall be documented on a *Peer Review Panel Orientation Form* (CBFO Form 10.5-4) (refer to Attachment V example) and shall be maintained as a QA record.

A4.0 Observer Protocol

4.1 The observer protocol shall be maintained during the peer review process. Observers are not active participants in the peer review process. Observer communication with peer review panel members during formal panel sessions is disallowed unless requested by a peer panel member or when prior approval is obtained from the peer review chairperson. The peer review chairperson is responsible for the conduct of the peer review and will maintain administrative control of the peer review process.

4.2 The peer review chairperson will ensure that all observers are introduced in the pre-review meeting and initial review sessions.

4.3 Prior to starting the panel session, the peer review chairperson will provide a brief introduction, summary of review objectives, and expectations for observer conduct.

4.4 Observers may submit questions in writing to the peer review chairperson during breaks or other designated times unless otherwise requested by peer review panel members or approved by the peer review chairperson. Observers will limit questions to issues directly related to the information/data being reviewed. Observer questions and peer review panel responses will be addressed only if prior approval is obtained from the peer review chairperson, and the approved questions are documented on the *Observer Inquiry Form* (CBFO Form 10.5-5) (refer to Attachment VI example). This form shall be maintained as a QA record.

4.5 Observers shall be permitted, upon request to the peer review chairperson, copies of any information provided to the peer review panel during the peer review process. Such requests for information shall be documented.

4.6 Observers are permitted to submit to the peer review panel relevant information that is within the scope of the peer review. The information must first be given to the peer review chairperson for documentation as a QA record before it is submitted to the peer review panel.

A5.0 Schedule/Status

5.1 The peer review chairperson will provide status updates to the CBFO Deputy Manager, CBFO OEP Director or designee, and the CBFO OQA Director.

5.2 The peer review chairperson will ensure observers are informed daily of schedule and room changes.

5.3 The peer review chairperson will provide the CBFO Deputy Manager, CBFO OEP Director or designee with a detailed peer review schedule and updates, as required. This information will be provided to observers as requested.

A6.0 General Peer Review Process

6.1 Peer Review Plan

The peer review chairperson shall ensure that a peer review plan is prepared and approved by the CBFO prior to each peer review. The peer review plan shall contain, at a minimum:

- The scope of the peer review and description of the work to be reviewed.
- The intended use of the work in performance assessment (if applicable).
- The composition of the peer review panel.
- Suggested methods (e.g., the method used to document observations, comments, and conclusions).
- The schedule to complete the peer review report.
- The frequency of status reports.

6.2 Subject Matter Peer Review Process.

6.2.1 Peer reviews shall be conducted in accordance with the requirements of the peer review procedure and the peer review plan. Major changes to the peer review procedure or the plan shall be submitted to the responsible CBFO Deputy

Manager, CBFO OEP Director or designee for review and concurrence. The peer review chairperson may approve minor changes (e.g., editorial, renumbering sections, reformatting forms, updating organization titles, and clarifications that do not change intent) to the peer review plan.

6.2.2 The peer review process shall consist of an in-depth analysis and evaluation of:

A. Validity of assumptions.

B. Alternate interpretations.

C. Uncertainty of results and consequences, if incorrect.

D. Appropriateness and limitations of methodology and procedures.

E. Adequacy of application.

F. Accuracy of calculations.

G. Validity of conclusions.

H. Adequacy of requirements and criteria in accordance with approved technical and QA requirements and the applicable peer review plan(s).

6.2.3 Peer review panel members shall interact to ensure that sufficient consideration is given to interdisciplinary and coupled data and information.

6.2.4 Each peer review panel member shall support the peer review chairperson in the preparation of the peer review report on their specific review areas.

6.2.5 The peer review chairperson shall provide technical leadership to the peer review panel members and determine the manner in which the required peer review evaluations and reporting are conducted.

6.2.6 The peer review chairperson shall delegate the assignments of specific review tasks and activities among peer review panel members.

6.2.7 The peer review chairperson shall coordinate peer review panel activities in accordance with applicable procedures and the peer review plan.

6.2.8 The peer review chairperson shall provide the required coordination between the peer review panel members and the responsible Deputy Manager, OEP Assistant Manager or designee to ensure that an effective and responsible flow of information and logistic/technical support is provided.

6.2.9 The peer review chairperson shall provide the Deputy Manager, OEP Assistant Manager or designee with periodic progress reports on the status of the peer review, as specified within the peer review plan.

6.2.10 The peer review chairperson shall ensure that all required forms and documentation are complete prior to the start of the peer review process.

6.2.11 The peer review chairperson shall ensure that the peer review is accomplished and documented in accordance with approved procedures or with this attachment, and in an effective and timely manner.

6.3 Peer Review Daily Caucus

6.3.1 When peer review activities are conducted, the peer review panel chairperson shall schedule and conduct daily caucuses of the peer review panel to address issues, concerns, questions, conflicts, etc.

6.3.2 The peer review chairperson shall ensure that written caucus minutes are developed, shall initial the minutes to signify that they have been reviewed and reasonably represent the work of the peer review panel, and shall ensure the minutes are maintained as QA records.

6.3.3 Authorization for observers to attend the caucus meetings shall be obtained through the peer review chairperson prior to admittance.

6.4 Peer Review Report

6.4.1 A written peer review report will be prepared under the direction of the peer review chairperson and will contain the following:

A. Listing of peer review panel members.

B. Description of the work or issue that was reviewed, documenting:

1. Validity of assumptions.

2. Alternate interpretations.

3. Uncertainty of results and consequences, if incorrect.

4. Appropriateness and limitations of methodology and procedures.

5. Adequacy of application.

6. Accuracy of calculations.

7. Validity of conclusions.

8. Adequacy of requirements and criteria in accordance with approved technical and QA requirements and the applicable peer review plan(s).

C. Conclusions reached by the peer review panel.

D. Individual statements by the peer review panel members, reflecting dissenting views or additional comments, as appropriate.

E. Signature of the peer review chairperson and each peer review panel member.

6.4.2 The peer review report will also include the following appendices:

A. Peer review panel chairperson qualification documentation.

B. Peer review plan(s) including peer review procedures (identify if different from Attachment I of CBFO MP 10.5).

C. Peer review panel member qualification and selection documentation including:

1. Verification of education/employment documentation (CBFO Form 10.5-1).

2. Determination of peer review panel member independence documentation (CBFO Form 10.5-2).

3. Justification/decision related to peer review panel selection (CBFO Form 10.5-3).

D. Acquisition documents (beginning with request for peer review from CBFO Office of Business Operations through peer review panel member service provider contracting documentation).

6.5 Supplemental Information and Data

In the event that issues affecting the defined purpose of the peer review are identified in the peer review report, the panel may be reconvened to review supplementary information provided to resolve such issues. If the panel is reconvened, the review of the supplementary data and information shall be conducted in accordance with this procedure. The results of the supplementary peer review shall be documented in a supplementary peer review report.

A7.0 Record Retention and Maintenance

7.1 QA records shall be retained by the peer review chairperson until completion of the peer review process. Upon completion of the peer review process, the peer review chairperson shall transfer all QA records to the responsible CBFO Deputy Manager, CBFO OEP Director or designee.

7.2 QA records to be retained include:

- Peer review plans
- Peer review procedures (if different from Attachment I of CBFO MP 10.5)
- Service acquisition documents
- Peer review panel member education/employment documentation
- Peer review panel member independence documentation
- Peer review panel selection justification
- Peer review panel member service provider contracting documentation
- Observer inquiry forms
- Peer review panel chairperson qualification documentation
- Peer review panel member selection documentation
- Peer review panel orientation documentation and attendance form
- Written minutes of meetings, deliberations, and activities
- Peer review report

Example of CBFO Form 10.5-1

Peer Review Panel Member Verification of Education/Employment Form

Section 1

Peer panel member nominee information:

My signature verifies that the information contained in this resume is correct. You are hereby authorized to verify this information.

Name:_____ _____ _____
Printed Date Signature

The resume will contain nominee's education and employment history.

I. EDUCATION: A list of educational institution(s), degree(s), discipline(s)/subject(s), and year(s).

II. EMPLOYMENT HISTORY: A list of employment history for the previous ten (10) years, starting with the latest. The history will include responsibilities [in general terms] and years with each employer.

Please note that (all) official transcript(s) is (are) to be in (a) sealed envelope(s) from the university registrar(s). Foreign degrees need to be verified and evaluated by credential evaluation services.

Section 2

The peer review chairperson is responsible for completing this section.

Position/Title: _____

Comments:_____

_____

_____

_____

_____

_____

_____

Peer Review Chairperson:

Name:_____ _____ _____
Printed Date Signature

EXAMPLE

Example of CBFO Form 10.5-2

Determination of Peer Review Panel Member Independence Form

Are you currently employed by DOE or a DOE contractor? ☐ Yes ☐ No

Were you employed by DOE or a DOE Contractor previously? ☐ Yes ☐ No

(If yes, give dates, location, organization, position, and type of work performed.)

Do you have or have you had any direct involvement or financial interest in the work under review? ☐ Yes ☐ No

(If yes, describe.)

Is there any reason why you cannot perform an impartial peer review? ☐ Yes ☐ No

(If yes, describe.)

Is there any aspect of your past that may lead to a perception of bias in the results of your peer review? ☐ Yes ☐ No

(If yes, describe.)

I pledge that my review of this work will be completely impartial and based solely on the information available during the review.

Name:_____ _____ _____
Printed Date Signature

EXAMPLE

Example of CBFO Form 10.5-3

Peer Review Panel Selection Justification/Decision Form

Selection committee members:

Peer review entitled:

_____

Peer review panel composition:

1._____
2._____
3._____
4._____
5._____
6._____
7._____
8._____
9._____
10._____

Justification:

Peer Review Chairperson:

Name:_____ _____ _____
Printed Date Signature

EXAMPLE

Example of CBFO Form 10.5-4

Peer Review Panel Orientation Form

Date:_____ Peer Review Chairperson:_____

Peer review subject or title:_____

Attendees:

PRINTED NAME	SIGNATURE	DATE

EXAMPLE

Example of CBFO Form 10.5-5

Observer Inquiry Form

Date:_____ Observer:_____ Organization:_____

Peer review subject or title:_____

COMMENTS:

RESPONSE:

Peer review chairperson:

Printed Name _____ Signature _____ Date _____

EXAMPLE

Waste Isolation Pilot Plant
Additional Panels Performance Assessment
Changed Conceptual Models
Peer Review Report
December 2021

APPENDIX C

Peer Review Panel Member Qualification and Selection Documentation

Includes:

1. Verification of Education/Employment Documentation

2. Determination of Peer Review Panel Member Independence Documentation

3. Justification/Decision Related to Peer Review Panel Selection

Determination of Peer Review Panel Member Independence Documentation

Additional Panels Performance Assessment Changed Conceptual Models
Candidate Evaluation Form

Candidate Name: Ronald W. Falta

Date Contacted: June 15, 2021

Phone Number: [redacted]

E-Mail Address: [redacted]

Record of Conversation

- Contacted 06/15/21 and left a voice mail message for Ron to give me a call back. I also e-mailed him and left my number for him to call me.
- Ron responded to my e-mail with his cell phone number. I will contact him on that number.
- I spoke with Ron while he was in his car on his way to an appointment. He is interested and potentially available. His current rate to DOE is [redacted] He will call me back when he is back in his office.
- Ron called late in the day and we discussed his availability. He will be on Vacation July 10 – 17th. He agreed to a rate of [redacted]

Are you available interested and available to serve as a peer reviewer for the Waste Isolation Pilot Plant Additional Panels Performance Assessment Changed Conceptual Models Peer Review? **Yes**

Are you currently or have you previously been employed by DOE or a DOE Contractor? **I worked for the Lawrence Berkeley National Lab as a graduate student and Post-Doc from 1984 through 1991. Since then I have not been employed by DOE or a DOE contractor as I have been a full-time professor at Clemson. I have had a number of research and consulting contracts with DOE and DOE contractors over the years and I have listed all of these since 1992:**

2019- present *U.S. Department of Energy through Savannah River Nuclear Solutions, LLC,* Aiken, SC (2019-present). Technical peer review support for the Hanford, WA Cumulative Impact Evaluation groundwater modeling project.

2020 *U.S. Department of Energy through Navarro Research & Engineering,* Oak Ridge, TN (2020). Participate on expert review panel related to uranium mill tailings sites in the western US.

2018 *U.S. Department of Energy through Navarro Research & Engineering,* Grand Junction, CO (2018). Participate in groundwater modeling and geochemistry group modeling summit related to uranium mill tailings sites.

2016-2018 Evaluating Thermal Heating with Elemental Mercury; Sponsored by *Savannah River National Laboratory*, Principal Investigator (100%), $63,656.

2010-2011	Incorporating Aerobic Processes into Remedies for Large Chlorinated Solvent Plumes, SCUREF from *Savannah River National Laboratory* through ESTCP, Principal Investigator (100%), $80,120.
2004	Department of Energy Monitored Natural Attenuation MNA/EPR Alternative Project: Review of RFI Packages, Westinghouse Savannah River Company, Principal Investigator, $7,973.
2002-2006	Fracture Dissolution of Carbonate Rocks: An Innovative Process for Gas Storage, *United States Department of Energy, National Energy Technology Laboratory*, Co-Investigator (25%), $713,060.
2002	*Idaho National Engineering and Environmental Laboratory*, Idaho Falls, ID, (2002), Numerical model development for simulating gas flow in the vadose zone due to barometric pressure fluctuations.
2002	Assessment of Air Sparging/Soil Vapor Extraction Operation at A-Area Burning/Rubble Pits and Rubble Pit (ABRP) Operable Unit, *Westinghouse Savannah River Company*, Principal Investigator, $35,143.
2000-2001	Numerical Modeling of Free-Phase TCE/PCE Emplacement and Transport in the M-Area Basin and Evaluation of Thermal Remediation Technologies, *Westinghouse Savannah River Company*, Principal Investigator, $61,671.
2000	DNAPL Characterization Program: Determining the Feasibility of DNAPL Remediation in the A/M Area Using Density Balanced Mobilization Techniques *Westinghouse Savannah River Company*, Principal Investigator, $21,224.
1998-2002	Quantitative Methods for Reservoir Characterization and Improved Recovery: Application to Heavy Oil Sands, *United States Department of Energy*, Co-Investigator, $588,707.
1998-2000	Book Describing the Current State of Science for the Vadose Zone, *Westinghouse Savannah River Company*, Principal Investigator, $49,698.
1998	Cosolvent Flooding Technology Development (I), *Westinghouse Savannah River Company*, Principal Investigator, $19,947.
1998	DNAPL Characterization Program: DNAPL Transport Modeling (II), *Westinghouse Savannah River Company*, Principal Investigator, $13,812.
1997-1998	DNAPL Characterization Program: DNAPL Transport Modeling (I), *Westinghouse Savannah River Company*, Principal Investigator, $55,387.
1997	Technical Support of DNAPL Characterization Program (II), *Westinghouse Savannah River Company*, Principal Investigator, $44,850.
1995-1996	Technical Support of DNAPL Characterization Program (I), *Westinghouse Savannah River Company*, Principal Investigator, $216,731.

1992	Savannah River Site Integrated Demonstration Project Analysis and Evaluation Technical Support, *Lawrence Berkeley Laboratory*, University of California, Principal Investigator, $37,214.
1990-1991	*Lawrence Berkeley National Laboratory*, Post Doctoral Researcher, Earth Sciences Division
1984-1990	*Lawrence Berkeley National Laboratory*, Graduate Research Assistant, Earth Sciences Division

Do you have or have you had any direct involvement or financial interest in the work under review? **No**

Is there any reason why you cannot perform an impartial peer review? **No**

Is there any aspect of your past that may lead to a perception of bias in the results of your peer review? **No**

Name: Ronald Falta
Ron Falta, Ph.D.

Date: 6/16/21

Name:
John A. Thies, Peer Review Panel Chairperson

Date: 09/27/21

Additional Panels Performance Assessment Changed Conceptual Models Candidate Evaluation Form

Candidate Name:	Edward M. Kwicklis
Date Contacted:	June 18, 2021
Phone Number:	[redacted]
E-Mail Address:	[redacted]

Record of Conversation

- Ed was recommended by David Moulton and I contacted him on 06/18/21 via e-mail. I left a message to give me a call back
- Ed responded via telephone late in the day and we discussed his availability. He is interested and available

Are you available interested and available to serve as a peer reviewer for the Waste Isolation Pilot Plant Additional Panels Performance Assessment Changed Conceptual Models Peer Review? **Yes**

Are you currently or have you previously been employed by DOE or a DOE Contractor? **Yes** (If yes, give dates, location, organization, position, and type of work performed.)

I am recently retired, but was employed as a staff scientist at Los Alamos National Laboratory in Los Alamos NM between February 1999 and April 2021 in the Earth and Environmental Sciences (EES) Division, Computational Earth Science Group. During this time I worked on the development of a numerical models of saturated and unsaturated groundwater flow and radionuclide transport for Yucca Mountain and the former Nevada Test Site (now the Nevada National Security Site), and also developed an independent understanding of long-term groundwater flow and transport behavior from the interpretation of naturally-occurring environmental tracers. I was team leader of the Subsurface Flow and Transport Team within EES between 2008 and 2014, and from 2008 to 2020 was DOE's chief scientist for the Yucca Flat region of the NTS where 747 underground nuclear tests were conducted between 1957 and 1992. Between 2015 and 2020, I also led a numerical modeling project to interpret radionuclide data from former US weapons tests to better understand radionuclide signatures associated with clandestine nuclear weapons programs. Though retired, I continue to hold a Q-clearance from the DOE.

Do you have or have you had any direct involvement or financial interest in the work under review? **No**

Is there any reason why you cannot perform an impartial peer review? **No**

Is there any aspect of your past that may lead to a perception of bias in the results of your peer review? **No**

Name: Edward M Kwicklis Date: 6/21/2021

Edward M. Kwicklis

Name: _____ Date: 09/27/21

John A. Thies, Peer Review Panel Chairperson

Additional Panels Performance Assessment Changed Conceptual Models
Candidate Evaluation Form

Candidate Name: Mengsu Hu

Date Contacted: June 18, 2021

Phone Number: [redacted]

E-Mail Address: [redacted]

Record of Conversation

- Contacted 06/18/21 via e-mail and left a message for Mengsu to give me a call back.
- Mengsu responded to my email by phone and indicated that she is interested and available.

Are you available interested and available to serve as a peer reviewer for the Waste Isolation Pilot Plant Additional Panels Performance Assessment Changed Conceptual Models Peer Review? **Yes**

Are you currently or have you previously been employed by DOE or a DOE Contractor? **Yes** (If yes, give dates, location, organization, position, and type of work performed.) Mengsu is currently employed by Lawrence Berkley National Laboratory.

Do you have or have you had any direct involvement or financial interest in the work under review? **No.** Mengsu has not previously worked on WIPP.

Is there any reason why you cannot perform an impartial peer review? **No**

Is there any aspect of your past that may lead to a perception of bias in the results of your peer review? **No**

Name: Mengsu Hu
Mengsu Hu, Ph.D.

Date: 06/20/2021

Name: John A. Thies
John A. Thies, Peer Review Panel Chairperson

Date: 09/27/21

Additional Panels Performance Assessment Changed Conceptual Models
Candidate Evaluation Form

Candidate Name: Carl Steefel

Date Contacted: June 15, 2021

Phone Number: [redacted]

E-Mail Address: [redacted]

Record of Conversation

- Contacted 06/15/21 via e-mail and left messages on his work and cell phones.
- Carl called back on 06/16/21 and agreed to be on the peer review panel. He is checking on whether he has to do it through LBL or can do it as a consultant. He is also checking on his rate.

Are you available interested and available to serve as a peer reviewer for the Waste Isolation Pilot Plant Additional Panels Performance Assessment Changed Conceptual Models Peer Review? **Yes**

Are you currently employed or have you previously been employed by DOE or a DOE Contractor? **Yes** (If yes, give dates, location, organization, position, and type of work performed.) See Carl's CV. Carl currently works for Lawrence Berkley National Laboratory, which is a DOE funded Laboratory.

Do you have or have you had any direct involvement or financial interest in the work under review? **No**

Is there any reason why you cannot perform an impartial peer review? **No**

Is there any aspect of your past that may lead to a perception of bias in the results of your peer review? **No**

Carl S. Steefel

Name: Carl Steefel, Ph.D. Date: June 18, 2021

Name: John A. Thies, Peer Review Panel Chairperson Date: 09/27/21

Additional Panels Performance Assessment Changed Conceptual Models Candidate Evaluation Form

Candidate Name:	Sherilyn Williams-Stroud
Date Contacted:	June 16, 2021
Phone Number:	[redacted]
E-Mail Address:	[redacted]

Record of Conversation

Contacted 06/16/21 called and left a message for Sheryl. Sherilyn returned my call asked questions and expressed interest. Her Rate is [redacted] She is available in the time frames required.

Are you available interested and available to serve as a peer reviewer for the Waste Isolation Pilot Plant Additional Panels Performance Assessment Changed Conceptual Models Peer Review? **Yes**

Are you currently or have you previously been employed by DOE or a DOE Contractor? **Yes**

I am a subrecipient on a DOE-funded research project: DE-FE0031784 "A Novel 'Smart Microchip Proppants' Technology for Precision Diagnostics of Hydraulic Fracture Networks" awarded to University of Kansas, 09/01/2018 – 08/31/2021. On this project I will contribute to the construction and validation of a high resolution reservoir model, providing fracture network scenarios to match the telemetry obtained from the smart proppants.

Do you have or have you had any direct involvement or financial interest in the work under review? **No**

Is there any reason why you cannot perform an impartial peer review? **No**

Is there any aspect of your past that may lead to a perception of bias in the results of your peer review? **No**

Name: _____ Date: 06/17/2021
Sherilyn Williams-Stroud, Ph.D.

Name: _____ Date: 09/27/21
John A. Thies, Peer Review Panel Chairperson

Justification/Decision Related to Peer Review Panel Selection

Memo

Date: June 9, 2021

To: Vann Bynum, Ph.D. and Anderson Ward, Ph.D.,

Subject: Selection of Peer Review Panel Members

I am requesting that you and Mr. Anderson Ward participate as part of the peer review selection committee for the Additional Panels Performance Assessment (APPA) Changed Conceptual Models peer review. As part of the peer review panel selection committee, you are requested to identify the composition of the peer review panel. The following presents the scope of the peer review and the criteria for selecting the panel members. The relevant peer review plan is attached. A list of candidate peer reviewers is attached. Please feel free to add to the list, if necessary.

APPA Changed Conceptual Models Peer Review

The scope of this peer review is to evaluate the adequacy of changes to the following conceptual models:

- Disposal System Geometry.
- Repository Fluid Flow.
- Direct Brine Release.

Disposal System Geometry - The Disposal System Geometry conceptual model expresses the dimensionality of the engineered system and surrounding geologic/hydrogeologic formations. The addition of new repository waste panels and associated drifts necessitate changes to the BRAGFLO (brine and gas flow) grid, which is a change in this conceptual model.

Repository Fluid Flow - The Repository Fluid Flow conceptual model addresses: (1) fluid distribution in the waste, (2) long-term fluid flow to-and-from the Salado Formation and shafts, and (3) long-term fluid flow between the repository and intrusion boreholes. The Repository Fluid Flow conceptual model is a complex description of simultaneous, interacting hydrologic, chemical, geomechanical, engineering design, and human intrusion scenarios. The effects can be described separately, but require numerical modeling to identify the combined, integrated outcome. The processes controlling repository fluid flow include brine inflow rates, halite creep rates, gas generation from anoxic iron corrosion, microbial degradation, and brine radiolysis. The computer (computational) model accepts inputs from other related computer models and provides numerical results of pressures, flow rates, and flow directions for brine and gas within the excavated areas of the Salado formation. The key elements of the repository layout, pertaining to the Repository Fluid Flow conceptual model, are the waste disposal area (the waste panels and access drifts), the panel closures, the shaft pillar access drifts area, the northern experimental area, the shafts, the WIPP site characterization boreholes in the vicinity of the repository, and any future inadvertent human intrusion boreholes that are modeled to penetrate the repository at random times and random locations.

Memo

Direct Brine Release - Direct Brine Release refers to the probability that brine containing actinides may flow from the waste panels up a borehole to the surface during an inadvertent human intrusion drilling event. In general, the important features of the DBR grid are retained in the APPA DBR grid; however, the change to modeling only a subsection of the waste area is a shift in the conceptual model.

Peer Review Panel Member Selection Criteria

The peer review panel will be composed of five individuals. Each Panel member must:

- Possess subject matter technical expertise to a degree at least equivalent to that needed for the original work.
- Be independent of the work being reviewed, which means that they have not been involved as participants, supervisors, technical reviewers, or advisors in the work being reviewed.
- Have sufficient freedom from funding considerations to ensure that the work is impartially reviewed.

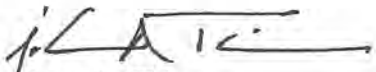
The panel members should include individuals who have expertise in modeling subsurface flow and transport, a general knowledge of geologic disposal systems, and familiarity with the use of performance assessment to meet regulatory requirements.

The collective technical expertise and qualifications of peer review panel members shall span the issues, and areas involved in the work to be reviewed, including any differing bodies of scientific thought. Technical areas more central to the work to be reviewed shall receive proportionally more representation on the peer review panel. The peer review panel should represent the major schools of scientific thought. The potential for technical or organizational partiality shall be minimized by the formation of a balanced peer review panel.

Please submit a list of 5 primary and 5 backup individuals to me by Friday June 18. Thank you for your support to this important task.

If you have any questions please contact me at the 505-239-4176 or johnathies@gmial.com.

Best Regards,



John A. Thies
APPA Changed Conceptual Models Peer Review Chairperson

Peer Review Panel Selection Justification/Decision Form

(CBFO Form 10.5-3)

Selection committee members:

- John A. Thies, Panel Chairperson
- Richard (Vann) Bynum, Ph.D.
- Anderson L. Ward

Peer review entitled:
Additional Panels Performance Assessment Changed Conceptual Models Peer Review

Peer review panel composition:
Panel Members

1. Sherilyn Williams-Stroud, Ph.D.
2. Mengsu Hu, Ph.D.
3. Ronald W. Falta, Jr., Ph.D.
4. Edward M. Kwicklis
5. Carl I. Steefel, Ph.D.

Alternate

1. Steve Alcorn, Ph.D.

Justification:

The peer review panel size and composition was determined by the peer review chairperson. The Chairperson discussed the complexity of the peer review with Sandia and DOE personnel and determined that 3 peer reviewers was adequate based on the complexity of the work, its importance in meeting safety and waste isolation performance goals, the number of technical disciplines involved, the degree to which uncertainties in the data exist, and the extent to which differing viewpoints are held within the applicable technical and scientific community concerning the issues under review. The Chairperson, based on discussions with DOE, decided that 5 peer reviewers would provide additional breadth of coverage for the topics being reviewed and additional depth of insight and analysis.

The peer review chairperson established a peer review panel member selection committee comprised of Vann Bynum, Ph.D. and Anderson Ward, Ph.D. The Chairperson also utilized a technical advisor, George Basabilvazo, to assist in the process of identifying and screening peer review panel member candidates. During the process of identifying candidates and selecting a short-list of recommended candidates, the peer reviewer selection committee considered the collective technical expertise and qualifications of peer review panel members. Peer review panel member candidates had to have education, knowledge, and/or experience that spans the issues and technical areas involved in the work to be reviewed, including any differing bodies of scientific thought. The technical areas more central to the work to be reviewed received proportionally more emphasis and representation on the peer review panel. The peer review panel member selection committee considered individuals with recognized and verifiable technical qualifications at least equivalent to those needed for the original work under review (the primary consideration in the selection process) in the technical area the panel member has been selected to cover. The technical qualifications of each panel member and of the peer review panel as a whole directly relates to the importance of the subject matter to be reviewed.

One alternate peer reviewer was identified in the case that a panel member cannot finish or fulfill the review process, the peer review chairperson will use the alternate as a replacement.

The acceptability of all of the peer review panel members was based on their technical qualifications and independence. The Peer review chairperson confirmed that the peers selected would provide an in-depth review that considered relevant data, models, and methods; and that conducted objectively and without bias. The peer review panel represents the major schools of scientific thought pertinent to the topics being reviewed. The potential for technical or organizational partiality has been minimized by the formation of a balanced peer review panel.

The peer review chairperson eliminated potential peer review panel members from consideration based upon there being more qualified individuals available and/or the candidate was not available, and/or the candidate had a potential or perceived organizational conflict of interest. All of the selected Peer review panel members are independent of the original work that they are reviewing.

Attachment 1 - Long-list of individuals identified as potentially qualified as peer review panel members.

Attachment 2 - Short-list of individuals recommended as peer review panel members by the selection committee.

Attachment 3 - List of peer review panel members selected by the Peer Review Chairperson.

Peer Review Chairperson Signature

Name: John A. Thies

09/27/21
Date

Attachment 1

Long-List of Individuals Identified as Potentially Qualified as Peer Review Panel Members.

Candidate
Steve Alcorn, Ph.D.
Jean Bahr, Ph.D.
Victor Baker, Ph.D.
Jens Birkholzer
Thomas A. Buscheck
Mathieu Debure, Ph.D.
Sylvia G. Dee, Ph.D.
Ronald W. Falta, Ph.D.
Andy Fisher, Ph.D.
George M. Hornberger, Ph.D.
Mengsu Hu, Ph.D.
Scott James, Ph.D., PE
Daniel I. Kaplan, Ph.D.
Edward M. Kwicklis
John T. Leftwich, Jr., Ph.D.
Nicolas Marty, Ph.D.
Diane McKnight, Ph.D.
Nigel Mote
J. David (Dave) Moulton, Ph.D.
Mark Person, Ph.D.
Karsten Pruess, Ph.D.
Jonny Rutqvist, Ph.D.
Bridget Scanlon, Ph.D.
Kirsten L. Siebach, Ph.D.
Carl I. Steefel, Ph.D.
Sherilyn Williams-Stroud, Ph.D.
Megan M Smith
Avner Vengosh, Ph.D.
Clifford I Voss, Ph.D.
John Walton, Ph.D.
Mark White, Ph.D., PE
Michael Young, Ph.D.

Attachment 2

Short-List of Individuals Recommended as Peer Review Panel Members by the Selection Committee.

Recommended Candidate	Available When Needed	Meets Technical Requirements	Independent	Unbiased	Notes
Steve Alcorn, Ph.D.	Yes	Yes	Yes	Yes	
Michael D. Annable, Ph.D.	No				
Ronald W. Falta, Ph.D.	Yes	Yes	Yes	Yes	
Andy Fisher, Ph.D.	No				
Mengsu Hu, Ph.D.	Yes	Yes	Yes	Yes	
Edward M. Kwicklis	Yes	Yes	Yes	Yes	
Nigel Mote	Not Contactede				Equally or more qualified person available.
J. David Moulton, Ph.D.	No				
Karsten Pruess, Ph.D.	No Response				
Jonny Rutqvist, Ph.D.	No Response				
Bridget Scanlon, Ph.D.	No				
Carl I. Steefel, Ph.D.	Yes	Yes	Yes	Yes	
Sherilyn Williams, Ph.D.	Yes	Yes	Yes	Yes	
Clifford I Voss, Ph.D.	Not Contacted				Equally or more qualified person available.
John Walton, Ph.D.	Not Contacted				Equally or more qualified person available.
Mark White, Ph.D., PE	No				
Michael Young, Ph.D.	Not Contacted				Equally or more qualified person available.

Attachment 3

Peer Review Panel Members Selected by the Peer Review Chairperson.

Panel Members Selected by the Peer Review Chairperson

- Sherilyn Williams-Stroud, Ph.D.
- Mengsu Hu, Ph.D.
- Ronald W. Falta, Jr., Ph.D.
- Edward M. Kwicklis
- Carl I. Steefel, Ph.D.

MEMO

June 11, 2021

This memo serves to document the selection of Richard Vann Bynum, Ph.D. and Anderson Ward, Ph.D. as the individuals that will assist me in the selection of peer reviewers for reviewing changes proposed to the three of the conceptual models for the Waste Isolation Pilot Plant (WIPP) Additional Panels Performance Assessment (APPA). Drs. Anderson and Bynum were chosen based on,

- Their knowledge of the regulatory requirements that guide the peer review process. and the plans and procedures that implement the peer review process for the Carlsbad Field Office (CBFO);
- Their in-depth knowledge of the technical aspects of WIPP performance assessment;
- Their knowledge of qualified candidates for the peer review panel; and
- Their impartiality and lack of organizational conflict of interest.

John A. Thies
Changed Conceptual Models
Peer Review Chairperson

Context

According to 40 CFR 4.27, a peer review is to be conducted in accordance with the Nuclear Regulatory Commission's document NUREG 1297, which stipulates requirements for conducting peer reviews. To implement the requirements, the Carlsbad Field Office developed Management Procedure (MP) 10.7, Rev. 10, which prescribes the peer review process.

The peer review panel size and composition were determined by the peer review chairperson based on:

- The range of complexity of the technical issues to be addressed (in this case 3 changed conceptual models).
- The importance of the subject matter to meeting waste isolation performance goals.
- The technical disciplines involved.
- The degree to which uncertainties in the models and technical approach exist.
- The extent to which differing viewpoints are held within the scientific community concerning the issues to be reviewed.

Individual Panel members were selected to ensure that their collective technical expertise and qualifications as a peer review panel spanned the issues and technical areas involved in the work to be reviewed, including differing bodies of scientific thought. Technical areas more central to the work to be reviewed received proportionally more representation on the Panel. The peer review panel members selected are balanced and impartial, providing good representation of the relevant areas of modeling and science. The acceptability of each peer review panel member was based on their technical qualifications and independence, both of which had to be satisfied.

Each peer review panel member has recognized and verifiable technical qualifications at least equivalent to those needed for the original work that was reviewed in the technical area(s) that the panel member has been selected to cover.

Verification of Education/Employment Documentation

Peer Review Panel Member Verification of Education/Employment Form

Section 1

Peer panel member nominee information:

My signature verifies that the information contained in this resume is correct. You are hereby authorized to verify this information.

Name: Ronald William Falta, Jr. (Printed) 9/21/21 (Date) Ronald William Falta, Jr (Signature)

The resume will contain nominee's education and employment history.

I. EDUCATION: A list of educational institution(s), degree(s), discipline(s)/subject(s), and year(s).

II. EMPLOYMENT HISTORY: A list of employment history for the previous ten (10) years, starting with the latest. The history will include responsibilities [in general terms] and years with each employer.

Please note that (all) official transcript(s) is (are) to be in (a) sealed envelope(s) from the university registrar(s). Foreign degrees need to be verified and evaluated by credential evaluation services.

Section 2

The peer review chairperson is responsible for completing this section.

Position/Title: Peer Review Panelist

Comments: Professional experience spans 20 years, predominantly with Clemson University. Dr. Falta's education includes a bachelor's and Masters of Science in Civil Engineering from Auburn University, and a PhD in Mineral Engineering from the University of California, Berkeley. Dr. Falta has extensive experience with consultations related to groundwater modeling and remediation efforts involving groundwater contamination. Dr. Falta has an extensive amount of publications in the field of modeling and contaminant transport.

Peer Review Chairperson:

Name: John A. Thies (Printed) 09/27/21 (Date) (Signature)

RESUME Ronald W. Falta, Jr.

PERSONAL DATA

Professor
Department of Environmental Engineering and Earth Science
Clemson University
Brackett Hall Room 336
Clemson, SC 29634-0919
[redacted]
[redacted]

EDUCATION

Ph.D., Mineral Engineering, 1990, *University of California, Berkeley*

MS., Civil Engineering, 1984, *Auburn University*

BS., Civil Engineering, 1982, *Auburn University*

PROFESSIONAL EXPERIENCE

Clemson University, 1999- , Professor of Geology and Environmental Engineering and Science

1995-1999 Associate Professor of Geology and Environmental Systems Engineering

1992-1995, Assistant Professor of Geology and Environmental Systems Engineering

Lawrence Berkeley National Laboratory, 1990-1991, Post Doctoral Researcher, Earth Sciences Division

HONORS AND AWARDS

2020	National Ground Water Association John Hem Award
2020	Honor Award for University Research, American Academy of Environmental Engineers & Scientists
1987	Second place award for the best paper of 1986 in the Journal *Ground Water*
1984	University of California Jane Lewis Fellowship
1981	Chi Epsilon Civil Engineering Honorary Society
1981	Tau Beta Pi Engineering Honorary Society

CONSULTING EXPERIENCE

Synterra Corp., Greenville, SC (2014-present). Expert support and development of groundwater flow and transport models for simulating closure and remediation at 14 coal ash basin sites in North Carolina, and one in South Carolina.

U.S. Department of Energy through Savannah River Nuclear Solutions, LLC, Aiken, SC (2019-present). Technical assistance support for the Hanford, WA Cumulative Impact Evaluation groundwater modeling project.

U.S. Department of Energy through Navarro Research & Engineering, Oak Ridge, TN (2020). Participate on expert review panel related to uranium mill tailings sites in the western US.

Hunton Andrews Kurth LLP, Charlotte, NC, (2019). Litigation support related to coal ash basin closure and remediation in North Carolina.

Duke Energy Business Services, Charlotte, NC, (2019). Litigation support related to coal ash basin contamination of groundwater in North Carolina.

U.S. Department of Energy through Navarro Research & Engineering, Grand Junction, CO (2018). Participate in groundwater modeling and geochemistry group modeling summit related to uranium mill tailings sites.

Electric Power Research Institute, Charlotte, NC (2017). Teach workshop on groundwater modeling for coal ash basin sites.

Regenesis, San Clemente, CA (2016). Groundwater modeling support.

Navarro Research and Engineering, Inc., Oak Ridge, TN (2016). Design of a thermal remediation system for site remediation.

Honeywell International, Inc., Morris Plains, NJ, (2016). Analysis of thermal remediation designs for site remediation.

ERM-West, Inc., Pasadena, CA, (2013-2015). Design and analysis of a steam injection treatability study for the DOE Paducah Gaseous Diffusion Plant, KY.

Kestrel Horizons, LLC, Greenville, SC (2014). Expert review of monitoring plans at the Pinewood Hazardous waste landfill.

ERM-UK, Ltd., Manchester, England (2014). Numerical modeling of a thermal remediation project.

Best Best & Krieger, Walnut Creek, CA, (2013-2015). Expert review of groundwater modeling efforts for the Rialto Colton Basin, CA.

Aiken Bridges Florence, SC (2012-2013). Expert for plaintiffs in a suit related to groundwater contamination by chlorinated solvents in South Carolina, John H. Nance, and JDS Development of Myrtle Beach, Inc. vs AVX Corporation, State of South Carolina Civil Action No.: 2008-CP-26-0436.

Kelaher, Connell & Connor, P.C., Surfside Beach, SC, (2011-2013). Expert for plaintiffs in a class action suit related to groundwater contamination by chlorinated

solvents in South Carolina, Clint A. Chestnut, et al. v. AVX Corporation, State of South Carolina, Civil Action No.: 2007-CP-26-7459.

LATA Kentucky, Kevil, KY, (2012-2013). Numerical modeling of thermal remediation of chlorinated solvents at the DOE Paducah Gaseous Diffusion Plant, KY.

ERM-Southeast Raleigh, NC, (2011-2012). Numerical modeling of thermal remediation projects at sites contaminated with chlorinated solvents and fuels.

Best Best & Krieger, Walnut Creek, CA, (2011-2012). Expert for plaintiffs in a suit related to groundwater contamination by perchlorate in California, City of Colton v. APE-West, et al., United States District Court Case Nos. ED CV 09-01864 PSG (SSx); CV 09-6630 PSG (SSx), CV 09-06632 PSG (SSx), CV 09-07501 PSG (SSx), CV 09-07508 PSG (SSx), and CV 10-00824 PSG (SSx).

Stratus Consulting, Boulder, CO (2004-2010) Expert for the United States in a lawsuit involving hydrocarbon contamination of a Department of Defense facility in Philadelphia, PA, U.S. vs. Sunoco, Inc., et al., Civil Action Number 05-6336; 90-11-3-07721.

Motley Rice LLC, Mt. Pleasant SC, (2006-2010) Expert for plaintiffs in case involving groundwater contamination by chlorinated solvents in Florida, Laura A. Ward et al., vs. Lockheed Martin Corporation, Florida Civil Action No. 2005-CA-4707.

GSI Environmental, Inc., Houston, TX (2009-2010) Develop and teach engineering short courses on REMChlor (funded by US DOE)

S.M. Stoller Corp., Grand Junction, CO, (2008) Assist in multiphase flow model testing for natural gas recovery.

Santarella and Eckert, LLC, Littleton, CO, and *Richard Wern Lawyers,* North Charleston, SC, (2007-2008) Expert for defense in a civil case involving damages from limestone quarrying and mine dewatering in South Carolina, Giant Cement Company v. Margaret Ann P. Westbury, State of South Carolina Case No. 2006-CP-18-0506.

Vandeventer Black, LLP, Norfolk, VA, *(2005-2006)* Expert support for dispute between petroleum terminal company and oil company in South Carolina

Nuclear Regulatory Commission, Rockville, MD, (2004-2006), Assist in development of a strategy for groundwater sampling at nuclear sites; teach workshops.

Speights and Runyan, Hampton, SC, (2004), Expert support in case involving leaking underground storage tanks in Alabama.

Daniel B. Stephens and Associates, Albuquerque, NM, (2004) Numerical modeling of vadose zone chemical transport.

Motley Rice LLC, Mt. Pleasant, SC, (2001-2004) Expert support in a case involving groundwater contamination by chlorinated solvents in South Carolina.

Speights and Runyan, Hampton, SC, (2001-2003) Expert for plaintiffs in a class action lawsuit related to leaking underground tanks at gasoline stations in South Carolina, Mary Louise Fairey, et al. v The Exxon Corporation, et al., State of South Carolina Civil Action No. 94-CP-38-118.

Conestoga-Rovers and Associates, Waterloo, Ontario, Canada, (2003) Analysis of multiphase flow and transport simulations at a Superfund site in Arizona

Environmental Protection Agency, Washington, DC, (2001-2003) Participation in an expert panel report on DNAPL remediation.

Ness, Motley, Loadholt, Richardson, and Poole (now Richardson, Patrick, Westbrook and Brickman), Mt. Pleasant, SC, (2001-2002) Expert for plaintiffs in a class action lawsuit involving impacts resulting from dewatering of a limestone quarry in South Carolina, Moses Brown et al. vs Martin-Marietta Materials, Inc, United States District Court, District of South Carolina, Civil Action No. 2:00-0793-18.

The Technical Research Center of Finland (VTT), Espoo, Finland, (2002) Short Course Organizer and Instructor, Subsurface Multiphase Fluid Flow and Remediation Modeling,

Idaho National Engineering and Environmental Laboratory, Idaho Falls, ID, (2002), Numerical model development for simulating gas flow in the vadose zone due to barometric pressure fluctuations.

The Proctor and Gamble Company, Cincinnati, OH, (2001-2002) Numerical model development and analysis of nonisothermal, compositional multiphase flow processes; presentation of a short course.

Purdue University, West Lafayette, IN, (2001) Numerical simulations of DNAPL source zone remediation.

Harding Lawson Associates, Denver, CO, (1998-1999) Simulation of multiphase flow contaminant transport in the vadose zone.

Dames and Moore, Santa Ana, CA, (1997-2000) Simulation of multiphase flow contaminant transport in the vadose zone.

Camp Dresser and McKee, Charlotte, NC, (1996-1997) Evaluation of groundwater resources in the Florence, SC area.

Hydrogeologic, Inc., Herndon, VA, (1992-1993), Development and verification of numerical models for compositional multiphase contaminant transport under nonisothermal conditions.

Paul A. Witherspoon, Inc., Berkeley, CA, (1991). Numerical modeling of a seasonal natural gas storage project in Illinois.

Erler and Kalinowski, Inc., San Mateo, CA, (1990-1991). Analysis of vadose zone chemical transport at a site in California.

Paul A. Witherspoon, Inc., Berkeley, CA, (1987-1991). Consultant for litigation support in connection with groundwater pollution problems at the Rocky Mountain Arsenal in Colorado, the Royal Hardage Superfund Site in

Oklahoma, the McColl Superfund Site in California, the Stringfellow Superfund Site in California, and a site in Montana.

Civil Engineering Department, University of California, Berkeley, Berkeley, CA, (1986). Development of a procedure for optimizing the design of air stripping systems for the removal of organic compounds from contaminated groundwater.

SPONSORED RESEARCH

2020-2023 Thermal In-Situ Sustainable Remediation (TISRSM) to Enhance Biotic and Abiotic Reactions and Accelerate Remediation Timeframes, Arcadis, through the Environmental Security Technology Certification Program ESTCP ER20-B2-5028, Principal Investigator (100%), $361,924.

2019-2022 Incorporating Matrix Diffusion in the New MODFLOW Flow and Transport Model for Unstructured Grids, Environmental Security Technology Certification Program ESTCP ER19-5028, Principal Investigator (100%), $857,213.

2019-2020 Evaluation of Hydraulic Source Isolation at the Barra Mansa Site and the Area P DuPont Camacari Site; Sponsored by DuPont, Principal Investigator (100%), $158,327.

2015-2019 Estimating Mobile-Immobile Mass Transfer Parameters using Direct Push Tools, Solutions-IES through the Strategic Environmental Research and Development Program SERDP 15 ER01-015, Principal Investigator (100%), $266,034.

2014-2018 A Practical Approach for Modeling Matrix Diffusion Effects in REMChlor, Environmental Security Technology Certification Program, ESTCP ER-201426, Principal Investigator (100%), $724,300.

2017-2018 Inhibitory and Synergistic Effects in Mixtures of Contaminants, and Evaluation of Hydraulic Source Isolation at the Area P DuPont Camacari Site; Sponsored by DuPont, Co-Investigator (50%), $143,976.

2016-2018 Evaluating Thermal Heating with Elemental Mercury; Sponsored by Savannah River National Laboratory, Principal Investigator (100%), $63,656.

2014-2017 Radionuclide Waste Disposal: Development of Multi-Scale Experimental and Modeling Capabilities, US Department of Energy, Co-Investigator, (5%), $5,250,000

2010-2016 Subsurface Thermal Energy Storage for Improved Heating and Air Conditioning Efficiency, Environmental Security Testing and Certification Program, ESTCP SI-1013, Principal Investigator (60%), $991,018

2009-2014 Understanding and Managing Risks Posed by Brines Containing Dissolved Carbon Dioxide, US Environmental Protection Agency Science

to Achieve Results (STAR) program, Principal Investigator (67%), $891,342.

2010-2011 Incorporating Aerobic Processes into Remedies for Large Chlorinated Solvent Plumes, SCUREF from Savannah River National Laboratory through ESTCP, Principal Investigator (100%), $80,120.

2007-2011 Contaminant Mass Transfer During Boiling in Fractured Geologic Media, Strategic Environmental Research and Development Program, SERDP ER-1553, Principal Investigator (50%), $541,000.

2007-2010 Decision & Management Tools for DNAPL Sites: Optimization of Chlorinated Solvent Source and Plume Remediation Considering Uncertainty, Environmental Security Testing and Certification Program, ESTCP ER-0704, Principal Investigator (100%), $572,000.

2003-2006 Impacts of DNAPL Source Zone Treatment: Modeling Assessment of the Benefits of Partial Source Removal, United States Environmental Protection Agency, Principal Investigator (100%), $353,910.

2002-2006 Fracture Dissolution of Carbonate Rocks: An Innovative Process for Gas Storage, United States Department of Energy, National Energy Technology Laboratory, Co-Investigator (25%), $713,060.

2004 Department of Energy Monitored Natural Attenuation MNA/EPR Alternative Project: Review of RFI Packages, Westinghouse Savannah River Company, Principal Investigator, $7,973.

2002 Assessment of Air Sparging/Soil Vapor Extraction Operation at A-Area Burning/Rubble Pits and Rubble Pit (ABRP) Operable Unit, Westinghouse Savannah River Company, Principal Investigator, $35,143.

2001 Application of Dual Media Concepts to Contaminant Migration in Heterogeneous Aquifers, Westinghouse Savannah River Company, Co-Investigator, $54,831.

2000-2001 Three-Dimensional Simulation of Multi-Phase Flow and Transport Processes for Evaluation of Soil Vapor Extraction Units 782-3M, -4M, and –7M, Westinghouse Savannah River Company, Principal Investigator, $101,565.

2000-2001 Numerical Modeling of Free-Phase TCE/PCE Emplacement and Transport in the M-Area Basin and Evaluation of Thermal Remediation Technologies, Westinghouse Savannah River Company, Principal Investigator, $61,671.

2000 DNAPL Characterization Program: Determining the Feasibility of DNAPL Remediation in the A/M Area Using Density Balanced Mobilization Techniques Westinghouse Savannah River Company, Principal Investigator, $21,224.

1998-2002	Quantitative Methods for Reservoir Characterization and Improved Recovery: Application to Heavy Oil Sands, United States Department of Energy, Co-Investigator, $588,707.
1998-2000	Book Describing the Current State of Science for the Vadose Zone, Westinghouse Savannah River Company, Principal Investigator, $49,698.
1998	Cosolvent Flooding Technology Development (I), Westinghouse Savannah River Company, Principal Investigator, $19,947.
1998	DNAPL Characterization Program: DNAPL Transport Modeling (II), Westinghouse Savannah River Company, Principal Investigator, $13,812.
1997-2002	Field Evaluation of DNAPL Remediation by Cosolvent Mobilization, United States Environmental Protection Agency, Principal Investigator, $518,036.
1997-1998	Field-Scale Model for Air Sparging Performance Assessment and Design, United States Department of Energy through a subcontract with Michigan Technological University, Principal Investigator, $75,083.
1997-1998	DNAPL Characterization Program: DNAPL Transport Modeling (I), Westinghouse Savannah River Company, Principal Investigator, $55,387.
1997	Technical Support of DNAPL Characterization Program (II), Westinghouse Savannah River Company, Principal Investigator, $44,850.
1995-1996	Technical Support of DNAPL Characterization Program (I), Westinghouse Savannah River Company, Principal Investigator, $216,731.
1994-1997	Field Evaluation of Cosolvent-Enhanced In-Situ Remediation, United States Environmental Protection Agency, Principal Investigator, $406,004.
1993-1994	Development and Evaluation of Remediation Alternatives for Subsurface NAPL Contamination, Westinghouse Savannah River Company, Principal Investigator, $253,519.
1992-1993	Remediation of Hydrocarbon Contaminated Groundwaters by Alcohol Flooding, South Carolina Universities Research and Educational Foundation Hazardous Waste Management Research Fund, Co-Investigator, $115,000.
1992	Savannah River Site Integrated Demonstration Project Analysis and Evaluation Technical Support, Lawrence Berkeley Laboratory, University of California, Principal Investigator, $37,214.

PUBLICATIONS

Books and Monographs

Looney, B.B., and R.W. Falta, editors, 2000, Vadose Zone Science and Technology Solutions, *Battelle Press*, Columbus, OH, 1540 p.

Refereed Journal Publications

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Farhat, S.K., D.T. Adamson, A. Gavaskar, S.W. Lee, R.W. Falta, and C.J. Newell, 2020, Impact of vertical discretization in numerical modeling of matrix diffusion in contaminated groundwater, accepted for publication, *Groundwater Monitoring & Remediation.*

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Castle, J.W., D.A. Bruce, R.W. Falta, and L.C. Murdoch, Manufactured Caverns in Carbonate Rock, US Patent 7,156,579 B2, January 2, 2007.

PROFESSIONAL ACTIVITIES

2019	Web-based seminar for the SERDP/ESTCP program, "REMChlor-MD Groundwater Transport and Remediation Model for Sites with Matrix Diffusion, presented to more than 500 people on February 7, 2019, https://serdp-estcp.org/Tools-and-Training/Webinar-Series/02-07-2019
2018	Session chair and Panelist, *The International Conference on Remediation of Chlorinated and Recalcitrant Compounds Conference*, Palm Springs, CA.
2016	Web-based seminar for the SERDP/ESTCP program, "Long Term Monitoring Issues at Chlorinated Solvent Sites", presented to more than 1000 people on April 21, https://www.serdp-estcp.org/Tools-and-Training/Webinar-Series/04-21-2016
2012	Web-based short course instructor, "Practical Models to Support Remediation Strategy Decision Making", EPA Office of Superfund Remediation and Technology Innovation, http://www.clu-in.org/conf/tio/gwmodel5_110712/
2011	Short course instructor, "Thermal Treatment Technologies, Lessons Learned", *SERDP/ESTCP Partners in Environmental Technology Technical Symposium & Workshop*, Washington, DC
2011	Short course instructor, "Practical Models Supporting Remediation of Chlorinated Solvents Training Course", Seattle, WA
2011	Short course instructor, "Practical Models Supporting Remediation of Chlorinated Solvents Training Course", Atlanta, GA
2010	Short course instructor, "Practical Models Supporting Remediation of Chlorinated Solvents Training Course", Kansas City, MO

2010 Session chair, *The International Conference on Remediation of Chlorinated and Recalcitrant Compounds Conference*, Monterey, CA

2010 Short course instructor, "Practical Models Supporting Remediation of Chlorinated Solvents Training Course", *The International Conference on Remediation of Chlorinated and Recalcitrant Compounds Conference*, Monterey, CA

2010 Invited speaker, *Savannah River National Laboratory Special Director's Seminar*, Aiken, SC

2010 Short course instructor "Practical Models Supporting Remediation of Chlorinated Solvents Training Course", Aiken, SC

2009 Short course instructor, "Tools for Management of Chlorinated Solvent-Contaminated Sites", *SERDP/ESTCP Partners in Environmental Technology Technical Symposium & Workshop*, Washington, DC

2009 Invited speaker, *Workshop on Strategies for Site Remediation and Diagnostics, Langan Engineering and Environmental Services*, East Brunswick, NJ.

2009 Short course instructor, *US EPA 19th Annual National Association of Remedial Project Managers Training Conference*, Atlanta, GA

2008 Invited speaker, *Groundwater Resources Association of California, Emerging Contaminants 2008*, San Jose, CA

2008 Short course instructor, *US Environmental Protection Agency*, Amherst, MA

2008 Invited speaker, *20th Annual National Tanks Conference and Expo, US EPA*, Atlanta, GA

2008 Invited speaker, *Southeastern In Situ Soil and Groundwater Remediation Conference*, Raleigh, NC

2008 Invited speaker, *Beazer East* environmental management meeting, Las Vegas, NV

2007 Keynote speaker, *Groundwater Quality 2007: Securing Groundwater Quality in Urban Environments*, Fremantle, Australia

2007 Invited speaker, *New England Interstate Water Pollution Control Commission* workshop, Atlanta, GA

2007 Short course instructor, *US Environmental Protection Agency*, Crystal City, VA.

2006 Invited speaker, *North Carolina Association of Groundwater Professionals*, Southern Pines, NC

2006 Short course instructor (twice), *Nuclear Regulatory Commission*, Rockville, MD

2006 Invited speaker, *Auburn University*, Auburn, Al

2005 Invited speaker, *Purdue University*, West Lafayette, IN

2005 Invited speaker, *The Fletcher Group*, Greenville, SC

2005 Invited speaker, *US Environmental Protection Agency*, Office of Solid Waste and Emergency Response / Office of Research and Development, Arlington, VA

2005 Invited speaker, *US Environmental Protection Agency*, Region 4 UST States Managers Meeting, Clemson, SC

2005	Invited speaker, *Tennessee Department of Environmental Control*, Nashville, TN
2004	Invited speaker, *US Environmental Protection Agency*, Region 3 States Leaking Underground Storage Tanks Technical Conference, Rocky Gap, MD.
2004	Member, Board of Examiners for Ph.D. thesis at the *Indian Institute of Technology*
2004	Session Chair, *US Department of Energy Office of Science* Conference on Numerical Modeling in the Geosciences, Gaithersburg, MD
2004	Invited speaker, *University of Oklahoma*, Norman, OK
2004	Invited speaker, *Santa Clara Valley Water District*, San Jose, CA
2003	Invited speaker, *South Carolina Department of Health and Environmental Control*, Columbia, SC
2003	Invited speaker, *US Environmental Protection Agency, Region 4*, Atlanta, GA
2003	Invited speaker, *Nuclear Regulatory Commission*, Rockville, MD
2003	Panelist and invited speaker, *Department of Energy* Workshop on Reactive Transport Modeling, Carmel Valley, CA
2002	Short Course Instructor, Contaminant Transport and Remediation, *Technical University of Delft*, Netherlands
2002	Co-Chair, Contaminant Fate and Transport working group, Strategic Planning Workshop for the new *Department of Energy Division of Environmental Remediation Sciences, Office of Science*, Washington, DC
2002	MS thesis examiner, *University of Newcastle*, Australia
2002	Workshop speaker, *Petroleum Technology Transfer Council* Workshop on Methods of Reservoir Characterization with Application to Heavy Oil Sands, Bakersfield, CA
2002	External Ph.D. Dissertation Committee Member, *University of South Carolina*
2001	Visiting Research Scholar, Department of Geological Engineering and Sciences, *Michigan Technological University*, Houghton, MI (while on sabbatical Fall, 2001)
2001	Short Course Organizer and Instructor, Multiphase Heat and Mass Transfer Simulation, *The Proctor and Gamble Company*, Mathematical Simulation Group, Cincinnati, OH
2001	Short Course Instructor, Subsurface Multiphase Fluid Flow and Remediation Modeling, *Colorado School of Mines*, Golden, CO
2001-2006	Member, *Department of Energy, Office of Basic Energy Sciences* Earth Sciences Council
2001	Invited Speaker and Panelist, *Environmental Protection Agency* Workshop on Hazardous Waste Source Remediation, Dallas, TX
2001	Invited Speaker, *Department of Energy Savannah River Site*
2001	Invited Speaker, *North Carolina Association of Engineering Geologists*, Raleigh, NC
2000	Press Conference with the United States Under Secretary of Energy, Washington, DC

2000 Short Course Instructor, Contaminant Source Zone Remediation, Taipei, Taiwan

2000 Short Course Instructor, Multiphase Flow Modeling, *Universitaet Braunschweig*, Germany

2000 Invited Speaker, *Purdue University*, West Lafayette, IN

2000 MS thesis advisor, *Universitaet Stuttgart*, Germany

1999 Co-Chair of *Department of Energy* Workshop on Remediation of Contaminants in the Vadose Zone, Seattle, WA

1999 Short Course Instructor, Subsurface Multiphase Fluid Flow and Remediation Modeling, *Colorado School of Mines*, Golden, CO

1999 Invited Speaker, *Colorado School of Mines*, Golden, CO

1998 Co-Chair of *Department of Energy* Workshop on Vadose Zone Characterization at Lawrence Berkeley National Laboratory, Berkeley, CA

1998 Invited Speaker, *Department of Energy Savannah River Site*

1998 Co-Chair of *Department of Energy Workshop* on Numerical Simulation of Fluid Flow and Chemical Transport in the Vadose Zone, Las Vegas, NV

1998 External Dissertation Committee Member, *Universitaet Stuttgart*, Germany

1998 Invited Speaker, *Lawrence Berkeley National Laboratory*, Berkeley, CA

1997 Visiting Scientist, Institut fur Wasserbau, Lehrstuhl fur Hydraulik und Grundwasser, *Universitaet Stuttgart*, Stuttgart, Germany, September-October.

1997 Invited Speaker, *Universitaet Tubingen*, Germany

1997 Invited Speaker, *Universitaet Braunschweig*, Germany

1997 Invited Speaker, *Ruhr Universitaet*, Germany;

1997 Invited Speaker, the *University of Strasburg*, France

1997 Invited Speaker; *Swiss Federal Institute of Technology*, Zurich, Switzerland

1997 Invited Speaker, *Environmental Protection Agency R.S. Kerr Laboratory*, Ada, OK

1997 Invited Speaker, *South Carolina University Research and Education Foundation* Advisory Board

1997 External Ph.D. Dissertation Committee Member, *Queens University*, Canada

1996 External Dissertation Committee Member, *Michigan Technological University*, Houghton, MI

1995 Session Chair, *American Chemical Society*, Emerging Technologies in Hazardous Waste Management VII Symposium, Atlanta, GA

1995 Invited Speaker, *Lawrence Berkeley National Laboratory*, Berkeley, CA

1995 Engineering Short Course Instructor, Hazardous Waste Remediation *Charleston Naval Shipyard*

1995 Invited Speaker, *Central Savannah River Geological Society*

1994 Engineering Short Course Instructor, Hazardous Waste Remediation, *Charleston Naval Shipyard*

1994 Invited Speaker, *Michigan Technological University*, Houghton, MI

1993	Invited Speaker, *Lawrence Berkeley National Laboratory*, Berkeley, CA
1993	Invited Speaker, *University of South Carolina*
1993-1996	Member of the *South Carolina Water Resources Research Institute* Review Committee
1992	Invited Speaker, *Department of Energy Savannah River Site*

OTHER PUBLICATIONS

Conference Proceedings

Falta, R.W., L. Zuo, and S.M. Benson, 2012, Migration of exsolved CO_2 following depressurization of saturated brines, *Proceedings, TOUGH Symposium 2012*, Lawrence Berkeley National Laboratory, Berkeley, CA, September 17-19, 2012.

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Ellison, K., R. Falta, L. Murdoch, and S. Brame, 2012, Behavior of brines containing dissolved CO_2 in abandoned wells, *Proceedings, TOUGH Symposium 2012*, Lawrence Berkeley National Laboratory, Berkeley, CA, September 17-19, 2012.

Patterson, C.G., and R.W. Falta, 2012, A simple history-dependent nonwetting phase trapping model for the TOUGH simulators, *Proceedings, TOUGH Symposium 2012*, Lawrence Berkeley National Laboratory, Berkeley, CA, September 17-19, 2012.

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2004 Brame, S.E., J.W. Castle, D.A. Bruce, R.W. Falta, L.C. Murdoch, and D.A. Brooks, Regional Assessment of Carbonate Formations in the Appalachian Basin Using GIS: Application to Creating Gas Storage Caverns by Dissolution of Carbonate Rock, *American Association of Petroleum Geologists, Program and Abstracts, 33rd Eastern Section Meeting*, October 2004, p. 64

2003 Hall, R.J., L.C. Murdoch, and R.W. Falta, Effects of Sand-Filled Hydraulic Fractures During Air Sparging, presented at the *Fall, 2003 Meeting of the American Geophysical Union*, San Francisco, CA.

2003 Myers, J.L., C.M. Lee, and R.W. Falta, Density Modification of an Industrial Chlorinated Solvent DNAPL by a Cosolvent Flooding Solution, presented at the *225th National American Chemical Society Meeting*, New Orleans, LA.

2003 Castle, J.W., F.J. Molz, C.L. Dinwiddie, S. Lu, R.W. Falta, and S.E. Brame, Application of the Fractal/Facies Concept to Predicting Sedimentologically Controlled Permeability Variation for Reservoir Modeling, presented at the *American Association of Petroleum Geologists Annual Convention*, May 11-14, 2003, Salt Lake City, UT.

2002 Falta, R.W., What Can We do About Modeling Heterogeneities That Occur at the Subgridblock Scale?, invited presentation given at the *Society for Sedimentary Geology SEPM/IAS Research Conference on Aquifer Heterogeneity and Environmental Implications of Ancient and Modern Coastal Plain Depositional Environments*, Charleston, SC, March 24-27.

2002 Fawumi, O.K., S.E. Brame, J.W. Castle, F.J. Molz, R.W. Falta, and C.J. Lorinovich, Reservoir Simulation Using Fractal-Based Petrophysical Models of Heavy Oil Sands in West Coaling Field, California, presented at the *American Association of Petroleum Geologists Annual Meeting,* March 10-13, 2002, Houston, TX

2001 Falta, R.W., Modeling Kinetic Interphase Mass Transfer During Air Sparging, presented at the *MODFLOW 2001 Conference, International Ground Water Modeling Center*, Colorado School of Mines, Golden, CO, September 11-14.

2001 Myers, J.L., C.M. Lee, and R.W. Falta, The Behavior of an Industrial Chlorinated Solvent DNAPL in the Presence of an Alcohol Cosolvent, presented at the *Fall 2001 Meeting of the American Geophysical Union,* San Francisco, CA

2001 Myers, J.L., C.M.Lee, and R.W. Falta, Density Modification of a Chlorinated Solvent DNAPL by a Saltwater-Propanol Cosolvent Flooding Solution, *221st American Chemical Society National Meeting*, San Diego, CA

2000 Falta, R.W., Issues and Difficulties Related to Multiphase Flow and Chemical Transport Modeling at the Field Scale, invited presentation given at the *Hydrogeology Symposium I: Modeling Aquifer Heterogeneity*, Columbia, SC, January 20-21.

2000 Falta, R.W., Modeling Kinetic Interphase Mass Transfer of Contaminants during Air Sparging With a Dual-Contiuum Approach, presented at the *Fifth International Symposium and Exhibition on Environmental Contamination in Central and Eastern Europe*, Prague, Czech Republic, September 12-14.

1999 Falta, R.W., C.M. Lee, E. Roeder, S.E. Brame, and H. Schweninger, Mobilization and Removal of Separate Phase Chlorinated Solvents as LNAPLs Using Neutrally Buoyant Alcohol Flooding Solutions, invited presentation given at the 1999 Spring Meeting of the *American Geophysical Union*, Boston, Mass., June 1-4.

1999 Falta, R.W., E. Roeder, C. Lee, S. Brame, H. Schweninger, J. Coates, T Ladaa, J. Meyers, J. Martin, J. Pace, and D. Micolet, Coupled Chemical Transport and Fluid Flow During Alcohol Flooding for DNAPL Remediation, presented at the *International Symposium on Dynamics of Fluids in Fractured Rocks*, Berkeley, Ca, February 10-12.

1999 Falta, R.W., Cosolvent Flooding for NAPL Remediation, invited presentation given at the *US EPA Conference on Abiotic In-Situ Technologies for Groundwater Remediation*, Dallas, TX, August 31-Sept. 2.

1999 Falta, R.W., Design of Multicomponent Cosolvent Flooding Solutions for NAPL Remediation, invited presentation given at the *Annual Meeting of the Geological Society of America*, Denver, CO, October 25-29.

1999 Rossabi, J., and R.W. Falta, Using Two Barometric Pumping Based Flow Regimes to Characterize the Location of Subsurface DNAPL, presented at the Spring 1999 Meeting of the *American Geophysical Union*, Baltimore, MD.

1997 Falta, R.W., S.E. Brame, C.M. Lee, and J.T. Coates, A Field Test of LNAPL Remediation by Tert-Butanol Injection, abstract in *American Chemical Society Preprints of Papers Presented at the 213th ACS National Meeting, San Francisco, Ca., April 13-17, 1997, Vol. 37, No. 1.*, p. 227.

1997 S.L. Meyers, C.L. Wright, C.M. Lee, J.T. Coates, and R.W. Falta, Effect of Cosolvent Flooding on Partitioning Tracer Behavior, abstract in *American Chemical Society Preprints of Papers Presented at the 213th ACS National Meeting, San Francisco, Ca., April 13-17, 1997, Vol. 37, No. 1*, p. 249.

1997 Falta, R.W., S.E. Brame, and E. Roeder, The Application of Density Controlled Flooding Solutions for Remediation, presented at the *1997 Annual Meeting of the Geological Society of America, Salt Lake City, Utah, October 20-27.*

1997 Falta, R.W., C.M. Lee, and S.E. Brame, A Field Test of NAPL Remediation by Alcohol Flooding, invited paper, *Fifth Chemical Congress of North America*, Cancun, Mexico, November 11-15.

1996 Haskell, P.A., J.T. Coates, C.M. Lee, and R.W. Falta, The use of Surrogate Compounds to Monitor NAPL Removal from a Contaminated Soil During a Cosolvent Flood, presented at *211th ACS National Meeting*, New Orleans, LA, March 24-28, paper in *Preprints of Papers, American Chemical Society*, p. 231-233.

1996 Falta, R.W. A Field Test of In-Situ NAPL Removal by Cosolvent Flooding, presented at *the1996 American Association of Petroleum Geologists Annual Convention*, San Diego, CA, May 20-25.

1996 Brame, S.E., R.W. Falta, and E. Roeder, "The Effect of Heterogeneities on the Remediation of LNAPLS Using Cosolvent Flooding at Hill AFB, Utah", presented at the *1996 Annual Meeting of the Geological Society of America* in Denver, Colorado, October 28-31, abstract in *Abstracts with Programs.*

1996 Roeder, E., C.L. Wright, S.A. Finsterle, S.E. Brame, R.W. Falta, and C.M.Lee, "Inversion of a 3-Dimensional Tracer Test", presented at the *1996 Annual Meeting of the Geological Society of America* in Denver, Colorado, October 28-31, abstract in *Abstracts with Programs.*

1995 Falta, R.W., Using Phase Behavior to Understand and Design Cosolvent Floods, Invited talk, presented at the *1995 Theis Conference, National Groundwater Association*, September 15-18.

1995 Falta, R.W., C.M. Lee, and S.M. Benson, A Field Test of NAPL Mobilization and Removal by Cosolvent Injection, presented at the *American Chemical Society, I&EC Division Emerging Technologies in Hazardous Waste Management VII Symposium* in Atlanta, Ga, September 17-20, extended abstract in Book of Abstracts.

1995 Roeder, E., S.E. Brame, and R.W. Falta, Numerical Simulation of Field Scale Cosolvent Flooding for LNAPL Remediation, presented at the *American Chemical Society, I&EC Division Emerging Technologies in Hazardous Waste Management VII Symposium* in Atlanta, Ga, September 17-20, extended abstract in Book of Abstracts.

1994 Falta, R.W. Numerical Simulation of NAPL Removal from Heterogeneous Formations Using Soil Vapor Extraction and Air Sparging, presented at the *1994 Special Symposium, Emerging Technologies in Hazardous Waste Management, American Chemical Society* in Atlanta, Ga, September.

1994 Falta, R.W., A General and Efficient Method for Analyzing Unsaturated Zone Gas Pump Tests, presented at the 1994 Annual Meeting of the Geological Society of America in Seattle, WA, abstract in *1994 Annual Meeting Abstracts with Program, Geological Society of America,* October.

1994 Kroening, D.E., D.S. Snipes, R.W. Falta, R.A. Hodges, S.M. Benson, J. Janssen, V. Price, and T.J. Temples, Well Redevelopment at the MWD Well

Field, Savannah River Site, South Carolina, presented at the *1994 Annual Meeting of the Geological Society of America* in Seattle, WA, abstract in *1994 Annual Meeting Abstracts with Program, Geological Society of America* October.

1994 Falta, R.W., J. Rossabi, B.D. Riha, J.D. Schramm, B.B. Looney, Quantitative Atmospheric/Subsurface Pressure Relationships: Theory and Practice, presented at the *1994 Fall Meeting of the American Geophysical Union* in San Francisco, CA, abstract in *EOS, Transactions American Geophysical Union, Vol. 75, No. 44*, December.

1993 Falta, R.W., Interpretation of Soil Vapor Extraction Well Pumping Tests, presented at *the 1993 Southeastern Section Geological Society of America Meeting*, Tallahassee, Fla., abstract in *1993 Abstracts with Program, Southeastern Section, Geological Society of America,* April.

1993 Brame, S.E., and R.W. Falta, Development of a Numerical Simulator for In-Situ Remediation by Alcohol Flooding, presented at the *1993 Southeastern Section Geological Society of America Meeting*, Tallahassee, Fla., abstract in *1993 Abstracts with Program, Southeastern Section, Geological Society of America,* April.

1993 Brame, S.E., and R.W. Falta, Development of a Numerical Simulator for In-Situ Remediation by Alcohol Flooding, presented at the *1993 Spring Meeting of the American Geophysical Union* in Baltimore, MD, abstract in *EOS, Transactions, American Geophysical Union, Vol. 74, No. 16,* May.

1993 James, A., and R.W. Falta, Optimization of Soil Vapor Extraction Well Design, presented at the *1993 Annual Meeting of the AIChE* in St. Louis, Abstract in *Extended Abstracts, AIChE 1993 National Meeting*, November.

1992 Farley, K., and R.W. Falta, Remediation of Hydrocarbon-Contaminated Groundwater by Alcohol Flooding, presented at the *1992 Joint Conference on Hazardous Waste, Hazardous Waste Management Research Fund.*

1991 Falta, R.W. and K. Pruess, Numerical Simulation of Steam Injection for the Removal of Nonaqueous Phase Liquids from the Subsurface, presented at *the Characterization of Transport in the Vadose Zone Workshop*, Abstract in *Proceedings of the Characterization of Transport in the Vadose Zone Workshop*, Tucson, AZ, April.

1991 Seely, G.E., R.W. Falta, and J.R. Hunt, Buoyant Advection of Gases in Isothermal Porous Media, presented at the *Fall 1991 Meeting of the American Geophysical Union*, Abstract in *EOS, Transactions, American Geophysical Union, Vol. 72, No. 44*, December.

1990 Falta, R.W. and K. Pruess, STMVOC: A Numerical Simulator for Three Phase Contaminant Transport in Nonisothermal Systems, *Proceedings of the TOUGH Workshop*, Berkeley, CA, September.

1989 Falta, R.W., K. Pruess, I. Javandel, and P.A. Witherspoon, A Numerical Simulator for Strongly Non-Isothermal Three-Phase Contaminant Transport,

presented at the *Fall 1989 Meeting of the American Geophysical Union*, Abstract in *EOS, Transactions, American Geophysical Union, Vol. 70, No. 43*.

1988 Javandel, I., R.W. Falta, and H.Y. Holman, Hydrocarbon Contaminants in Shallow Soil Systems, *Proceedings of the Second Berkeley Symposium on Topics in Petroleum Engineering*, March.

1987 Falta, R.W., and I. Javandel, A Numerical Method for Multiphase Multicomponent Contaminant Transport in Groundwater Systems, presented at the *Fall 1987 Meeting of the American Geophysical Union*, Abstract in *EOS, Transactions, American Geophysical Union, Vol. 68, No. 44*.

1984 Falta, R.W., O. Guven, F.J. Molz, and J.G. Melville, An Analysis of Single-Well Tracer Dispersion Tests in Stratified Aquifers, presented at the *Spring 1984 Meeting of the American Geophysical Union*, Abstract in *EOS, Transactions, American Geophysical Union, Vol. 65, No. 16*.

Graduate Student Advisees

Present	Kien Pham, Field determination of matrix diffusion simulation parameters, PhD
Present	Eric Cheek, Field and numerical modeling analysis of aquifer thermal energy storage at Ft. Benning, GA, MS
Present	Adam Ornelles, Solar powered thermal remediation, MS
2020	Marcus Guarnieri, non-thesis
2019	Wesley Prater, Modeling matrix diffusion at field sites, MS
2018	Thomas Spain, Thermal remediation of mercury contamination, MS
2018	Yoel Gebrai, Hydraulic isolation of contaminant source zones, MS
2018	Brian Hardin, non-thesis.
2017	Noelia Muskus, Modeling contaminant matrix diffusion using a semi-analytical approach, MS
2015	Alexandra-Selene Jarvis, Feasibility of using compressed air storage for energy storage in the southeast, MS
2015	Wenwen Wang, Semi-analytical method for simulating matrix diffusion in clay aquitards, MS
2014	Catherine Ruprecht, Comparison of dissolved and supercritical CO_2 injection schemes for CO_2 sequestration, Ph.D.
2014	Zheng, Qi, High temperature aquifer thermal energy storage for electricity production, MS
2014	Jill Branby, non-thesis, MS.

2013	Laura Daniels, Simulation of aerobic degradation of dissolved chlorinated solvents in large groundwater plumes MS.
2011	Kirk Ellison, CO_2 exolution from saturated brines during depressurization, MS.
2011	Chris Patterson, Nonwetting phase trapping during NAPL transport and CO_2 sequestration, MS.
2011	Chen, F., Contaminant mass transfer during boiling in fractured rocks, Ph.D.
2009	Liang, H., Probabilistic optimization of groundwater source and plume remediation, Ph.D
2008	Tyre, S., Simulation of non-classical groundwater transport using analytical source-plume models, MS
2008	Henderson, J., Biodegradation and transport of EDB in groundwater, Ph.D.
2007	Hodges, R.A., Injection of Noncondensible Gases for the Pneumatic Control of Shallow Environmental Steam Flood Operations, Ph.D.
2006	Richard Mayer, Analysis of EDB contamination at retail gasoline service stations, MS
2006	VanAntwerp, D., Numerical simulation of air sparging and steam flooding operations for source zone remediation
2005	Liang, H., Modeling Assessment of the Benefit of DNAPL Source Zone Remediation, MS.
2004	Bulsara, N., Analysis of underground storage tank sites in South Carolina for EDB contamination, MS.
2003	Schweninger, H., Laboratory analysis of cosolvent flooding designs for DNAPL remediation, MS.
2002	Fawumi, L., Numerical Simulation of Heavy Oil Recovery by Steam Flooding at the West Coalinga Oil Field, California, MS
2001	Melshimer, K.E., In-Situ Measurement of Soil Thermal Conductivity, MS
2000	Hornberger, J.P., Laboratory Studies of Cosolvent Flooding for the Removal of DNAPLs, MS
2000	Micolet, D., Hydraulic Design of Cosolvent Flooding Systems for NAPL Remediation, MS
2000	Ochs, S.O., Predictive Modeling of Field Scale DNAPL Remediation by Steam Injection, MS (Universitaet Stuttgart)
1999	Rossabi, J. The Influence of Atmospheric Pressure Variations on Subsurface Soilgas and the Implications for Environmental Characterization and Remediation, Ph.D.

1998	Zitsch, K.H., Steam Flooding Simulations of DNAPL Removal from the Subsurface, MS
1998	Martin, J.D., Quantitative Analysis of Nonaqueous Phase Liquid Trapping Using Etched Glass Micromodels, MS
1998	Roeder, E., Phase Density Modifications for the Remediation of DNAPLs by Cosolvent Flooding Utilizing Separate Phase Mobilization, Ph.D.
1997	Price, S.W., Selection of a Cosolvent Flooding Solution for Removal of a Multicomponent LNAPL at Operable Unit One, Hill Air Force Base, Utah, MS
1996	Larson, A.G., Numerical Simulation of Field Air Sparging Operations, MS
1994	McCray, J.E., Numerical Analyses of Air Sparging for Subsurface Remediation, MS
1994	James, A.L., Optimization of Soil Vapor Extraction Well Design, MS
1993	Brame, S.E., Development of a Numerical Simulator for the In-Situ Remediation of Dense Non-Aqueous Phase Liquids by Alcohol Flooding, MS

TEACHING

Subsurface Remediation Modeling, Clemson University GEOL/EES 8090. A graduate course on nonisothermal, compositional multiphase flow and transport of organic chemicals in the subsurface with an emphasis on integral finite difference numerical simulation techniques. Taught 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2012, 2013, 2014, 2016, 2017, 2018, 2020

Groundwater Modeling, Clemson University GEOL/EES 8080. A graduate course on finite difference and integral finite difference methods for simulating groundwater flow and chemical transport. Taught 1993, 1995, 1996, 1998, 2000, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 20009, 2011, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020

Analytical Methods in Hydrogeology, Clemson University GEOL/EES 810. A graduate course on applied mathematical methods of analysis for solving partial differential equations in hydrogeology. Taught Fall Semester 1992, 1994, 1997, 1999, Spring 2003.

Engineering Geology, Clemson University GEOL 320. An undergraduate course on engineering mechanics and analyses applied to geological problems. Taught Spring Semester 1996, 1997, 2000, 2002

Geoanalysis II, Geoanalysis II Lab, Clemson University GEOL 212, 212L. Undergraduate Geology course in applied mathematics, covering advanced calculus, ordinary differential equations, and Visual Basic computer programming. Taught Spring Semester 2008, 2009

Special Topics in Geology, Clemson University GEOL 100, Seminar series for freshman Geology majors and nonmajors, Fall, 1998.

Hydrogeology Graduate Seminar, Clemson University GEOL 851, Seminar series for graduate Hydrogeology majors, Fall, 1995, Spring 1996, 2002, 2004.

UNIVERSITY AND PUBLIC SERVICE

Committees

Department:	Chairman, Tenure and Promotion Committee (2007-)
	Member, Tenure and Promotion Committee (2003-)
	Chairman, Faculty Search Committee (2007)
	Chairman, Curriculum Committee (1993-1995)
	Chairman, Faculty Search Committee (1996)
	Chair, Faculty Search Committee (1995)
	Member, Advisory Committee (1996-1999)
	Member, Faculty Search Committee (1995-1996)
College:	Member, Deans Search Committee (2013)
	Member, Deans Advisory Committee (2004-2005)
	Member, Curriculum Committee (1993-1995)
	Member, By-Laws Committee (1995)
	Member, Computer Committee (1996-1999)
University:	Grievance Committee (2018-2021)
	Faculty Senator (2016-2019)
	Member, Search Committee for Vice Provost (1996)

Revised 1/3/21

Peer Review Panel Member Verification of Education/Employment Form

Peer panel member nominee information:

My signature verifies that the information contained in this resume is correct. You are hereby authorized to verify this information.

Name: Mengsu Hu (Printed) 09/09/2021 (Date) _____ (Signature)

Section 2

Position/Title: Peer Review Panelist

Comments: Work experience spans 5 years of work with Lawrence Berkeley National Laboratory and teaching experience in hydrogeology. Education includes Bachelor's and PhD degrees from China University of Mining and Technology, and Hohai University. Hu is a very decorated scholar, and her research interests match the task well including subjects such as: machine learning in geoscience, analysis of THM process in energy-geoscience applications such as nuclear waste disposal and geothermal exploitation, along with numerical model studies involving carbonate compact, clay swelling, fracture alteration, and fracture healing. Hu also has many publications spanning the fields of rock mechanics, rock engineering, mining sciences, computational geotechnics and specific studies in brine migration in salt, brine availability to heated boreholes in bedded salt, and water flow modeling.

Peer Review Chairperson:

Name: John A. Thies (Printed) 09/09/21 (Date) _____ (Signature)

Mengsu Hu

Research Scientist

Energy Geosciences Division
Lawrence Berkeley National Laboratory
1 Cyclotron Road, MS74R316C, Berkeley, CA 94720
[redacted]



Education

2010- 2016, PhD, Hohai University

2012- 2014, Visiting PhD student, Lawrence Berkeley National Laboratory

2006- 2010, BEng, China University of Mining and Technology

Work Experience

2018-Present, Research Scientist, Lawrence Berkeley National Laboratory

2019-Present, Instructor, University of California, Berkeley, EPS 200 001 - LEC 001, Problems in Hydrogeology

2016-2018, Postdoctoral Fellow, Lawrence Berkeley National Laboratory

Research Interests

Numerical modeling and machine learning of coupled thermal-hydro-mechanical-chemical (THMC) processes in the energy geosciences, including:

- Novel computational methods development: extended finite volume method (XFVM), numerical manifold method (NMM);
- Numerical modeling of microscale mechanical-chemical processes such as pressure solution, carbonate compaction, clay swelling, fracture alteration and fracture healing;
- Multi-scale, long-term analysis of THM processes in energy-geosciences applications such as nuclear waste disposal, geothermal exploitation;
- Machine learning applications in geosciences.

Selected Awards

2020, ARMA Future Leader, American Rock Mechanics Association

2019, Early Career Enrichment Program, Lawrence Berkeley National Laboratory

2018, No. 1 Ranked Outstanding PhD Thesis Award, Chinese Society for Rock Mechanics and Engineering

2018, 2016, Spot Recognition Award, Lawrence Berkeley National Laboratory

2015, The National Scholarship, Ministry of Education, China.

2014, The National Scholarship, Ministry of Education, China.

2008, The National Scholarship, Ministry of Education, China. (Ranking 1/252)

2007, The National Scholarship, Ministry of Education, China. (Ranking 2/252)

2010, Outstanding Graduate, China University of Mining and Technology, China
2008, Pacemaker to Merit Student, China University of Mining and Technology, China

Journal Publications----------

[1] **Mengsu Hu,** Jonny Rutqvist. Multi-scale Coupled Processes Modeling of Fractures as Porous, Interfacial and Granular Systems from Rock Images with the Numerical Manifold Method. *Rock Mechanics and Rock Engineering* 2021. https://doi.org/10.1007/s00603-021-02455-6 (*ARMA Invited*)

[2] **Mengsu Hu,** Jonny Rutqvist, Carl I. Steefel. Mesh Generation and Optimization from Digital Rock Fractures Based on Neural Style Transfer. *Journal of Rock Mechanics and Geotechnical Engineering* 2021. https://doi.org/10.1016/j.jrmge.2021.02.002

[3] Tianjiao Li, Chun'an Tang, Jonny Rutqvist, **Mengsu Hu**. TOUGH-RFPA: Coupled Thermal-Hydraulic-Mechanical Rock Failure Process Analysis with Application to Deep Geothermal Wells. *International Journal of Rock Mechanics and Mining Sciences* 2021. https://doi.org/10.1016/j.ijrmms.2021.104726

[4] Siji Tao, Xuhai Tang, Jonny Rutqvist, Quansheng Liu, **Mengsu Hu**. The influence of stress anisotropy and stress shadow on frost cracking in rock. *Computers and Geotechnics* 2021. 133: 103967. https://doi.org/10.1016/j.compgeo.2020.103967

[5] **Mengsu Hu,** Carl I. Steefel, Jonny Rutqvist. Guest Editorial to the CouFrac 2018 Special Issue Coupled Thermal-Hydro-Mechanical-Chemical Processes in Fractured Media: Microscale to Macroscale Numerical Modeling. *Computational Geosciences* 2020. 24: 1747–1749. https://doi.org/10.1007/s10596-020-09998-7

[6] **Mengsu Hu,** Jonny Rutqvist. Microscale mechanical modeling of deformable geomaterials with dynamic contacts based on the numerical manifold method. *Computational Geosciences* 2020. 24: 1783–1797. https://doi.org/10.1007/s10596-020-09992-z

[7] **Mengsu Hu**, Jonny Rutqvist. Numerical manifold method modeling of coupled processes in fractured geological media at multiple scales. *Journal of Rock Mechanics and Geotechnical Engineering* 2020. 12(4): 667-681. https://doi.org/10.1016/j.jrmge.2020.03.002

[8] **Mengsu Hu**, Jonny Rutqvist. Finite volume modeling of coupled thermo-hydro-mechanical processes with application to brine migration in salt. *Computational Geosciences* 2020. 24: 1751–1765. https://doi.org/10.1007/s10596-020-09943-8

[9] Siji Tao, Xuhai Tang, Jonny Rutqvist, **Mengsu Hu**, Quansheng Liu. Simulating three dimensional thermal cracking with TOUGH-FEMM. *Computers and Geotechnics* 124: 103654, 2020. https://doi.org/10.1016/j.compgeo.2020.103654

[10] Eric Guiltinan, Kristopher Kuhlman, Jonny Rutqvist, **Mengsu Hu**, Hakim Boukhalfa, Melissa Mills, Shawn Otto, Douglas Weaver, Brian Dozier, and Philip Stauffer. Temperature response and brine availability to heated boreholes in bedded salt. *Vadose Zone Journal* 19: e20019, 2020. https://doi.org/10.1002/vzj2.20019

[11] Tianjiao Li, Chun'an Tang, Jonny Rutqvist, **Mengsu Hu**, Lianchong Li, Liaoyuan Zhang, Bo Huang. The influence of an interlayer on dual hydraulic fractures propagation. *Energies* 13: 555, 2020. doi:10.3390/en13030555

[12] Xuhai Tang, Jonny Rutqvist, **Mengsu Hu**, Nithin Manohar Rayudu. Modeling three-dimensional fluid-driven propagation of multiple fractures using TOUGH-FEMM. *Rock Mechanics and Rock Engineering* 52 (2): 611-627, 2019.

[13] **Mengsu Hu**, Jonny Rutqvist, Yuan Wang. A numerical manifold method model for analyzing fully coupled hydro-mechanical processes in porous rock masses with discrete fractures. *Advances in Water Resources* 102: 111-126, 2017.

[14] **Mengsu Hu**, Yuan Wang, Jonny Rutqvist. Fully coupled hydro-mechanical numerical manifold modeling of porous rock with dominant fractures. *Acta Geotechnica* 12(2): 231-252, 2017.

[15] **Mengsu Hu**, Jonny Rutqvist, Yuan Wang. A practical model for flow in discrete-fracture porous media by using the numerical manifold method. *Advances in Water Resources* 97: 38-51, 2016.

[16] **Mengsu Hu**, Yuan Wang, Jonny Rutqvist. On continuous and discontinuous approaches for modeling groundwater flow in heterogeneous media using the numerical manifold method: model development and comparison. *Advances in Water Resources* 80: 17-29, 2015.

[17] **Mengsu Hu**, Yuan Wang, Jonny Rutqvist. Development of a discontinuous approach for modeling fluid flow in heterogeneous media using the numerical manifold method. *International Journal for Numerical and Analytical Methods in Geomechanics* 39: 1932- 1952, 2015.

[18] **Mengsu Hu**, Yuan Wang, Jonny Rutqvist. An effective approach for modeling water flow in heterogeneous media using Numerical Manifold Method. *International Journal for Numerical Methods in Fluids* 77: 459-476, 2015.

[19] Yuan Wang, **Mengsu Hu**, Quanlin Zhou, Jonny Rutqvist. Energy-work-based numerical manifold seepage analysis with an efficient scheme to locate the phreatic surface. *International Journal for Numerical and Analytical Methods in Geomechanics* 38: 1633-1650, 2014.

[20] Yuan Wang, **Mengsu Hu**, Quanlin Zhou, Jonny Rutqvist. A new second-order numerical manifold method model with an efficient scheme for analyzing free surface flow with inner drains. *Applied Mathematical Modelling* 40: 1427-1445, 2016.

Book Chapters

[1] Jonny Rutqvist, Bruno Figueiredo, **Mengsu Hu**, Chin-Fu Tsang. Continuum modeling of hydraulic fracturing in complex fractured rock masses. Hydraulic Fracture Modeling. Edited by Yu-Shu Wu. Houston: Gulf Professional Publishing, 2018.

Invited Talks

[1] **Mengsu Hu**. Integrated machine learning and numerical modeling for multiscale analyses of coupled processes in geosystems. *The 11th Asian Rock Mechanics Symposium-Numerical Analysis Methods and Numerical Simulations Forum*. October 21-25, 2021, Beijing, China. (Invited Keynote)

[2] **Mengsu Hu**. Coupled processes modeling for porous, fractured and granular systems in energy geosciences. *1st International Youth Scientists Forum for Discontinuous Deformation Analysis (IYSF-DDA)*. January 9, 2021, online. (Invited Keynote)

[3] **Mengsu Hu**. Modeling coupled processes in fractured media at multiple scales. *International Conference on Coupled Processes in Fractured Geological Media: Observation, Modeling, and Application* (CouFrac) 2020. November 11-13, 2020, Seoul, Korea. (Invited Plenary)

[4] **Mengsu Hu**. NMM model development for analysis of coupled hydro-mechanical processes in heterogeneous media. *51st meeting of Commission on DDA Application of Rock Engineering*, Japan. December 17, 2015, Tokyo, Japan.

[5] **Mengsu Hu**. Model development of NMM for analysis of flow in heterogeneous media with application to hydro-mechanical coupling in fractured rock masses. *5th Northeastern University Forum of Rock mechanics- Numerical Methods for Discontinuous Media*. June 23, 2015, Shenyang, China.

Selected Conference Presentations----------

[1] **Mengsu Hu**, Jonny Rutqvist. Microscale mechanical modeling of granular salt: Insights for creep. *55th U.S. Rock Mechanics/Geomechanics Symposium*, 20-23 June, 2021.

[2] **Mengsu Hu**, Jonny Rutqvist. Microscale mechanical modeling of deformable geomaterials with dynamic contacts. *2020 AGU Fall meeting*, December 1-17, online.

[3] Shaswat Babhulgaonkar, **Mengsu Hu***, Keurfon Luu, Zahra Derakhshandeh, Jonny Rutqvist. Machine Learning of Fracture Morphology and Growth in Geological Media: Preliminary Study. *International Conference on Coupled Processes in Fractured Geological Media: Observation, Modeling, and Application (CouFrac)* 2020, November 11-13, Seoul, Korea.

[4] Tianjiao Li, Chun'an Tang, Jonny Rutqvist, **Mengsu Hu**. Coupled TOUGH3-RFPA3D simulator for modelling hydraulic fracturing of horizontal wells. *International Conference on Coupled Processes in Fractured Geological Media: Observation, Modeling, and Application* (CouFrac) 2020, November 11-13, Seoul, Korea.

[5] Francois Bonneau, Luc Scholtès, **Mengsu Hu**. Discrete element modeling of fractured media using conforming and adaptive particle assemblies. *2020 RING Meeting*, September 7-11, Nancy, France.

[6] Jonny Rutqvist, Lehua Pan, Nicholas Spycher, Patrick Dobson, Quanlin Zhou, **Mengsu Hu**. Coupled processes analysis of flexible geothermal production from a liquid-dominated geothermal system: impact on wells. *World Geothermal Congress 2021*, May 21-26, Reykjavik, Iceland.

[7] Jonny Rutqvist, Quanlin Zhou, Lehua Pan, Nicholas Spycher, Patrick Dobson, **Mengsu Hu**. Coupled processes analysis of flexible geothermal production from steam- and liquid-dominated systems: impact on wells. *Stanford Geothermal Workshop 45th Annual 2020*. February 10-12, Stanford, USA.

[8] Tianjiao Li, Jonny Rutqvist, **Mengsu Hu**, Lianchong Li, Chunan Tang, et al. Numerical investigation of hydraulic fracturing and well placement in multilayered shale oil reservoirs using RFPA-Petrol. *53rd U.S. Rock Mechanics/Geomechanics Symposium*, 23-26 June, 2019, New York City, New York USA.

[9] **Mengsu Hu**, Jonny Rutqvist. Zero-dimensional fracture model for fluid flow and heat transfer in discrete fracture networks. *International Conference on Coupled Processes in Fractured Geological Media: Observation, Modeling, and Application* (CouFrac) 2018, November 12-14, Wuhan, China.

[10] **Mengsu Hu**, Jonny Rutqvist. An extended finite volume method model for fully coupled thermal-hydro-mechanical analysis. *TOUGH Symposium 2018*, October 8-10, Berkeley, USA.

[11] **Mengsu Hu**, Jonny Rutqvist. Fully coupled thermal-hydro-mechanical analysis for porous rock masses with discrete fractures by using the numerical manifold method (NMM). *CMWR 2018*, June 3-7, St Malo, France.

[12] Antonio P. Rinaldi, Jonny Rutqvist, Laura Blanco-Martín, **Mengsu Hu**, Manuel L. Sentís. Coupling TOUGH3 with FLAC3D for parallel computing of fluid-flow and geomechanics. *TOUGH Symposium 2018*, October 8-10, Berkeley, USA.

[13] Jonny Rutqvist, Lehua Pan, **Mengsu Hu**. T2Well-FLAC3D for advanced well integrity analysis. *TOUGH Symposium 2018*, October 8-10, Berkeley, USA.

[14] Tianjiao Li, Chunan Tang, Jonny Rutqvist, **Mengsu Hu**. TOUGH-RFPA: A coupled thermal-hydraulic-mechanical-damage model for simulation of fracture propagation in unsaturated geological media. *TOUGH Symposium 2018*, October 8-10, Berkeley, USA.

[15] Jonny Rutqvist, Lehua Pan, **Mengsu Hu**, Quanlin Zhou, Patrick Dobson. Modeling of coupled flow, heat and mechanical well integrity during variable geothermal production. *43rd Workshop on Geothermal Reservoir Engineering*, February 12-14, 2018, Stanford, USA.

[16] **Mengsu Hu**, Jonny Rutqvist. A dual-continuum model for brine migration in salt associated with heat-generating nuclear waste: fully coupled THM analysis. *2017 AGU Fall meeting*, New Orleans.

[17] **Mengsu Hu**, Jonny Rutqvist, Yuan Wang. A fully coupled hydro-mechanical model for discrete fractured porous rock masses based on numerical manifold method. *50th U.S. Rock Mechanics/Geomechanics Symposium*, June 26- June 29, 2016, Houston, Texas, USA.

[18] **Mengsu Hu**, Yuan Wang, Jonny Rutqvist. Numerical manifold modeling of coupled hydro-mechanical processes in fractured rock. *49th U.S. Rock Mechanics/Geomechanics Symposium*, June 28- July 1, 2015, San Francisco, California, USA.

[19] **Mengsu Hu**, Yuan Wang, Jonny Rutqvist. On the new approaches for modeling water flow in heterogeneous media with numerical manifold method. *The 13th International Symposium on Rock Mechanics*, May 10-13, 2015, Montreal, Canada.

[20] **Mengsu Hu**, Yuan Wang, Jonny Rutqvist. Derivation and comparison of different new approaches for boundary constraints in numerical simulation of water flow in heterogeneous media using Numerical Manifold Method. *48th U.S. Rock Mechanics/Geomechanics Symposium*, June 1- 4, 2014, Minneapolis, Minnesota, USA.

Funded Research Project Awards

2019-2021, **PI**, Extended Finite Volume Method for Coupled Processes in Complex Fractured Geological Systems, Early Career Laboratory Directed Research Development (LDRD), Lawrence Berkeley National Laboratory, USA.

2018-2019, **PI**, Modeling of Hydraulic Fracturing Using Numerical Manifold Method. State Key Laboratory of Geomechanics and Geotechnical Engineering, China.

2015-2016, **PI**, Model Development of Coupled Hydro-mechanical Processes in Fractured Rock Using Numerical Manifold Methods with Application to Geological Storage of CO2. The Fundamental Research Funds for the Central Universities, China.

2012-2016, **PI**, Modeling of Coupled Hydro-mechanical Processes Associated with Geological Storage of CO2 Based on Modern Numerical Methods. Graduates Science Innovation Research Project, Jiangsu Province, China.

Scholarly Service----------

2021, Session Organizer, 55th US Rock Mechanics/Geomechanics Symposium (Co-organizer: Jonny Rutqvist)

2020, Session Organizer, International Conference on coupled processes in fractured geological media: observation, modeling, and application, CouFrac 2020 (Co-organizers: Adriana Paluszny, Pania Newell, Shaojun Li, Laura Blanco-Martín)

2020, Session Organizer, 54th US Rock Mechanics/Geomechanics Symposium (Co-organizer: Zhou Lei), symposium cancelled due to COVID-19.

2019-2020, Guest Editor, Computational Geosciences Special Issue: CouFrac 2018 (Co-editors: Carl Steefel, Jonny Rutqvist)

2019-, Reviewer, NSF CAREER proposal

2020-, Early/Mid Career Representatives, Commission on Coupled Thermal-Hydro-Mechanical-Chemical Processes in Fractured Rock, International Society for Rock Mechanics and Rock Engineering

2018-2019, General Secretary and Member, Commission on Coupled Thermal-Hydro-Mechanical-Chemical Processes in Fractured Rock, International Society for Rock Mechanics and Rock Engineering

2018, Co-Chair, International Conference on Coupled Processes in Fractured Geological Media: Observation, Modeling, and Application, CouFrac 2018 (Conference chair: Jonny Rutqvist; Co-chairs: Ki-Bok Min, Pengzhi Pan)

2018, Organizing Committee Member, TOUGH Symposium 2018 (Symposium chair: Curtis Oldenburg; Co-organizers: Yingqi Zhang, Matthew Reagan, Eric Sonnenthal)

2017, Session Co-Chair, 51st US Rock Mechanics/Geomechanics Symposium (Co-organizer: Jonny Rutqvist)

2017, Organizing Committee Member, 13th International Conference on Analysis of Discontinuous Deformation (ICADD 13)

Reviewer for peer-review journals:

Advances in Geosciences, Advances in Water Resources, Applied Mathematical Modelling, Computers and Geotechnics, Computer Methods in Applied Mechanics and Engineering, Engineering Analysis with Boundary Elements, Environmental Geotechnics, Geofluids, Geomechanics and Geophysics for Geo-Energy and Geo-Resources, Hydrogeology Journal, International Journal for Numerical and Analytical Methods in Geomechanics, International

Journal of Rock Mechanics and Mining Sciences, Journal of Geophysical Research - Solid Earth, Journal of Hydrology, Journal of Rock Mechanics and Geotechnical Engineering, Mathematical Methods in the Applied Sciences, Rock Mechanics and Rock Engineering, Scientific Reports, SoftwareX, Tunneling and Underground Space Technology, Structural Engineering, SPE Journal, Water Resources Research

Reviewer, 6th Biot conference on Poromechanics

Reviewer for books:

"Hydraulic Fracture Modeling" (Elsevier), "Science of Carbon Storage in Deep Saline Formation: Process Coupling Across Time and Spatial Scales" (Elsevier).

Teaching Experiences----------

2019-, Instructor, University of California, Berkeley, EPS 200 001 - LEC 001, Problems in Hydrogeology (Co-teaching with: Carl Steefel, Jonny Rutqvist, Curt Oldenburg)

Committees and Councils----------

2021-2022, Steering Committee Member, Early Career ERG Council, Lawrence Berkeley National Laboratory

Supervision/Co-Supervision----------

Postdocs (PhD institutes): Martin Lesueur (University of New South Wales), Liuchi Li (Caltech)

Graduate students: Yuan Tian (UC Berkeley), Shaswat Babhulgaonkar (Cal State East Bay, funded by Berkeley Lab CSUEB Intern Pilot Program)

Undergraduate intern students: Sage Quinn (UC Berkeley, funded by Cal Energy Corps)

Peer Review Panel Member Verification of Education/Employment Form

Section 1

Peer panel member nominee information:

My signature verifies that the information contained in this resume is correct. You are hereby authorized to verify this information.

Name: Edward M. Kwicklis (Printed) 9/21/2021 (Date) Edward M. Kwicklis (Signature)

The resume will contain nominee's education and employment history.

I. EDUCATION: A list of educational institution(s), degree(s), discipline(s)/subject(s), and year(s).

II. EMPLOYMENT HISTORY: A list of employment history for the previous ten (10) years, starting with the latest. The history will include responsibilities [in general terms] and years with each employer.

Please note that (all) official transcript(s) is (are) to be in (a) sealed envelope(s) from the university registrar(s). Foreign degrees need to be verified and evaluated by credential evaluation services.

Section 2

The peer review chairperson is responsible for completing this section.

Position/Title: Peer Review Panelist

Comments: Work Experience includes 35 years of experience predominantly with Los Alamos National Laboratory and the U.S. Geological Survey. Education includes a bachelor's and Masters degrees in Geology from Queens College and University of Colorado, Boulder respectively. Professional experience also includes multiple publications demonstrating aptitude for subject matter related to this peer review task including, performance assessment, hydrology and borehole data, subsurface gas transport, and modeling radionuclide transport.

Peer Review Chairperson:

Name: John A. Thies (Printed) 09/27/21 (Date) (Signature)

Edward M. Kwicklis

Current Address
111 Valley Drive
Santa Fe, NM 87501
Email: [redacted]

[redacted]

Education

M.S. in Geology — 1982-1987
University of Colorado, Boulder

B.A. in Geology — 1978-1981
Queens College, City University of New York

Work Experience

Los Alamos National Laboratory, Los Alamos NM — 1999-2021

- LANL subsurface modeling lead for the Underground Nuclear Explosion Signatures Experiment (UNESE) to identify non-prompt signatures of underground nuclear explosions
- LANL Contract Manager for the Underground Test Area (UGTA) Activity at the former Nevada Test Site, part of the U.S. DOE Environmental Management Program
- Leads LANL subsurface modeling projects at the former Nevada Test Site to evaluate the impact of nuclear weapons testing on groundwater quality
- Served as Team Leader, LANL Earth and Environmental Sciences Division Subsurface Flow and Transport (SFT) Team (2008-2014)
- Serves as DOE Technical Lead to assess impacts of nuclear testing on ground water in Yucca Flat at the former Nevada Test Site
- Conducted geochemical studies of groundwater flow systems at Pahute Mesa, Rainier Mesa, Yucca Flat and Frenchman Flat at the former Nevada Test Site
- Led geochemical analysis of groundwater flow systems at Yucca Mountain, Nevada, to interpret groundwater flow patterns around a potential high-level nuclear waste repository
- Served as member of team that conducted groundwater modeling studies of the LANL site and regional flow system

U.S. Geological Survey — 1988-1999

- Participated in studies of groundwater geochemistry near Yucca Mountain, Nevada
- Co-led the development of unsaturated-zone groundwater flow model for the Yucca Mountain Site

- Developed unsaturated-zone models for the Yucca Mountain site using temperature, moisture and pneumatic pressure data

Selected Publications

- Bennett, K.E., G. Miller, C. Talsma , A. Jonko , A. Bruggeman, A. Atchley , A. Lavadie-Bulnes , **E. Kwicklis**, R. Middleton, 2020. Future water resource shifts in the high desert Southwest of Northern New Mexico, USA. Journal of Hydrology Regional Studies V. 28 April 2020 100678. (https://doi.org/10.1016/j.ejrh.2020.100678)
- Bodvarsson, G.S., **E.M. Kwicklis**, C. Shan, and Y.S. Wu, 2002. Estimation of percolation flux from borehole temperature data at Yucca Mountain, Nevada, Journal of Contaminant Hydrology, 62-63: 3-22.
- Bourret, S.M., **E.M. Kwicklis**, T.A. Miller, and P.H. Stauffer, 2019. Evaluating the importance of barometric pumping for subsurface gas transport near an underground nuclear test site, Vadose Zone Journal 18:180134. Doi:10.2136/vzj2018.07.0134.
- Bourret, S.M., **Kwicklis, E.M.**, Harp, D.R., Ortiz, J.P., Stauffer, P.H. 2020. Beyond Barnwell: Applying lessons learned from the Barnwell site to other historic underground nuclear tests at Pahute Mesa to understand radioactive gas-seepage observations. J. Environ. Radioact. 222C. doi:10.1016/j.jenvrad.2020.106297.
- Bourret, S.M., **Kwicklis, E.M.**, and Stauffer, P.H., 2021. Evaluation of several relevant fractionation processes as possible explanations for radioxenon isotopic activity ratios in samples taken near underground nuclear explosions in shafts and tunnels (accepted by J. Environ. Radioact.).
- Constantz, J., S.W. Tyler, and **E. Kwicklis, 2003**. Temperature-profile methods for estimating percolation rates in arid environments, Vadose Zone Journal, 2:12-24.
- Flint, A.L., L.E. Flint, **E.M. Kwicklis**, J.T. Fabryka-Martin, and G.S. Bodvarsson, 2002. Estimating recharge at Yucca Mountain, Nevada, USA: comparison of methods, Hydrogeology Journal, 10:180-204.
- Flint, A.L., L.E. Flint, **E.M. Kwicklis**, G.S. Bodvarsson, and J.T. Fabryka-Martin, 2001. Hydrology of Yucca Mountain, Nevada, Reviews of Geophysics, v. 39, no. 4, p. 447-470.
- Flint, A.L., L.E. Flint, G.S. Bodvarsson, **E.M. Kwicklis**, and J.T. Fabryka-Martin, 2001. Evolution of the conceptual model of the unsaturated zone hydrology of Yucca Mountain, Nevada, Journal of Hydrology 247, p. 1-30.
- Harp, D. R., Bourret, S. M., Stauffer, P. H., & **Kwicklis, E. M.** (2020). Discriminating underground nuclear explosions leading to

late-time radionuclide gas seeps. Geophysical Research Letters, 47, e2019GL086654. https://doi.org/10.1029/2019GL086654

- https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2019GL086654
- Hershey, R.L., J.B. Paces, M.J. Singleton, **E.M. Kwicklis**, D.L. Decker, W.M. Fryer, and S. Earman, 2008. Geochemical and Isotopic Evaluation of Groundwater Movement in Corrective Action Unit 99: Rainier Mesa and Shoshone Mountain, Nevada Test Site. Desert Research Institute Publication No. 45229.
- **Kwicklis, E.M.**, and R.W. Healy, 1993. Numerical Investigation of steady liquid water flow in a variably saturated fracture network, Water Resources Research, vol. 29, no. 12, p. 4091-4102.
- **Kwicklis, E.M.**, Z. Lu, R. Middleton, T. Miller, S. Bourret, and K. Birdsell, 2019. Numerical evaluation of unsaturated-zone flow and transport pathways at Rainier Mesa, Nevada. Vadose Zone Journal 18:1900005.doe:102136/vzj2019.01.005.
- **Kwicklis, E.**, A. Meijer, and J.T. Fabryka-Martin, 2003. Geochemical inverse models of groundwater mixing and chemical evolution in the Yucca Mountain area, in Proceedings of the 10th International High-Level Radioactive Waste Management Conference, Las Vegas, Nevada, March 30-April 2, 2003.
- **Kwicklis, E.M.**, F. Thamir, R.W. Healy, and D. Hampson, 1998. Numerical Simulation of Air- and Water-Flow Experiments in a Block of Variably Saturated, Fractured Tuff from Yucca Mountain, Nevada. U.S. Geological Survey Water-Resources Investigations Report 97-4274.
- **Kwicklis, E.M.**, M. Witkowski, K. Birdsell, B. Newman, and D. Walther, 2005. Development of an infiltration map for the Los Alamos Area, New Mexico, Vadose Zone Journal, 4:672-693.
- **Kwicklis, E.M.**, T.P. Rose and F.C. Benedict, 2005. Evaluation of groundwater flow in the Pahute Mesa – Oasis Valley flow system using groundwater chemical and isotopic data, Los Alamos National Laboratory Report LA-UR-05-4344.
- **Kwicklis, E.M.**, A.V. Wolfsberg, P.H. Stauffer, M.A. Walvoord, and M.J. Sulley, 2006. Multi-phase, multicomponent parameter estimation for liquid and vapor fluxes in deep arid systems using hydrologic data and natural environmental tracers, 2006. Vadose Zone Journal, 5:934-950.
- **Kwicklis. E.**, G. Ruskauff, N. DeNovio, N. Becker, B. Wilborn, 2011. A groundwater flow and transport model of long-term radionuclide migration in central Frenchman Flat, Nevada Test Site, Proceedings of Waste Management Conference, Phoenix, Arizona, February 28 - March 3, 2011.
- **Kwicklis, E.**, and Farnham, I., 2014. Testing the ^{14}C ages and conservative behavior of dissolved ^{14}C in a carbonate aquifer in Yucca

Flat, Nevada (USA), using ^{36}Cl from groundwater and packrat middens, Hydrogeology Journal, 22:1359-1381.

- Lu, N., **E.M. Kwicklis**, and J.P. Rousseau, 2001. Determining fault permeability from subsurface barometric pressure. Journal of Geotechnical and Geoenvironmental Engineering, Vol. 127, No. 9, p. 801-808.
- Lu, Z. and **E.M. Kwicklis**, 2012. Numerical evaluation of effective unsaturated hydraulic properties of fractured rocks using a stochastic continuum approach, Vadose Zone Journal., 11:4 - doi:102136/vzj2011.0164.
- Middleton, R.S., **E.M. Kwicklis**, K.H. Birdsell, D.G. Levitt, and J. Hevesi, 2019. Net Infiltration Models for the Pahute Mesa Area, LA-UR-16-27513, Rev 1. Los Alamos, NM: Los Alamos National Laboratory.
- Rousseau, J.P., **E.M. Kwicklis**, and D.C. Gillies (editors), 1999. Hydrogeology of the unsaturated zone, North Ramp area of the Exploratory Studies Facility, Yucca Mountain, Nevada, U.S. Geological Survey Water-Resources Investigations Report 98-4050, Denver Colorado.
- Zyvoloski, G., **E. Kwicklis**, A.A. Eddebbarh, B. Arnold, C. Faunt, and B.A. Robinson, 2002. The site-scale saturated zone flow model for Yucca Mountain: calibration of different conceptual models and their impact on flow paths, Journal of Contaminant Hydrology, v. 62-63, p. 731-750.

Selected Project Reports

- BSC (Bechtel SAIC Company), 2004. Geochemical and isotopic constraints on groundwater flow directions, mixing, and recharge at Yucca Mountain, Nevada, Yucca Mountain Project Analysis and Modeling Report, ANL-NBS-HS-000021, Rev. 01. Las Vegas, Nevada: Bechtel SAIC Company.
- Farnham, I.M., T.P. Rose, **E.M. Kwicklis**, R.L. Hershey, J.B. Paces and W.M. Fryer, 2006. Geochemical and isotopic evaluation of groundwater movement in corrective action unit 97: Yucca Flat/Climax Mine, Nevada Test Site, Nevada. Stoller-Navarro Publication S-N/99205-070, Stoller-Navarro Joint Venture, Las Vegas, Nevada.
- Farnham, I.M., **E.M. Kwicklis**, R.L Hersehy, A. Visser, and J. Hoagland III, 2020. Phase II geochemical and isotopic evaluation of groundwater flow in the Pahute Mesa – Oasis Valley Flow System, Nevada. Navarro Report N/0002653-069, July 2020. Las Vegas, Nevada.
- Stoller-Navarro, 2006. Phase II groundwater flow model of Corrective Action Unit 98: Frenchman Flat, Nevada Test Site, Nye County, Nevada, S-N/99205—074.
- Navarro Nevada Environmental Services, LLC, 2010. Phase II Transport Model of Corrective Action Unit 98: Frenchman Flat, Nevada Test Site, Nye County, Nevada, N-I/28091—004 (S-N/99205—122).
- Navarro-Intera, 2013. Yucca Flat/Climax Mine flow and transport model, Nevada National Security Site, Nye County, Nevada, N-I/28091—065.

Edward Kwicklis

Ed received his B.A. in geology from Queens College of the City University of New York in 1981 and his M.S. in Geology from the University of Colorado, Boulder, in 1987. While still completing his M.S., he worked as a student for the U.S. Geological Survey in Denver, Colorado as a groundwater flow and transport modeler, helping to develop an unsaturated-zone flow and transport code for use by the USGS on the Yucca Mountain Project (YMP). Yucca Mountain was then under consideration as the Nation's first high-level nuclear-waste repository. He was hired as a full-time employee by the USGS in late 1988 where he continued to work on numerical model development for the unsaturated at Yucca Mountain. In the early 1990s, he co-led the development of a three-dimensional site-wide unsaturated-zone (UZ) flow model of Yucca Mountain with staff at Lawrence Berkeley National Laboratory (LBNL). In his capacity as co-lead for the Yucca Mountain UZ modeling effort, Ed represented YMP multiple times to the site regulator (the U.S. Nuclear Regulatory Commission) and congressional oversight groups such as the Nuclear Waste Technical Review Board (NWTRB). The YMP UZ model was innovative in many respects, and incorporated many site data such as naturally occurring environmental tracers, subsurface barometric pressure responses, and borehole saturation, water potential and temperature data to calibrate rock properties necessary to analyze flow-system behavior and provide estimates of unsaturated-zone seepage rates in the mountain, which was critical to quantify in order to address issues such as rates of canister corrosion and radionuclide transport to the water table.

Ed joined Los Alamos National Laboratory as a staff scientist in early 1999 where he helped develop groundwater flow models for the saturated groundwater system at Yucca Mountain as well as for the Espanola Basin in northern New Mexico which contains the Los Alamos National Laboratory. The regional model for the Espanola Basin provided a broader hydrologic understanding that helped guide the development of more localized groundwater models of contaminant migration at the Laboratory. In addition to developing these numerical models, he also helped develop an understanding of the Yucca Mountain and Espanola Basin groundwater flow systems from naturally occurring groundwater tracers that provided an independent check on interpretations based on numerical models developed primarily from hydraulic data.

In the early 2000s, Ed also began work on groundwater studies for the Underground Test Area (UGTA) Project at the former Nevada Test Site (NTS), now known as the Nevada National Security Site (NNSS). Under the UGTA project, the NNSS was divided into four major former nuclear testing areas known as Corrective Action Units (CAUs): Frenchman Flat, Yucca Flat/Climax Mine, Rainer Mesa/Shoshone Mountain, and Pahute Mesa. Ed played a prominent role in developing groundwater flow and transport models for each of these major testing areas, as well as helping to develop independent interpretations of these flow systems from naturally occurring groundwater tracers, some of which also served as useful surrogates for understanding the groundwater migration of testing-derived radionuclides. The transport models for each of these areas were developed in a probabilistic framework to acknowledge the uncertainty in many of the model parameters. Output of from these models was presented as maps of the probabilities

that various locations in the aquifers downstream of the nuclear testing areas would have radionuclide concentrations above the drinking water standards at some time over the 1,000 years following closure. Ed served in the role of chief scientist for the Yucca Flat/Climax Mine area of the NNSS from 2008 to 2021, where he represented the Department of Energy's technical understanding of the area to the state regulator (the Nevada Division of Environmental Protection or NDEP) and other stakeholders (representatives from Nye County, and the Citizens Advisory Board). In his capacity as chief scientist, Ed led the development of models and analysis that led to the regulatory closure of Yucca Flat/Climax Mine and the development of a long-term groundwater monitoring network. While at LANL, Ed also served as co-team lead for the Subsurface Flow and Transport modeling team of the Earth and Environmental Sciences Division between 2008 and 2014, supervising approximately 20 Ph.D. level scientists during that time.

In addition to UGTA, Ed also led the LANL modeling team for the Underground Nuclear Explosion Signatures Experiment (UNESE) between 2015 and 2020. In this capacity, Ed led the development of subsurface models for the transport of gaseous radionuclides generated by underground nuclear tests. These models investigated the factors that led to the appearance of test-generated radionuclides at ground surface, where they could be detected through on-site inspections or by global monitoring networks maintained by the International Atomic Energy Agency for compliance with nuclear non-proliferation treaties. Part of this work involved the use of historic U.S. nuclear testing data to help understand how isotope fractionation during subsurface transport could alter the isotope ratios currently being used by international agencies to distinguish nuclear tests from civilian sources. Ed retired from Los Alamos National Laboratory in April, 2021.

Selected Publications (in Alphabetical order)

- Bennett, K.E., G. Miller, C. Talsma , A. Jonko , A. Bruggeman, A. Atchley , A. Lavadie-Bulnes , **E. Kwicklis**, R. Middleton, 2020. Future water resource shifts in the high desert Southwest of Northern New Mexico, USA. Journal of Hydrology Regional Studies V. 28 April 2020 100678. (https://doi.org/10.1016/j.ejrh.2020.100678)
- Bodvarsson, G.S., **E.M. Kwicklis**, C. Shan, and Y.S. Wu, 2002. Estimation of percolation flux from borehole temperature data at Yucca Mountain, Nevada, Journal of Contaminant Hydrology, 62-63: 3-22.
- Bourret, S.M., **E.M. Kwicklis**, T.A. Miller, and P.H. Stauffer, 2019. Evaluating the importance of barometric pumping for subsurface gas transport near an underground nuclear test site, Vadose Zone Journal 18:180134. Doi:10.2136/vzj2018.07.0134.
- Bourret, S.M., **Kwicklis, E.M.**, Harp, D.R., Ortiz, J.P., Stauffer, P.H. 2020. Beyond Barnwell: Applying lessons learned from the Barnwell site to other historic underground nuclear tests at Pahute Mesa to understand radioactive gas-seepage observations. J. Environ. Radioact. 222C. doi:10.1016/j.jenvrad.2020.106297.
- Bourret, S.M., **Kwicklis, E.M.**, and Stauffer, P.H., 2021. Evaluation of several relevant fractionation processes as possible explanations for

radioxenon isotopic activity ratios in samples taken near underground nuclear explosions in shafts and tunnels, J. Environ. Radioact 237, https://doi.org/10.1016/j.jenvrad.2021.106698

- Constantz, J., S.W. Tyler, and **E. Kwicklis, 2003**. Temperature-profile methods for estimating percolation rates in arid environments, Vadose Zone Journal, 2:12-24.
- Flint, A.L., L.E. Flint, **E.M. Kwicklis**, J.T. Fabryka-Martin, and G.S. Bodvarsson, 2002. Estimating recharge at Yucca Mountain, Nevada, USA: comparison of methods, Hydrogeology Journal, 10:180-204.
- Flint, A.L., L.E. Flint, **E.M. Kwicklis**, G.S. Bodvarsson, and J.T. Fabryka-Martin, 2001. Hydrology of Yucca Mountain, Nevada, Reviews of Geophysics, v. 39, no. 4, p. 447-470.
- Flint, A.L., L.E. Flint, G.S. Bodvarsson, **E.M. Kwicklis**, and J.T. Fabryka-Martin, 2001. Evolution of the conceptual model of the unsaturated zone hydrology of Yucca Mountain, Nevada, Journal of Hydrology 247, p. 1-30.
- Harp, D. R., Bourret, S. M., Stauffer, P. H., & **Kwicklis, E. M.** (2020). Discriminating underground nuclear explosions leading to late-time radionuclide gas seeps. Geophysical Research Letters, 47, e2019GL086654. https://doi.org/10.1029/2019GL086654
- https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2019GL086654
- **Kwicklis, E.M.**, and R.W. Healy, 1993. Numerical Investigation of steady liquid water flow in a variably saturated fracture network, Water Resources Research, vol. 29, no. 12, p. 4091-4102.
- **Kwicklis, E.M.**, Z. Lu, R. Middleton, T. Miller, S. Bourret, and K. Birdsell, 2019. Numerical evaluation of unsaturated-zone flow and transport pathways at Rainier Mesa, Nevada. Vadose Zone Journal 18:1900005.doe:102136/vzj2019.01.005.
- **Kwicklis, E.**, A. Meijer, and J.T. Fabryka-Martin, 2003. Geochemical inverse models of groundwater mixing and chemical evolution in the Yucca Mountain area, in Proceedings of the 10th International High-Level Radioactive Waste Management Conference, Las Vegas, Nevada, March 30-April 2, 2003.
- **Kwicklis, E.M.**, F. Thamir, R.W. Healy, and D. Hampson, 1998. Numerical Simulation of Air- and Water-Flow Experiments in a Block of Variably Saturated, Fractured Tuff from Yucca Mountain, Nevada. U.S. Geological Survey Water-Resources Investigations Report 97-4274.
- **Kwicklis, E.M.**, M. Witkowski, K. Birdsell, B. Newman, and D. Walther, 2005. Development of an infiltration map for the Los Alamos Area, New Mexico, Vadose Zone Journal, 4:672-693.
- **Kwicklis, E.M.**, T.P. Rose and F.C. Benedict, 2005. Evaluation of groundwater flow in the Pahute Mesa – Oasis Valley flow system using groundwater chemical and isotopic data, Los Alamos National Laboratory Report LA-UR-05-4344.
- **Kwicklis, E.M.**, A.V. Wolfsberg, P.H. Stauffer, M.A. Walvoord, and M.J. Sulley, 2006. Multi-phase, multicomponent parameter estimation for liquid

and vapor fluxes in deep arid systems using hydrologic data and natural environmental tracers, 2006. Vadose Zone Journal, 5:934-950.

- **Kwicklis. E.**, G. Ruskauff, N. DeNovio, N. Becker, B. Wilborn, 2011. A groundwater flow and transport model of long-term radionuclide migration in central Frenchman Flat, Nevada Test Site, Proceedings of Waste Management Conference, Phoenix, Arizona, February 28 - March 3, 2011.
- **Kwicklis, E.**, and Farnham, I., 2014. Testing the ^{14}C ages and conservative behavior of dissolved ^{14}C in a carbonate aquifer in Yucca Flat, Nevada (USA), using ^{36}Cl from groundwater and packrat middens, Hydrogeology Journal, 22:1359-1381.
- **Kwicklis, E.M.**, I. Farnhmam, R. Hershey, A. Vissar and J. Hoaglund III, 2021. Understanding long-term groundwater flow at Pahute Mesa and vicinity, Nevada National Security Site, USA, from naturally occurring geochemical and isotopic tracers. Accepted by Hydrogeology Journal.
- Lu, N., **E.M. Kwicklis**, and J.P. Rousseau, 2001. Determining fault permeability from subsurface barometric pressure. Journal of Geotechnical and Geoenvironmental Engineering, Vol. 127, No. 9, p. 801-808.
- Lu, Z. and **E.M. Kwicklis**, 2012. Numerical evaluation of effective unsaturated hydraulic properties of fractured rocks using a stochastic continuum approach, Vadose Zone Journal., 11:4 - doi:102136/vzj2011.0164.
- Middleton, R.S., **E.M. Kwicklis**, K.H. Birdsell, D.G. Levitt, and J. Hevesi, 2019. Net Infiltration Models for the Pahute Mesa Area, LA-UR-16-27513, Rev 1. Los Alamos, NM: Los Alamos National Laboratory.
- Rousseau, J.P., **E.M. Kwicklis**, and D.C. Gillies (editors), 1999. Hydrogeology of the unsaturated zone, North Ramp area of the Exploratory Studies Facility, Yucca Mountain, Nevada, U.S. Geological Survey Water-Resources Investigations Report 98-4050, Denver Colorado.
- Zyvoloski, G., **E. Kwicklis**, A.A. Eddebbarh, B. Arnold, C. Faunt, and B.A. Robinson, 2002. The site-scale saturated zone flow model for Yucca Mountain: calibration of different conceptual models and their impact on flow paths, Journal of Contaminant Hydrology, v. 62-63, p. 731-750.

Selected Project Reports

- BSC (Bechtel SAIC Company), 2004. Geochemical and isotopic constraints on groundwater flow directions, mixing, and recharge at Yucca Mountain, Nevada, Yucca Mountain Project Analysis and Modeling Report, ANL-NBS-HS-000021, Rev. 01. Las Vegas, Nevada: Bechtel SAIC Company.
- Farnham, I.M., T.P. Rose, **E.M. Kwicklis**, R.L. Hershey, J.B. Paces and W.M. Fryer, 2006. Geochemical and isotopic evaluation of groundwater movement in corrective action unit 97: Yucca Flat/Climax Mine, Nevada Test Site, Nevada. Stoller-Navarro Publication S-N/99205-070, Stoller-Navarro Joint Venture, Las Vegas, Nevada.
- Farnham, I.M., **E.M. Kwicklis**, R.L Hersehy, A. Visser, and J. Hoagland III, 2020. Phase II geochemical and isotopic evaluation of groundwater flow in the Pahute Mesa – Oasis Valley Flow System, Nevada. Navarro Report N/0002653-069, July 2020. Las Vegas, Nevada.
- Hershey, R.L., J.B. Paces, M.J. Singleton, **E.M. Kwicklis**, D.L. Decker, W.M. Fryer, and S. Earman, 2008. Geochemical and Isotopic Evaluation of Groundwater Movement in Corrective Action Unit 99: Rainier Mesa and Shoshone Mountain, Nevada Test Site. Desert Research Institute Publication No. 45229.
- Stoller-Navarro, 2006. Phase II groundwater flow model of Corrective Action Unit 98: Frenchman Flat, Nevada Test Site, Nye County, Nevada, S-N/99205—074.
- Navarro Nevada Environmental Services, LLC, 2010. Phase II Transport Model of Corrective Action Unit 98: Frenchman Flat, Nevada Test Site, Nye County, Nevada, N-I/28091—004 (S-N/99205—122).
- Navarro-Intera, 2013. Yucca Flat/Climax Mine flow and transport model, Nevada National Security Site, Nye County, Nevada, N-I/28091—065.

Peer Review Panel Member Verification of Education/Employment Form

Section 1

Peer panel member nominee information:

My signature verifies that the information contained in this resume is correct. You are hereby authorized to verify this information.

Name: Sherilyn Williams-Stroud (Printed) 9/21/2021 (Date) [signature] (Signature)

The resume will contain nominee's education and employment history.

I. EDUCATION: A list of educational institution(s), degree(s), discipline(s)/subject(s), and year(s).

II. EMPLOYMENT HISTORY: A list of employment history for the previous ten (10) years, starting with the latest. The history will include responsibilities [in general terms] and years with each employer.

Please note that (all) official transcript(s) is (are) to be in (a) sealed envelope(s) from the university registrar(s). Foreign degrees need to be verified and evaluated by credential evaluation services.

Section 2

The peer review chairperson is responsible for completing this section.

Position/Title: Peer Review Panelist

Comments: Work experience includes 45 years of experience in the field of geology working with the U.S. Geological Survey, various commercial organizations, and universities. Dr. Williams-Stroud is a California Licensed Professional Geologist. Her educational history includes a Bachelor's of Art in Geology from Oberlin College, and a Masters of Art and PhD in Structural Geology from The Johns Hopkins University. Dr. Williams-Stroud is active in the area of fracture analysis and modeling. She is familiar with repository disposal of nuclear waste through her support to the Yucca Mountain Project.

Peer Review Chairperson:

Name: John A. Thies (Printed) 09/27/21 (Date) [signature] (Signature)

SHERILYN C. WILLIAMS-STROUD

[redacted]

EDUCATION

PH.D., STRUCTURAL GEOLOGY, 1987, *The Johns Hopkins University, Baltimore, MD*
M.A. STRUCTURAL GEOLOGY, 1984, *The Johns Hopkins University, Baltimore, MD*
B.A. GEOLOGY, 1981, *Oberlin College, Oberlin, Ohio*

CERTIFICATIONS

CALIFORNIA LICENSED PROFESSIONAL GEOLOGIST
License Number: 9672

EMPLOYMENT

RESEARCH SCIENTIST, STRUCTURAL GEOLOGIST (JUNE 2018 – PRESENT)
Illinois State Geological Survey
http://isgs.illinois.edu
In the Energy & Minerals/Petroleum Geology Section, my duties are to contribute to and lead multi-disciplinary subsurface research programs within and beyond the ISGS in the areas of structural geology and geomechanics. Active research areas are structural and fracture analysis and modeling for hydrocarbon and geothermal energy production, and carbon sequestration applying specialized expertise in microseismic data interpretation and induced seismicity analysis.

PRESIDENT AND CHIEF EXECUTIVE OFFICER (MAY 2016 – PRESENT)
Confractus, Inc. Pasadena, CA 91105
http://www.confractusinc.com
As a consultant, I provide specialized technical support, training, and tech transfer to clients in the oil & gas industry. Areas of expertise include geological interpretation, analysis, and modeling related to fractured (and fracturing) rock, performing project work involving structural geology analysis, fracture modeling, fractured reservoir characterization, microseismic data interpretation, structural restoration, fault and fracture prediction and analysis, rock mechanics and stress analysis.

PART-TIME FACULTY (AUGUST 2017 – MAY 2018)
California State University Northridge, Geological Sciences Department, Northridge, CA 91330
Teach the course "Geology of Planet Earth".

ADJUNCT FACULTY (FEBRUARY 2017 – MAY 2017)
California State University, Los Angeles, Dept. Geosciences and Environment 90032
Taught laboratory section for the course "Natural Hazards"

SENIOR GEOLOGICAL ADVISOR (AUGUST 2012 – JANUARY 2016)
California Resources Corporation, 10800 Stockdale Hwy, Bakersfield, CA 93311
(Independent spinoff, formerly Occidental Oil & Gas Corp.)

Provided technical expertise and support in the areas of fracture and rock mechanics analysis, microseismic monitoring results, structural geological analysis and modeling, earth stress analysis, and drilling and wellbore stability. I mentored and trained interns and new hires as well as experienced hires interested in developing expertise in my specialty areas. I also provided formal training to geoscience staff in the form of short courses, seminars, and workshops.
Occidental Oil & Gas Corp., 5 Greenway Plaza, Suite 110, Houston, TX 77046
(AUGUST 2012 – DECEMBER 2014)
Same position and responsibilities.

CHIEF GEOLOGIST (JUNE 2012 – AUGUST 2012)
MicroSeismic, Inc., 10777 Westheimer Road, Suite 500, Houston, TX 77042
Led the development of geological tools, analysis, and products and their integration into the microseismic monitoring and analysis technology. Managed integrated technical projects utilizing client data and develop new geological products by working with geophysicists and engineers to optimize utility of microseismic data and analysis results. Recruited, interviewed and evaluate new hires to the company. Reviewed and evaluated new geological products developed by geology team members for market-readiness and patent potential.
GEOLOGIC ADVISOR (March 2008 – May 2012)
MicroSeismic, Inc., 10777 Westheimer Road, Suite 500, Houston, TX 77042
Developed structural geology interpretation products for passive seismic monitoring results from hydraulic fracture stimulations and reservoir production monitoring. Provided client presentations and training courses, presented technical papers at professional society meetings, and published technical results. Performed quality control review of all geological products and reports generated by geology staff. Provided internal technical training and mentoring to geoscience and reservoir engineer staff in the areas of fractured reservoir analysis and structural geology. Supported business development activities through interactions with clients regarding new products, tools and applications, publications and technical presentations.

PRINCIPAL GEOLOGIST, GEO TEAM LEADER (September 2004 – March 2008)
Midland Valley Exploration, Floor 9, West Regent Street, Glasgow, UK G2 1RW
Managed the team of project geologists responsible for delivery of high-quality technical analysis in structural geology to the petroleum industry. Responsibilities included oversight of day-to-operations of geology team activities including project resource scheduling, and project review. Facilitated cross-team technical exchange, technical, business and professional mentoring of geologists in consulting and software development projects. Coordinated and provided internal training of structural geologists to help them reach their individual goals as well as company needs. Contributed to strategic business planning for short and long-term software and consulting sales and software development. Had the lead role in business development in the Middle East and North American geographic portfolios. Performed technical consulting work and participated in software development and testing. Was technical lead for fracture modeling technology, geologist product champion for fracture modeling software, advised on development of software code, wrote help documentation, tutorial manuals, and marketing material.

FACULTY (Fall and Winter Term, 2004)
Whittier College, Whittier, California, CA 90608-4413
Developed and taught undergraduate courses and laboratory in introductory earth science and structural geology, supervise independent study in structural geology. Designed and ran a 1-month geology field course in southern California.

SENIOR RESEARCH SCIENTIST (August 1998 – August 2004)
ChevronTexaco Exploration and Production Technology, 4800 Fournace Pl., Bellaire, TX 77401
Applied fracture evaluation technologies and structural geologic modeling to exploration and production efforts to better define reservoir seals and hydrocarbon migration pathways. Worked with basin, geochemical & stratigraphic modelers to integrate fracture models and basin structure models into basin geology interpretations. Interacted with business units to delineate necessary activities for fracture core research program. Coordinated funding for university fracture research consortia, tracked and reviewed the results of their research, disseminated resulting technologies to the business units. Developed fracture prediction methods based on volume strain analysis and borehole fracture interpretations that were used to plan additional wells in reservoirs in the Arabian Plateau. Evaluated stress magnitudes in gas sand reservoirs in the Sichuan Basin that were used as a basis for understanding active tectonic stresses for use in borehole stability calculations.

ADJUNCT FACULTY (Fall term 2000 – Spring term 2002)
University of Houston - Downtown, One Main Street, Houston, TX 77002
Taught Saturday section of the introductory physical geology course.

STAFF SCIENTIST FOR PROGRAM (1996-1998)
U.S. Geological Survey, Denver Federal Center, Denver, CO 80225
Performed oversight to the internal programs of the Central Region USGS Geologic Division, including the National Reactor Facility, National Ice Core Laboratory, Core Research Center, Central Publications Support Services, and the Geologic Division Microbeam Laboratory. The managers of each of these facilities reported to me. Facilitated planning and development, reviewed proposals and recommended approval for internal program projects. Accomplished or supervised special internal projects involving safety, Human Resources, and EEO issues, by compiling matrices for Regional activities and contributing to State Fact Sheets. Helped redesign the funding mechanism for the microbeam laboratory and revised the position description of the microbeam scientist. Chaired a committee that developed recommendations for implementing revised cost structure for USGS publications by publication type and priority. Served as the first chair of the Minority Affairs Committee, which sought to improve inclusion, communication and diversity within the Geologic Division.

GUEST FACULTY (July-August 1996)
Keck Geology Consortium, Carleton College, Northfield, MN 55057
Participated in the Keck Geology Consortium field camp, environmental geophysics project in Butte, Montana. Assisted undergraduate (junior-senior) level geology students with design, logistics and field data collection for so that they would leave the field camp with sufficient data and project organization to complete their senior geology thesis project. Served as faculty advisor, maintained advisory contact with students to help them complete their senior projects.

RESEARCH GEOLOGIST (1988-1996)
U.S. Geological Survey, Denver Federal Center, Denver, CO 80225
Yucca Mountain Project: Conducted mapping and collected fracture data from surface and subsurface exposures to construct structural model of volcanic tuff rocks at Yucca Mountain, NV, toward the site suitability assessment of its potential as the national nuclear waste repository. Created fracture database used to generate the fracture synthesis report of Yucca Mountain fracture data required for site suitability assessment. Paradox Basin Project: Conducted research in evaporite geology using petrographic analysis of salt rock drill cores, field studies, mass balance calculations and geochemical computer models to develop models for depositional history and brine evolution of salt and potash deposits. Served as Commodity Specialist for potash, bromine and iodine. Team member on scientific exchange project with the Polish Geological Survey to study and compare large evaporite basins in the U.S. and in Poland.

US GEOLOGICAL SURVEY GRADUATE INTERNSHIP (1986-1987)
U.S. Geological Survey, National Center, Reston, VA 22092
Conduct experiments in the deformation of gypsum, make micro-structural analyses, prepare thin sections, do photo-microscopy and other research leading to the completion of a Ph.D. thesis.

EDUCATION AND OUTREACH ACTIVITIES

- Narrator in 2017 AAPG documentary "Rock Stars: Pioneering Women in Petroleum Geology" and profiled in the associated book "Anomalies: Pioneering Women in Petroleum Geology 1917-2017"
- Member National Academy of Sciences Committee on Seismology and Geodynamics 2015-2019
- AAPG Visiting Geoscientist since October 2014 http://www.aapg.org/career/training/in-person/visiting-geoscientist/details/articleid/17054/sherilyn-williams-stroud
- AAPG-SEG West Coast 2013 Student Expo Mini-Course, "Possible Pitfalls for Interpreting b-values as a Stress Meter – Geological Considerations for Earthquake Swarms to Microseismic Event Sets", California State University, Northridge, CA, USA
- AAPG-SEG West Coast 2011 Student Expo Mini-Course, "Surface-Based Monitoring of Microseismicity from Hydraulic Fracture Stimulation Treatments, California State University, Northridge, CA, USA
- Guest Scientist in Annenberg/CPB video "Earth & Space Science: Session 6. Restless Landscapes" Harvard-Smithsonian Center for Astrophysics, 2004
  http://www.learner.org/courses/essential/earthspace/session6/index.html

GEOGRAPHIC AREAS OF WORK PERFORMED

North America: Illinois Basin, Basin and Range Province, Paradox Basin – Colorado and Utah, Permian Basin, Appalachian Basin, Williston Basin – North Dakota, South Texas Basin Eagle Ford Shale, San Joaquin Basin – California, Deepwater Gulf of Mexico, Belize, Central America, Guaduas Basin, Colombia, Pri-Caspian Basin, Kazakhstan, Arabian Plateau, Kuwait and Saudi Arabia, Sichuan Basin, China, Offshore and deep-water Nigeria, North Sea, United Kingdom and Norway,

LANGUAGES

Conversational German (spoken), Scientific German (reading)

COMPUTER SKILLS

- FracMan (Golder Associates) fractured reservoir analysis and modeling software
- Move™ structural analysis and modeling software
- Paradigm SKUA-Gocad geological modeling software
- Petrel (Schlumberger) geologic modeling software
- JMP (SAS) and Spotfire statistical analysis software
- OpenWorks/SeisWorks seismic interpretation and well data management system
- 3D Slicer visualization and medical image computing
- ArcGIS software
- Graphics software packages: GIMP, Canvas, Adobe Illustrator, Affinity Designer
- Basic script-writing capability in SAS, IDL and R

AWARDS

- Mentoring Excellence in Technology - selection for participation as a mentee in 1-year Texaco training program, March 2000 - March 2001
- AAPG Bulletin Citation of Excellence for review of "Three-Dimensional Visualization of the Neogene Structures of an External Sector of the Northern Apennines, Italy", May 2001
- USGS "Star Award" for exceptional accomplishment in the job of Staff Scientist for Program in support of the reorganization of the USGS Central Region Publications Group, 1997
- Sigma-Xi Grant in Aid of Research, 1984
- National Science Foundation Minority Graduate Fellowship, 1982-1985
- American Geological Institute Minority Participation in Earth Sciences Scholarship, 1982-1985

PROFESSIONAL SOCIETY MEMBERSHIPS

- American Association of Petroleum Geologists (**AAPG**)
- Society of Exploration Geophysicists (**SEG**)
- American Geophysical Union (**AGU**)
- Geological Society of America (**GSA**)
- National Association of Black Geoscientists (**NABG**)
- Seismological Society of America (**SSA**)
- American Rock Mechanics Association **(ARMA)**

PROFESSIONAL SOCIETY SERVICE WORK

- Organizing Committee 2021 Discrete Fracture Network Engineering Conference
- Panel moderator for National Academies of Science Engineering and Medicine (NASEM) Committee on Earth Sciences Fall 2020 Meeting, topic: Pathways Toward the Future Just, Equitable, Diverse, and Inclusive (JEDI) Energy Workforce https://www.nationalacademies.org/event/12-01-2020/committee-on-earth-resources-fall-2020-meeting
- Chair, Geological Society of America Committee on Diversity (2020-2021)
- Member Seismological Society of America Diversity, Equity, and Inclusion Task force (2020-2021)
- Organizing committee for AAPG Petroleum Geomechanics & Structure Division meeting, 2019 and 2020.
- Session Chair for Theme 6: Carbon Capture and Storage I & II, AAPG ACE 2020
- Organizing Committee 2016 American Rock Mechanics Association (ARMA) Annual Symposium
- Technical program committee, NABG Annual Convention, 2010 (San Antonio, TX), and 2011 (San Francisco, CA)

- Co-Leader of Mini-Summit on Diversity in AAPG, AAPG Leadership Meeting, Tulsa, OK, 2002.
- AAPG Core and Sample Preservation Committee, 2000 to 2008 (Vice-Chair of Committee, 2002-2004, Chair, 2004-2006)
- Local Chair, USGS Geologic Division Ethnic Minority Advisory Committee, 1992-1995

PUBLICATIONS

(LINK TO GOOGLE SCHOLAR)

Williams-Stroud, S., Bauer, R., Leetaru, H., Oye, V., Stanek, F., Greenberg, S., & Langet, N. (2020). Analysis of microseismicity and reactivated fault size to assess the potential for felt events by CO_2 injection in the Illinois Basin. Bulletin of the Seismological Society of America, 110(5):2188-2204. https://doi.org/10.1785/0120200112

Williams-Stroud, S. (2020). Seeking Diversity in the Geosciences when Black Lives Matter, *GSA Today*

Langet, N., Goertz-Allmann, B., Oye, V., Bauer, R. A., **Williams-Stroud, S.**, Dichiarante, A. M., & Greenberg, S. E. (2020). Joint focal mechanism inversion using downhole and surface monitoring at the decatur, illinois CO_2 injection site. Bulletin of the Seismological Society of America, 110(5): 2168-2187. https://doi.org/10.1785/0120200075

Holt, N. M., Garcia-Veigas, J., Lowenstein, T. K., Giles, P. S., and **Williams-Stroud, S.** C. (2014), The major-ion composition of Carboniferous seawater, Geochemica et Cosmochemica Acta, v. 134, pp. 317-334

Duncan, P. M., Smith, P. G., Smith, K., Barker, W. B., **Williams-Stroud, S.**, and Eisner, L. (2013), Microseismic Monitoring in Early Haynesville Development, *in* Geology of the Haynesville Gas Shale in East Texas and West Louisiana, AAPG Memoir 105, Chapter 12, pp. 219-236

Detring, J., and **Williams-Stroud, S.** (2012), Using Microseismicity To Understand Subsurface Fracture Systems and Increase the Effectiveness of Completions: Eagle Ford Formation, Texas. Society of Petroleum Engineers. doi:10.2118/162845-MS

Williams-Stroud, S.C., Ozgen, C., and Billingsley, R. (2012), Microseismicity-constrained discrete fracture network models for stimulated reservoir simulation, Geophysics, 78(1), https://doi.org/10.1190/geo2011-0061.1

Wessels, S. A., De La Pena, A., Kratz, M., **Williams-Stroud, S.**, Jbeili, T. (2011), Identifying faults and fractures in unconventional reservoirs through microseismic monitoring, First Break, 29, July 2011.

Eisner, L., **Williams-Stroud, S. C.**, Hill, A., Duncan, P., and Thornton, M. (2010), Beyond the dots in the box: Microseismicity-constrained fracture models for reservoir simulation, The Leading Edge, vol. 29, 326-333.

Petrychenko, O. Y., **Williams-Stroud, S.**, C., and Peryt, T. M. (2012), The relationship of brine chemistry of the Paradox Evaporite Basin (southwestern USA) to secular variation in seawater chemistry, Geological Quarterly, vol. 56, p. 25-40.

Williams-Stroud, S. C., Kilpatrick, J. E. Cornette, B., Eisner, L. and Hall, M. (2010), Moving outside of the borehole: Characterizing natural fractures through microseismic monitoring, First Break, 28, no. 7.

Sweetkind, D. S., Anna, L. O., **Williams-Stroud, S. C.**, and Coe, J. A. (1997), Characterizing the fracture network at Yucca Mountain, Nevada, Part 1, Integration of field data for numerical simulations, Hoak, T. E., Klawitter, A. L., and Blomquist, P. K., eds., Fractured Reservoirs: Characterization and Modeling, p. 185-196.

Williams-Stroud, S., and Paul, J. (1997), Initiation and growth of gypsum piercement structures in the Zechstein Basin, Journal of Structural Geology, 19 (7), p. 897-907.

Sweetkind, D. S., and **Williams-Stroud, S. C.** (1996), Synthesis of fracture data from the Yucca Mountain project: Administrative Report for U. S. Dept. of Energy.

Williams-Stroud, S. (1995), Solution to the Paradox? Results of some chemical equilibrium models and mass balance calculations as applied to the Paradox basin evaporite deposit, American Journal of Science, vol. 294, p. 1189-1228.

Williams-Stroud, S. (1994), Potash Mining Engineering (industrial Minerals 1993 annual review article), June 1994, p. 540-542.

Williams-Stroud, S., Searls, J. P. and Hite, R. J. (1994), Potash Resources, in Industrial Minerals and Rocks, 6th Edition, Society for Mining, Metallurgy, and Exploration, Inc., p. 783-802.

Williams-Stroud, S. (1994), Evolution of an inland sea of marine origin to a non-marine saline Lake: The Pennsylvanian Paradox salt deposit, SEPM Special Publication 50, p. 293-306.

Williams-Stroud, S. (1992), Potash, Saline brines and brine deposits, in Minerals and Energy Resources of the BLM Roswell Resource Area East-Central New Mexico, USGS Open-File Report 92-0261.

Williams-Stroud, S. (1992), Potash, Saline brines and brine deposits, in Minerals and Energy Resources of the BLM Roswell Resource Area East-Central New Mexico, USGS Open-File Report 92-0261.

Williams-Stroud, S. (1991), Descriptive model of Potash-bearing bedded salt (Model 35ab(T), p. 26-28; Descriptive Model of Naturally Occurring Iodine Brines (Model 35am), p. 36-37; Descriptive Model of Naturally Occurring Bromite Brine (Model 35 am), p. 38-39; Descriptive Model of Iodine-Bearing Nitrate (Model 35bl), p. 45-46; in Orris G.J., and Bliss, J.D., eds., Some Industrial Mineral Deposit Models: Descriptive Deposit Models, U.S. Geological Survey Open-File Report 91-11A.

Williams, S. (1988), The shear strength of gypsum single crystals on three cleavage planes, Tectonophysics, v. 148, p. 163-173.

Williams, S. (1988), The shear strength of gypsum single and polycrystals and its implications for petrofabric analysis. Unpublished Ph.D. dissertation, The John Hopkins University, 152 p.

CONFERENCE PROCEEDINGS/EXPANDED ABSTRACTS

Stanek, F., **S. Williams-Stroud,** R. Bauer, and L. Eisner (2020). Importance of monitoring seismicity induced by CO 2 sequestration at Illinois Basin – Decatur Project, in SEG Technical Program Expanded Abstracts, Society of Exploration Geophysicists, 2226–2230.

Williams-Stroud, S., Leetaru, H., Bauer, R., Greenberg, S., Whittaker, S. (2019), Overview of active and passive seismic data acquisition and monitoring at the Illinois Basin – Decatur Project, SEG Technical Program Expanded Abstracts.

Williams-Stroud, S. (2018), Calculating Fault and Fracture Plane Size from Microseismic Events and Rock Elastic Properties, 2nd International Discrete Fracture Network Engineering Conference, Seattle, ARMA-DFNE-18-1384.

Williams-Stroud, S. (2017), Earth stress and seismic hazard from the size-frequency distribution of seismic events, 51st US Rock Mechanics/Geomechanics Symposium, San Francisco, ARMA 17-985.

Williams-Stroud, S., (2017), A geological approach to seismicity b-values: Implications for hazard assessment, SEG Technical Program Expanded Abstracts, pp. 5381-5385

Neuhaus, C., **Williams-Stroud, S.**, Remington, C., Barker, W., Blair, K., Neshyba, G., and McCay, T. (2012), Integrated microseismic monitoring for field optimization in the Marcellus Shale – A case study, SPE Canadian Unconventional Resources Conference, Calgary, AB, SPE161965

Williams-Stroud, S., Neuhaus, C., Telker, C., Remington, C., Barker, W., Neshyba, G., and Blair, K. (2012), Temporal evolution of stress states from hydraulic fracturing source mechanisms in the Marcellus Shale, SPE Canadian Unconventional Resources Conference, Calgary, AB, SPE162786

Williams-Stroud, S., Barker, W., Smith, K. (2012), Induced Hydraulic Fractures or Reactivated Natural Fractures? Modeling the Response of Natural Fracture Networks to Stimulation Treatments, ARMA 12-667, 46th US Rock Mechanics/Geomechanics Symposium, Chicago, IL.

Williams-Stroud, S. C., Barker, W. B., and Smith, K. L. (2011), Linear bi-wing fracture trends do not indicate induced hydraulic fractures, 73rd EAGE Conference & Exhibition, Vienna, Austria.

Williams-Stroud, S. C., and Eisner, L. (2010), Stimulated fractured reservoir DFN models calibrated with Microseismic source mechanisms, 44th US Rock Mechanics Symposium and 5th US-Canada Rock Mechanics Symposium, Salt Lake City, UT, ARMA 10-520.

Williams-Stroud, S. C., and R. L. Billingsley (2010), Techniques to estimate fracture effectiveness when mapping low-magnitude microseismicity, SEG Expanded Abstracts, pp. 2075-2079.

Williams-Stroud, S. C. (2008), Using microseismic events to constrain fracture network models and implications for generating fracture flow properties for reservoir simulation, SPE Shale Gas Production Conference, Fort Worth Texas, doi:10.2118/119895-MS.

CONFERENCE PRESENTATIONS

Williams-Stroud, S., Leetaru, H., Eisner, L., Stanek, F. (2020), Integration of induced seismicity with subsurface fault interpretations at the Illinois Basin – Decatur Project, AAPG Annual Conference and Exhibition.

Williams-Stroud, S. (2019), Deterministic DFN modeling: A methodology to estimate actual fracture plane size using rock lithology and microseismic event source information, AAPG Annual Conference and Exhibition, San Antonio, TX.

Williams-Stroud, S. and Leetaru, H. (2018), Geological Characterization of Seismicity in the Illinois Basin, Geological Society of America Annual Meeting, Indianapolis, IN.

Williams-Stroud, S., and Yielding, G. (2017), Earth stress and seismic hazard from the size-frequency distribution of seismic events, abstract, AAPG Annual Conference and Exhibition, Houston, TX.

Williams-Stroud, S. C., Zhou, R., and Hulsey, B., 2012, Fracture Mechanics Interpreted from Stress Inversion Analysis on Microseismic Event Source Mechanisms in the Marcellus Shale, AAPG 2012 Annual Conference and Exhibition, Long Beach, CA

Williams-Stroud, S., and Hulsey, B. J. (2011), Stress analysis using source mechanisms from failure along joints and faults in the Marcellus Formation during hydraulic fracture stimulation treatment, AAPG International Conference and Exhibition, Milan, Italy

Eisner, L., Grechka, V., and **Williams-Stroud, S.** (2011), Future of microseismic analysis – Integration of monitoring and reservoir simulation, AAPG Annual Conference and Exhibition, Houston, TX.

Abbott, D., **Williams-Stroud, S.**, and Shaffer, R. (2009), Surface Microseismic Monitoring of Hydraulic Fracture Stimulations, Bakken Formation, Nesson Anticline, Williston Basin, North Dakota, AAPG Annual Convention, Denver, CO.

Williams-Stroud, S. (2008), Integration of Structural Analysis with Microseismic Fracture Mapping, American Association of Petroleum Geologists Eastern Section Meeting.

Williams-Stroud, S., Griest, S., and Meddaugh, S. (2006), A geologic strain and attribute-based fracture network (DFN) model of the Humma Field, Partitioned Neutral Zone, AAPG Annual Convention.

Williams-Stroud, S., Griest, S., and Meddaugh, S. (2006), Building a discrete feature network model of fractures within the reservoir property model: Humma Field, PNZ, Kuwait and Saudi Arabia, GEO 2006 Middle East Conference and Exhibition.

Williams-Stroud, S. C. and Barton, C. (2000), Stress magnitudes associated with flexural slip in a hanging wall anticline, Geological Society of America Annual Meeting.

Sweetkind, D. S., and **Williams-Stroud, S.** (1995), Controls on the genesis of fracture networks, Paintbrush Group, Yucca Mountain, Nevada, EOS, Transactions, American Geophysical Union, 76 (46, Suppl.), p. 597, American Geophysical Union 1995 fall meeting, San Francisco, CA

Dean, W. E., Peryt, T. M., Czapowski, G., **Williams-Stroud, S.**, Johnson, K. S., Gasiewicz, A. (1995), Comparative anatomy of large Permian evaporite basins: the Zechstein basin of Poland and the Permian Basin of southwestern United States, XIII Carboniferous-Permian Congress, Krakow, Poland.

Petrychenko, O., **Williams-Stroud, S.** (1995), Chemical composition of water in the Late Carboniferous evaporite Paradox Basin (USA), XIII Carboniferous-Permian Congress, Krakow, Poland.

Dean, W. E., Peryt, T. M.., Czapowski, G., Paul, J., **Williams-Stroud, S.** (1994), Comparative anatomy of large evaporite basins: The Zechstein Basin of central Europe and the Delaware Basin of Texas and New Mexico, AAPG Annual Convention Program.

Williams-Stroud, S.C., and Kyser, T. K. (1994), Evolution of basin brines in the Paradox Formation, Western United States: Evidence from sedimentary textures, fluid inclusions, and stable isotopes, AAPG Annual Convention Program.

Williams-Stroud, S.C. (1993), Fluid inclusion evidence for multiple generations of halite crystallization in the Paradox Formation, Colorado and Utah, Geological Society of America Annual Meeting, Boston, MA.

Herring, J.R., Piper, D.Z., **Williams-Stroud, S.**, Spirakis, C.S. and Sheppard, R.A. (1991), U.S. Geological Survey research on agricultural industrial minerals in the United States--Implications for Exploration, in Good, E.E., Slack, J.F., and Kotra, R.K., eds., U.S. Geological Circular 1062, USGS Research on Mineral Resources 1991 programs and abstracts p. 38-39

Williams-Stroud, S. (1991), The Evolution of an inland sea of Marine Origin to a non-marine saline lake: The Pennsylvanian Paradox Salt Deposit, Conference on Sedimentary and Paleolimnological Records of Saline Lakes, Saskatoon, Saskatchewan, Canada, Aug. 13-16, 1991.

Williams, S. (1986), Experimental pressure solution of gypsum, American Association of Petroleum Geologists Annual Convention.

Williams, S. (1986), Deformation mechanisms observed during in-situ deformation of gypsum, American Geophysical Union Spring Meeting.

OTHER PUBLICATIONS

Duncan, P., and **Williams-Stroud, S.**, 2009, Marcellus Microseismic, OilandGasInvestor.com, November 2009

Williams-Stroud, S.C. and Peter M. Duncan, 2008, Fracturing Technology: Microseismic mapping – the geological factor, Hart's E&P Magazine, September 2008

Williams-Stroud, S. C., 2007, Fast DFN Generation for Reservoir Properties Scenario Analysis, Petroleum Africa Technology and Solutions article, December 2007

PATENTS

Williams-Stroud et al., United States Patent 8,902,710, "Method for determining discrete fracture networks from passive seismic signals and its application to subsurface reservoir simulation"

Peer Review Panel Member Verification of Education/Employment Form

Section 1

Peer panel member nominee information:

My signature verifies that the information contained in this resume is correct. You are hereby authorized to verify this information.

Name: Carl Iver Steefel (Printed) September 23, 2021 (Date) Carl I. Steefel (Signature)

The resume will contain nominee's education and employment history.

I. EDUCATION: A list of educational institution(s), degree(s), discipline(s)/subject(s), and year(s).

II. EMPLOYMENT HISTORY: A list of employment history for the previous ten (10) years, starting with the latest. The history will include responsibilities [in general terms] and years with each employer.

Please note that (all) official transcript(s) is (are) to be in (a) sealed envelope(s) from the university registrar(s). Foreign degrees need to be verified and evaluated by credential evaluation services.

Section 2

The peer review chairperson is responsible for completing this section.

Position/Title: Peer Review Panelist

Comments: (See attached CV for additional information) Experience Includes 35 years' experience predominantly in the field of geology/earth and environmental sciences. Education spans 20 years of education in geology from universities such as Princeton, Washington University, University of Colorado, and Yale University. Dr. Steefel's unique qualifications include, reactive transport modeling, high performance computing, machine learning, and mineral-water kinetics.

Peer Review Chairperson:

Name: John A. Thies (Printed) 09/27/21 (Date) (Signature)



Curriculum Vitae for
CARL I. STEEFEL

Energy Geosciences Division
Lawrence Berkeley National Laboratory
1 Cyclotron Road, Mail Stop 74R316C
Berkeley, CA 94720
[redacted]

EDUCATION:

1992	Yale University - Ph.D Geochemistry
1987	Yale University - M.Phil. Geology
1982	University of Colorado, Boulder - M.S. Geology.
1974	Washington University - B.A. English Literature
1972	Princeton University

EXPERIENCE:

2016-Present	Department Head, Geochemistry, Earth and Environmental Sciences Area
2012-Present	Senior Scientist, Lawrence Berkeley National Lab
2004-2012	Staff Scientist, Lawrence Berkeley National Lab
1998-2004	Staff Scientist, Environmental Science Division, Lawrence Livermore National Laboratory
1995-1998	Assistant Professor of Geology, University of South Florida
1995	Senior Research Scientist, Interfacial Geochemistry Group, Battelle Pacific Northwest Laboratories
1993-1995	Research Scientist, Interfacial Geochemistry Group, Battelle Pacific Northwest Laboratories
1991-1992	Post-Doctoral Associate, Mineralogisch-Petrographisches Institut, Universitat Bern, Switzerland
1985-1991	Teaching and research fellowships, Yale University Department of Geology
1979-1985	Geologist, Anaconda Minerals
1978	Geological Assistant, USGS Branch of Exploration Research
1976	Manuscripts librarian, Huntington Library, San Marino, California

RESEARCH INTERESTS:

Reactive transport modeling: Numerical modeling of pore scale processes, reactive contaminant transport, reactive transport in clays, negative emissions of CO_2, chemical weathering

High performance computing: HPC modeling of integrated terrestrial water and nutrients, subsurface fracture evolution

Machine learning: Hybrid and reduced dimension or order models for watershed biogeochemical function

Mineral-water kinetics: Mineral dissolution and precipitation kinetics

Biogeochemistry: Biogeochemical reactions in groundwater, estuaries, and oceans

AWARDS & RECOGNITION:

2020 Berkeley Lab Director's Award for Exceptional Scientific Achievement
2019 American Geophysical Union Fellow
2017 R&D 100 Award Winner for reactive transport software CrunchFlow (https://www.rd100conference.com/awards/winners-finalists/year/2017/)
2007 Award for outstanding contributions to basic research in the geosciences, Geosciences Research Program, Division of Chemical Sciences, Geosciences, and Biosciences, U.S. Department of Energy, May 2007.
1990 Philip M. Orville Prize for outstanding research and scholarship, Dept. of Geology and Geophysics, Yale University
1990 Best Student Contribution, 2nd International Symposium on the Geochemistry of the Earth's Surface and of Mineral Formation, Aix-en-Provence, France
1989 Outstanding Mention, GSA Research Proposal
1974 Phi Beta Kappa, Washington University

CURRENT PROJECT LEADERSHIP

- Lead PI, Subsurface Exascale Computing Project (DOE: 6 years, ~$18M)
- Lead PI, ExaSheds Project (DOE BER: 4 years, ~$8.3M)
- Co-PI and Component Lead, Watershed Function Science Focus Area (3 years, $21M)
- Component Lead, Discovery Geosciences for DOE Basic Energy Science
- Deputy Director, *Nanoscale Control of Geologic CO_2* Energy Frontier Research Center (DOE BES: 8 years, ~$15M)

MENTORSHIP & SUPERVISION

Supervision of approximately 20 early career staff over 25 years, and mentoring of many early career in reactive transport modeling through collaborations and 17 short courses.

PROFESSIONAL SERVICE & ACTIVITIES (SELECT):

Editorships:

- Specialty Chief Editor, Water and Critical Zone, *Frontiers in Water, 2018-present*
- Associate Editor, *Geochimica et Cosmochimica Acta*, June 2011-present
- Lead Editor, *Reviews in Mineralogy and Geochemistry* **80** "Pore-Scale Geochemical Processes" 2015.
- Co-Editor, *Reviews in Mineralogy* **34**, "Reactive Transport in Porous Media", 1996.
- Lead Editor of a Special Issue of *Computational Geosciences* on Subsurface Environmental Benchmark Modeling, 2015
- *Journal of Contaminant Hydrology*, Associate Editor 2005-present
- *Journal of Hydrology*, Associate Editor, 2002-2007
- *American Journal of Science*, Associate Editor, 2002-2004

Workshop / Committee / Advisory Leadership:

- Workshop Co-Organizer , Reactive Transport for the Earth and Environmental Sciences in the 21st Century, Clos Lucé, Amboise, France, October 2-4, 2017.
- Lead organizer and editor: Reviews in Mineralogy and Geochemistry short course and volume on "Pore Scale Geochemical Processes", 2015
- Chair: International benchmarking for reactive transport working group, 2012-2018

- Panelist 2011 Goldschmidt theme *Frontiers in Computational Geochemistry.*
- Co-chair for 2009 Goldschmidt Theme *Frontiers in Computational Geochemistry.*

DOE and Other Federal Agency Service:

- 2020: Panelist for Federal interagency workshop on *Integrated Hydro-Terrestrial Modeling*
- 2016: Keynote speaker and panelist for DOE-BES *Basic Research Needs for Environmental Management*
- 2015: Panelist and writer for DOE-BER *Virtual Terrestrial Ecosystems* workshop
- 2014: Keynote speaker for NSF workshop on *Expanding the Role of Reactive Transport Modeling (RTM) within the Biogeochemical Sciences*
- 2010: Panelist, writer for DOE-BER *Complex System Science for. Subsurface Fate and Transport*
- 2009: Panelist for National Academy of Sciences workshop on *Waste Forms*, October, 2009
- 2007: Panelist, writer DOE-BES *Basic Research Needs for Subsurface* workshop
- 2005: Panelist for DOE *Review of State of Flow and Transport Modeling at the Hanford Site*
- 1999: Panelist for *Yucca Mountain Unsaturated Zone/Radionuclide Transport Model Peer Review*

Instructor

- Developer and instructor: 17 short courses in reactive transport modeling
- Co-instructor: Graduate level course in "Numerical Modeling in the Earth and Environmental Sciences", UC Berkeley, Spring 2019.
- Lead Instructor, CrunchTope Short Course at CouFrac Conference, Wuhan, China, November 10-11, 2018.
- Lead Instructor, CrunchTope Short Course at "Reactive Transport for the Earth and Environmental Sciences in the 21st Century" workshop in Amboise, France, October 5, 2017
- Lead Instructor, CrunchTope Short Course, Pohang University of Technology, Pohang, South Korea, December 6-8, 2016.
- Lead instructor for short course in Reactive Transport Modeling: University of Bern (4 times), Bureau de Recherches Géologiques et Minières, LBNL, Penn State, Shell Oil, Heriot-Watt University, University of Minnesota
- Lead Instructor, CrunchTope Short Course, 2016 Goldschmidt Conference, June 25-26, 2016.
- Lead Instructor, CrunchTope Short Course, University of Illinois, June 8-9, 2016.
- Lead Instructor, CrunchFlow Short Course, March 22-23, 2016, Imperial College, London.
- Lead Instructor, CrunchFlow Short Course, August 24-25, 2013 Goldschmidt Conference, Florence, Italy.

Other:

- Principal developer of CrunchFlow Reactive Transport software package
- Member: American Geophysical Union, Geochemical Society

KEYNOTE AND INVITED PRESENTATIONS:

2020 Keynote Address "Data-Intensive Models for Pore to Plume to Watershed Scales", Goldschmidt 2020, Oahu, Hawaii.

2020 Keynote Address "Reactive Transport at the Crossroads: Progress and New Directions", "How to integrate geochemistry at affordable costs into reactive transport for large-scale systems", 5 - 7 February 2020, Helmholtz-Zentrum Dresden-Rossendorf, Germany.

2019 Invited Address "Modeling Reactive Transport in Clay Fractures", with C. Tournassat, 2019 AGU Meeting

2019 Keynote address, "Reactive Transport at the Crossroads", P. Van Cappellen Festschrift Workshop, University of Waterloo, Canada.

2019 Keynote address, "CrunchClay: A Mean Electrostatic Potential Model for Ion Transport in Clay", EuroClay 2019, July 5, 2019, Paris, France.

2019 Invited Address "Reactive Transport at the Crossroads", Panel Review and Workshop for the TPC Project Taiwan, Taipei, Taiwan, June 26, 2019

2018 Keynote Address "Crossing Scales in Porous Media", Tough Symposium, Berkeley, CA, October 10, 2018.

2018 Keynote Address "Modeling Chemical and Mechanical Effects in Fractures", CouFrac Conference, Wuhan, China, November 12, 2018

2018 Keynote Address "Interpreting Laboratory and Field Geochemical Systems with Reactive Transport Modeling", 2018 Goldschmidt Conference, August 15, 2018, Boston.

2017 Keynote Address "A Mean Electrostatic Model for Ion Transport through Heterogeneous Clay", 2017 Clay Conference, Davos, Switzerland, September 27, 2017.

2017 Keynote Address "Reactive Transport at the Crossroads", Workshop on *Reactive Transport for the Earth and Environmental Sciences in the 21st Century*, Clos Lucé, Amboise, France, October 2, 2017.

2017 "The Lab-Field Rate Discrepancy Revisited", Invited talk at Susan Brantley 2017 Geochemistry Medal session, American Chemical Society, April 4, 2017.

2016 "Multi-Scale Reactive Transport Modeling," Workshop at Bureau de Recherches Géologiques et Minières, Orleans, France, October 25, 2016

2016 "Multi-scale reactive transport modeling of terrestrial systems," Plenary Invited Talk, EPSRC Workshop on *Reactive Transport in Porous Media*, Imperial College London.

2016 "New Approaches to Modeling Water-Rock-Gas Interaction," Invited Talk at Cambridge University, UK, March 24, 2016

2016 "Reactive transport modeling for evaluation and optimization of architected materials," with C. Tournassat, Keynote Talk at 2016 Goldschmidt

2016 "A New Approach to Modeling Nucleation, Crystal Growth, and the Ostwald Step Rule," Invited Talk at Spring 2016 American Chemical Society Meeting, San Diego, CA

2015 "Multiple Scale (and Multi-Scale) Reactive Transport Modeling of Terrestrial Systems," Keynote Address at 2015 Goldschmidt in Prague, Czech Republic, Aug. 20, 2015.

2015 "Contaminant Fate and Transport in Geological Environments," Keynote address at Basic Research Needs workshop for Environmental Management, Bethesda, MD, 8 July, 2015.

2015 "Modeling Reactive Transport in Fractured Shales," Invited Talk at the *Shale at all Scales* Workshop, Santa Fe, NM, 10 June, 2015.

2014 "The GEWaSC Framework: Multiscale Modeling of Coupled Biogeochemical, Microbiological, and Hydrological Processes," Invited Talk at 2014 Goldschmidt Conference, Sacramento, CA, June 13, 2014

2014 "What is the State of the Art in Reactive Transport Modeling," presented at an NSF workshop on Expanding the Role of Reactive Transport Modeling (RTM) within the Biogeochemical Sciences, Arlington, VA, April 14, 2014

2014 "Genome-Enabled Watershed Simulation Capability (GEWaSC)," Plenary Talk at Terrestrial Ecosystem and Subsurface Biogeochemical Research meeting, Potomac, MD, May 6, 2014

2014 "Reactive Transport Models (RTM): Pores to Plots to Watersheds" presented at DOE Workshop on Computational Challenges for Mechanistic Modeling of Terrestrial Environments, Gaithersburg, MD, March 26, 2014.

2013 "What are the Time Scales for Carbonate Mineral Sequestration in the Subsurface?" presented at the 2013 Fall American Geophysical Union meeting, San Francisco, CA, Dec. 11, 2013.

2013 "Intercomparison of Reactive Transport Models" at 2013 SIAM meeting, Padova, Italy, June 19, 2013.

2013 "Approaches for Assessing Time Scales for Carbonate Mineral Sequestration" at Helmholtz-Zentrum fur Umweltforschung (UFZ), Potsdam, Germany, May 13, 2013.

2013 "Reaction Fronts: Microscopic and Macroscopic" at Kongsberg Seminar, Kongsberg, Norway, May 9, 2013.

2013 "Time Scales for Carbonate Mineral Sequestration" at Washington University, May 1, 2013.

2013 "What are the time Scales for Carbonate Mineral Sequestration of CO_2 in the Subsurface," Yale University Department of Geology, February 14, 2013.

2013 "Experimental and Modeling Studies to Determine Time Scales for Carbonate Mineral Sequestration" at Le Studium Conference, Orleans, France, February 25, 2013.

2012 "Pore to Flood Plain Scale Modeling of Reactive Transport" at 2012 Fall AGU Meeting, San Francisco, Ca, December 4, 2012.

2012 "Characterization and Modeling of Reactivity in a Sandstone containing Internal Diffusion-Controlled Zones" at BES Geosciences Workshop on Reaction and Transport within Internal Domains of Porous Medium, December 2, 2012.

2012 "What are the time Scales for Carbonate Mineral Sequestration of CO_2 in the Subsurface," Colorado School of Mines, November 15, 2012.

2012 "What are the time Scales for Carbonate Mineral Sequestration of CO_2 in the Subsurface," University of Missouri, Kansas City, November 7, 2012.

2012 "New Directions in Reactive Transport Modeling" at Subsurface Simulation Benchmark Workshop, National Central University, Taiwan, November 29, 2012.

2012 "What are the time Scales for Carbonate Mineral Sequestration of CO_2 in the Subsurface," UCLA Department of Earth and Planetary Sciences, October 4, 2012.

2012 "Diffusion versus Surface Reaction Control of Mineral Precipitation and Dissolution Kinetics at the Pore Scale" at Goldschmidt 2012, Montreal, Canada, June 27, 2012.

2011 Invited speaker, Upscaling Carbonate Precipitation Associated with CO_2 Sequestration, American Geophysical Union Fall Meeting

2011 Invited speaker, Pore Scale Modeling of Mixing-Induced Carbonate Precipitation, American Geophysical Union Fall Meeting

2011 Keynote speaker, American Chemical Society Symposium *Multiscale Spatiotemporal Complexity in Geologic Carbon Sequestration: Linking Experimentation and Modeling*, August 2011.

2011 Invited speaker, Stanford University Geochemistry Colloquium.

2011 Invited speaker at Geochemical Transport in Compacted Clays, Bern, Switzerland.

2011 Invited speaker at workshop on Glass Corrosion, Manchester, England.

2010 Invited speaker, American Geophysical Union symposium *CO_2 Sequestration Inside Pores: From Molecules to Microbes*, December, 2010.

2010 Invited speaker at Department of Geological Sciences, University of Oregon.

2009 Invited speaker, Modeling Waste Form Performance in the Near-Field Environment, *Waste Form Performance and Technology*, U.S. National Academy of Sciences, November 4, 2009.

2008 Keynote speaker, 2008 Goldschmidt Conference, *Modeling of Thermodynamic and Kinetic Controls on Complex Biogeochemical Reaction Networks*.

2007 Keynote speaker, 2007 Goldschmidt Conference, *Interpreting Reaction Rates at the Field Scale*.

2006 Keynote speaker, American Chemical Society Symposium *Understanding Radionuclide Transport in the Environment: Remediation, Nuclear Waste Disposal, and Long-Term Stewardship*, March 2007.

2005 Keynote speaker, Geochemical and Transport Modeling, *10th International Conference on Migration of Behaviour of Actinides and Fission Products in the Geosphere*, Migration 2005 Avignon, France, September, 2005.

2005 Invited speaker, Conceptualizing Subsurface Biogeochemical Processes, *2005 International Symposium for Subsurface Microbiology, Jackson, Wyoming, August, 2005.*

2004 Invited speaker, Quantifying Rates in Biogeochemical Reaction Networks, *2004 Goldschmidt Conference*, June 2004.

2004 Keynote speaker, Reactive transport modeling of multicomponent cation exchange at the laboratory and field scale, *Workshop on Conceptual Model Development for Subsurface Reactive Transport Modeling of Inorganic Contaminants, Radionuclides, and Nutrients*, April 20-22, 2004, Albuquerque, New Mexico.

2003 Keynote speaker, *International Conference on Gas-Water-Rock Interaction with Application to CO_2 Sequestration and Petroleum Migration*, Institut Francaise du Petrole, Rueuil-Malmaison, France, Nov. 20-22, 2003.

2001 Invited speaker, DOE NABIR Workshop on Biogeochemical Modeling, October 21-22, 2001 at Pennsylvania State University.

2001 Invited speaker, 2001 Goldschmidt Meeting, Session on *Metals in the Weathering Environment*

2000 Plenary session speaker, *Computational Methods in Water Resources XIII*, June 25-29, 2000, Calgary, Canada.

2001 Invited speaker, AGU special session *Coupled Biogeochemical Processes Affecting the Transport of Contaminants in the Subsurface,* spring 2000

1999 University of Waterloo, Waterloo, Canada, a seminar entitled *Comparing Laboratory and Field Reaction/Weathering Rates: Is There a Discrepancy,* April 27, 1999.

1999 Woods Hole Oceanographic Institute, a seminar on *Reactive Transport in Discrete Fractures: The role of Chemical Kinetics and Permeability Change*, April 15, 1999.

1999 University of Oregon Department of Geology, a seminar on *Reactive Transport in Discrete Fractures: A Case Study from Maqarin, Jordan*, March 12, Eugene, Oregon.

1999 Oregon State University Department of Geology, a seminar on *Reactive Transport in Discrete Fractures: A Case Study from Maqarin, Jordan*, March 11, Corvallis, Oregon.

1998 *Geochemical Kinetics: From the Laboratory to the Field*, presented at the European Research Conference on *Geochemistry of Crustal Fluids: Characterization of Reactive Transport in Natural Systems*. May 22-27, Heraklion, Crete.

1997 *Overview of Modeling of Coupled Reactive Transport Processes* presented at the Alternative Models and Interpretations for the Near-Field Altered Zone Coupled Effects Expert Elicitation Workshop, Dec. 3-4, 1997, Las Vegas, Nevada.

1997 *Incorporating Intra-Aqueous Kinetics into Reactive Transport Models* presented at a Workshop on Modeling Reactive Transport held at Battelle PNNL, Nov. 28-Dec.2, 1997.

1996 Geological Society of America Symposium on *Application of Reactive Transport Modeling to Natural Systems*, October 28.

1996 Approaches to Modeling Reactive Transport, presented at the Mineralogical Society of America Short Course on *Reactive Transport in Porous Media*, October 25-27, Golden, Colorado.

1995 Keynote Speaker, European Research Conference on *Natural Waters and Water Technologies*, November 3-8, Lenggries, Germany.

1995 Departmental colloquium, University of Idaho, March 10, Moscow, Idaho.

1994 Keynote Speaker, Chapman Conference on "Hydrogeologic Processes: Building and Testing Atomistic to Basin-Scale Models," June 6-9, 1994, Lincoln, New Hampshire

PUBLICATIONS:

Google Scholar for Carl Steefel:
https://scholar.google.com/citations?user=Yv-KZG0AAAAJ&hl=en

ResearcherID for Carl Steefel:
http://www.researcherid.com/rid/B-7758-2010

ORCID: 0000-0002-2802-611X

Articles

Steefel, C.I. and Yang, L. (submitted) Secondary magnesite formation under CO_2 sequestration conditions via coupled heterogeneous nucleation and crystal growth. *Geochimica et Cosmochimica Acta.*

Dwivedi, D., **C.I. Steefel**, …. (submitted) From legacy contamination to watershed systems science: A review of scientific insights and technologies developed through DOE-supported research in water and energy security. *Environmental Research Letters.*

Hu, M., Rutqvist, J., **Steefel, C.** (2021) Mesh generation and optimization from digital rock fractures based on neural style transfer. *Journal of Rock Mechanics and Geotechnical Engineering.* https://doi.org/10.1016/j.jrmge.2021.02.002

Maavara, T., Siirila-Woodburn, E.R., Maina, F., Maxwell, R.M., Sample, J.E., Chadwick, K.D., Carroll, R., Newcomer, M.E., Dong, W., Williams, K.H. and **Steefel, C.I.**, … (2021) Modeling geogenic and atmospheric nitrogen through the East River Watershed, Colorado Rocky Mountains. PLoS ONE 16(3): e0247907. DOI: 10.1371/journal. pone.0247907

Birkholzer JT, J Morris, JR Bargar, F Brondolo, A Cihan, D Crandall, H Deng, W Fan, W Fu, P Fu, A Hakala, Y Hao, J Huang, AD Jew, T Kneafsey, Z Li, C Lopano, J Moore, G Moridis, S Nakagawa, V Noël, M Reagan, CS Sherman, R Settgast, **C Steefel**, M Voltolini, W Xiong, J Ciezobka (2021) A New Modeling Framework for Multi-Scale Simulation of Hydraulic Fracturing and Production from Unconventional Reservoirs. *Energies* **14 (3)**: 641.

Yan, Q., Wainwright, H., Dafflon, B., Uhlemann, S., **Steefel, C.I.**, Falco, N., Kwang, J. and Hubbard, S.S., 2021. Hybrid data-model-based mapping of soil thickness in a mountainous watershed. *Earth Surface Dynamics Discussions*: 1-23.

Newcomer, Michelle, Nicholas J. Bouskill, Haruko Wainwright, Taylor Maavara, Bhavna Arora, Erica R. Siirila-Woodburn, Dipankar Dwivedi, Ken Williams, **Carl Steefel**, and Susan S. Hubbard. (2021) Hysteresis patterns of watershed nitrogen retention and loss over the past 50 years in United States hydrological basins. *Global Biogeochemical Cycles*, **35(4)**, e2020GB006777. DOI: 10.1029/2020GB006777

Steefel, C.I. and C. Tournassat (2021) A model for discrete fracture-clay rock interaction incorporating electrostatic effects on transport. *Computational Geosciences* **25 (1):** 395-410. DOI: 10.1007/s10596-020-10012-3.

Liu X, Tournassat, C and **Steefel CI** (2020) Preface to multiscale simulation in geochemistry. *Geochimica et Cosmochimica Acta* **291**: 1-4. DOI: 10.1016/j.gca.2020.09.011

Hu, M., **Steefel CI** and Rutqvist, J (2020) Guest editorial to the CouFrac 2018 special issue Coupled Thermal-Hydro-Mechanical-Chemical Processes in Fractured Media: Microscale to Macroscale Numerical Modeling. *Computational Geosciences* **24:** 1747-1749. DOI: 10.1007/s10596-020-09998-7

Ackerer J, **Steefel C**, Liu F, Bart R, Safeeq M, O'Geen A, Hunsaker C and Bales R (2020) Determining how Critical Zone structure constrains hydrogeochemical behavior of watersheds: Learning from an elevation gradient in California's Sierra Nevada. *Frontiers in Water* **2**:23. DOI: 10.3389/frwa.2020.0002

Arora B, Burrus M, Newcomer M, **Steefel C**, Carroll RWH, Dwivedi D, Dong W, Williams K and Hubbard S (2020) Differential C-Q analysis: A new approach to inferring lateral

transport and hydrologic transients within multiple reaches of a mountainous headwater catchment. *Frontiers of Water* **2:24**. DOI: 10.3389/frwa.2020.00024

Mital, U, D. Dwivedi, J.B. Brown, B. Faybishenko, S.L. Painter, **C.I. Steefel** (2020) Sequential imputation of missing spatio-temporal precipitation data using Random Forests. *Frontiers in Water* **2**: 20. doi: 10.3389/frwa

Cheng, Y., B. Arora, S. Sengor, J. Druhan, C. Wanner, B. M. van Breukelen, and **C. I. Steefel** (2020), Microbially mediated kinetic sulfur isotope fractionation: Reactive transport modeling benchmark, *Computational Geoscience* DOI: 10.1007/s10596-020-09988-9.

Arora, B., M.S. Briggs, J. Zarnetske, J. Stegen, J. Gomez-Valez, D. Dwivedi, **C. I. Steefel** (2020) Hot spots and hot moments in the Critical Zone: Identification of and incorporation into reactive transport models. Springer Nature. J. Chorover (ed.)

Reinoso-Maset, Estela, Perdrial, Nicolas, **Steefel, Carl**, Um, Wooyong, Chorover, Jon, O'Day, Peggy (2020) Dissolved carbonate and pH control the dissolution of uranyl phosphate minerals in flow-through porous media. *Environmental Science and Technology.* https://DOI.org/10.1021/acs.est.9b06448

Özgen-Xian, I., G. Kesserwani, D. Caviedes-Voullième, S. Molins, Z. Xu, D. Dwivedi1, J. D. Moulton, and **C. I. Steefel** (2020) Wavelet-based local mesh refinement for rainfall-runoff simulations. *Journal of Hydroinformatics*. https://DOI.org/10.2166/hydro.2020.198

Tournassat, C., **C. Steefel**, T. Gimmi (2020) Solving the Nernst-Planck equation in heterogeneous porous media with finite volume methods: Averaging approaches at interfaces. *Water Resources Research* https://DOI.org/10.1029/2019WR026832.

Milesi, V.P., M. Debure, N.C.M Marty, M. Capano, D. Jézéquel, **C. Steefel**, …, M. Ader (2020) Early diagenesis of lacustrine carbonates in volcanic settings: The role of magmatic CO_2 (Lake Dziani Dzaha, Mayotte, Indian Ocean). *Earth and Space Chemistry*. https://dx.DOI.org/10.1021/acsearthspacechem.9b00279.

Alexander, F., A. Almgren, … D.B. Kothe, …**C.I. Steefel**, … (2020) Exascale applications: skin in the game, *Philosophical Transactions of the Royal Society A* **378** (2166), 20190056.

Molins, S., Soulaine, C., Prasianakis, N.I., …, **C.I. Steefel** (2020). Simulation of mineral dissolution at the pore scale with evolving fluid-solid interfaces: review of approaches and benchmark problem set. *Computational Geosciences*. https://DOI.org/10.1007/s10596-019-09903-x

Maina, F.Z., E. Siriila-Woodburn, M. Newcomer, C.I. Steefel (2020) Determining the impact of a severe dry to wet transition on watershed hydrodynamics in California, USA with an integrated hydrologic model. *J. Hydrology* **580**: https://DOI.org/10.1016/j.jhydrol.2019.124358

Tournassat, C.M., **Steefel, C.I.** (2019) Modeling diffusion processes in the presence of a diffuse layer at charged mineral surfaces. A benchmark exercise. *Computational Geosciences*. 1-18. https://DOI.org/10.1007/s10596-019-09845-4.

Steefel, C.I. (2019) Reactive transport at the crossroads. *Reviews in Mineralogy and Geochemistry* **85:** 1-26.

Seigneur, N., Mayer, K.U., **Steefel, C.I.** (2019) Reactive transport of evolving porous media. *Reviews in Mineralogy and Geochemistry* **85:** 197-238.

Tournassat, C.M., **Steefel, C.I.** (2019) Reactive transport modeling of coupled processes in nanoporous media. *Reviews in Mineralogy and Geochemistry* **85**: 75-109.

Zhi, W., L. Li, W. Dong, W. Brown, J. Kaye, C.I. Steefel, K.H. Williams (2019) Distinct source water chemistry shapes contrasting concentration-discharge patterns. *Water Resources Research* **55***: 4233-4251.* 10.1029/2018WR024527.

Molins, S., Trebotich, D., Arora, B., Steefel, C. I., & Deng, H. (2019) Multi-scale model of reactive transport in fractured media: Diffusion limitations on rates. *Transport in Porous Media* 128 (2): 701-721.

Soler, J. M., Steefel, C. I., Gimmi, T., Leupin, O. X., & Cloet, V. (2019). Modeling the ionic strength effect on diffusion in clay. The DR-A experiment at Mont Terri. *ACS Earth and Space Chemistry* **3**: 442-451.

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Additional Panels Performance Assessment Changed Conceptual Models
Candidate Evaluation Form

Candidate Name:	Carl Steefel
Date Contacted:	June 15, 2021
Phone Number:	[redacted]
E-Mail Address:	[redacted]

Record of Conversation

- Contacted 06/15/21 via e-mail and left messages on his work and cell phones.
- Carl called back on 06/16/21 and agreed to be on the peer review panel. He is checking on whether he has to do it through LBL or can do it as a consultant. He is also checking on his rate.

Are you available interested and available to serve as a peer reviewer for the Waste Isolation Pilot Plant Additional Panels Performance Assessment Changed Conceptual Models Peer Review? **Yes**

Are you currently employed or have you previously been employed by DOE or a DOE Contractor? **Yes** (If yes, give dates, location, organization, position, and type of work performed.) See Carl's CV. Carl currently works for Lawrence Berkley National Laboratory, which is a DOE funded Laboratory.

Do you have or have you had any direct involvement or financial interest in the work under review? **No**

Is there any reason why you cannot perform an impartial peer review? **No**

Is there any aspect of your past that may lead to a perception of bias in the results of your peer review? **No**

Name: Carl J. Steefel
Carl Steefel, Ph.D.

Date: June 18, 2021

Name: _____
John A. Thies, Peer Review Panel Chairperson

Date: _____

Waste Isolation Pilot Plant
Additional Panels Performance Assessment
Changed Conceptual Models
Peer Review Report
December 2021

APPENDIX D

Acquisition Documents

(North Wind declined the Peer Review Panel Chairperson's request for redacted copies of the pertinent acquisition documents)