SUMMARY OF FISCAL YEAR 2015 ACTIVITIES: DISPOSAL-RELATED INTEGRATED SPENT NUCLEAR FUEL REGULATORY ACTIVITIES—IDENTIFICATION AND ANALYSIS OF KEY REGULATORY AND TECHNICAL ISSUES FOR DISPOSAL OF SPENT NUCLEAR FUEL AND HIGH-LEVEL WASTE

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QUALITY OF DATA, ANALYSES, AND CODE DEVELOPMENT

DATA: No data are contained in this report, which contains only summaries of technical results

ANALYSES AND CODES: No scientific or engineering software was used in the analyses contained in this report.

1 INTRODUCTION

The Center for Nuclear Waste Regulatory Analyses (CNWRA®) continues to provide technical support to the U.S. Nuclear Regulatory Commission (NRC) in the Disposal-Related Integrated Spent Nuclear Fuel Regulatory Activities (ISFR) program. This program enhances regulatory efficiency and effectiveness as the agency responds to an evolving national policy on the management and disposal of spent nuclear fuel (SNF) and other high-level radioactive wastes. CNWRA technical assistance activities are conducted as Charter contract Task Order 9—titled Identification and Analysis of Key Regulatory and Technical Issues for Disposal of Spent Nuclear Fuel and High-Level Waste. The objective of this task order is for CNWRA to provide NRC with technical assistance on the identification and analysis of key regulatory and technical issues associated with a variety of alternatives for managing the back end of the fuel cycle, including ultimate disposal. These activities are needed regardless of the direction of national policy, and were designed to support the Agency's mission under a range of policy outcomes—all of which are likely to require geologic disposal as a key component.

During fiscal year 2015, the team's independent technical investigations focused on selected key technical issues associated with ultimate disposal. These activities were conducted as five subtasks, each focused on analyses of a particular technical topic and each conducted by a team of CNWRA and NRC staff members. Work on these topics builds on previous years' activities regarding risk-significant features and processes and efforts at familiarization with alternative geologic repository host rocks and designs, with a focus on those topics most generally applicable and potentially useful in terms of maintaining and enriching the NRC and CNWRA staffs' skills, knowledge, and technical contributions supporting NRC's regulatory responsibilities.

This annual report, organized by subtask, briefly summarizes activities conducted during Southwest Research Institute® fiscal year 2015 (i.e., September 27, 2014, to September 25, 2015). An appendix to this report provides a table listing all intermediate milestones (IMs) and administrative items (AIs) produced under this task order during that period. CNWRA activities conducted under the precursor projects in fiscal year 2012 and in the first 2 months of fiscal year 2013 were documented in Pickett (2012a,b). After Task Order 9 was established, subsequent reports were prepared for the fiscal 2013 year-end (Pickett et al., 2013), fiscal 2014 mid-year and year-end (Pickett et al., 2014a,b), and fiscal 2015 mid-year (Pickett et al., 2015).

2 TECHNICAL ACTIVITIES

2.1 Continued Participation in DECOVALEX

CNWRA continued supporting NRC participation in the international DECOVALEX program by further developing in-house modeling tools and expertise in thermohydrological-mechanical (THM) behavior of swelling clays. CNWRA participated along with NRC staff in (i) the 6th Workshop held in London, England, in November 2014 (Stothoff and Fedors, 2014) and (ii) the 7th workshop held in Brno, Czech Republic, in April 2015 (Manepally and Fedors, 2015). In addition, code development of xFlo continued. The Subtask 1 team also contributed to the buffer performance assessment (PA) workshop (Pickett, 2015a) and the THM workshop, which were joint activities with Subtasks 4 and 5, respectively. The Subtask 1 team took the lead on documenting the latter workshop in a letter (Pickett, 2015b) just after the end of fiscal year 2015.

The major CNWRA modeling task involved coupling the thermohydrological (TH) code xFlo with the geomechanical code FLAC3D™ to produce the tool to be used in the **DE**velopment of

COupled Models and their **VAL**idation Aginst **EX**periments (DECOVALEX) Task B1. This coupled code will be an important tool for supporting potential involvement in future DECOVALEX programs and for supporting other task order activities, as well as for enhancing NRC's ability to evaluate alternative repository designs.

DECOVALEX Task B1 is designed to understand coupled THM processes in a bentonite buffer and argillaceous host rock at the Mont Terri underground research laboratory in Switzerland. The activities for this fiscal year mainly focused on:

- Completing revisions to the numerical model representing the column test. Modifying the constitutive relationship of thermal conductivity and saturation and accounting for effects of temperature on the coefficient of thermal expansion resulted in an improved match with the column test measurements. The results of the column test model were presented at the 2015 International High-Level Radioactive Waste Management Conference (Manepally et al., 2014; Stothoff et al., 2015a).

- Developing a numerical model to represent the THM behavior of granular bentonite in the HE-E test (Manepally et al., 2015), which is the final task for the current phase of the DECOVALEX program.

xFlo was used to develop a two-dimensional cross-section model focusing on the granular bentonite section of the HE-E test. Comparison of temperature and relative humidity measurements and simulation results indicated that, in general, xFlo was able to capture TH processes in the buffer, bentonite block, and Opalinus Clay. The differences between measurements and xFlo simulation results can be attributed to uncertainties regarding the representation of the host rock, especially the excavation damage zone (EDZ), and engineered components such as cement blocks and concrete fill. Predictive analyses focusing on the THM response to potential future rewetting of buffer indicated that the buffer resaturation rate was twice as fast when the heater remained on because water viscosity decreases by at least a factor of two for the temperature range considered. The presence and nature of the EDZ fractures also strongly influences the time of rewetting. The xFlo estimate of the time to rewetting is highly uncertain because swelling processes in the Opalinus Clay EDZ fractures during rewetting were not included in the xFlo model.

Geomechanical modeling using FLAC focused on the geomechanical response of the granular bentonite and bentonite blocks in the unsaturated regime, assuming that the Opalinus Clay was saturated. FLAC estimates show deformation and porosity changes occuring in specific circumferential bands. Model results suggested that (i) zones of compression (i.e., decrease in porosity) occur near the heater liner and near the host rock and (ii) zones of extension occur in the buffer interior and locations immediately adjacent to the side and bottom of the heater liner.

Auxiliary analyses focused on matching pore pressure measurements in the saturated Opalinus Clay, the impact of power failures during the HE-E and HE-D tests, and extensometer data from the Opalinus Clay. These analyses provided several insights to the behavior of the host rock and identified potential thermal-mechanical relationships that need further investigation.

xFlo code development focused on improving its flexibility in representing constitutive relationships and developing a Microsoft® Windows version. A version of xFlo (originally developed in a Linux® environment) for the Windows operating system was transmitted to NRC as an intermediate milestone (Pickett, 2014). The milestone also contained (i) documentation for installing xFlo on Windows and descriptions of the installation-verification test cases and (ii) a compressed file containing the source code and input and output files for the installation-verification test cases. Efforts to couple FLAC (geomechanical code) with xFlo were initiated, using MATLAB® to handle data transfer and simulation sequencing.

The team evaluated constitutive relationships for thermal conductivity, moisture retention curve, and permeability parameters that are suitable for granular bentonite buffer material, which has distinct pore scales ranging from nanometers to millimeters and presented the results at the International High-Level Radioactive Waste Management Conference (Stothoff et al., 2014; 2015b).

An approach to mechanical modeling of unsaturated soils using the moisture retention characteristic curve and the Bishop principle of effective stress to evaluate suction effects on stress, developed as a part of the geomechanical modeling for the DECOVALEX project, was documented in a journal article (Ofoegbu et al., 2015a). The approach incorporates swelling, thermal expansion, and soil hardening and stiffening due to suction or compaction, and uses stress-strain relationships based on elastoplasticity.

In addition to these new fiscal year 2015 activities, efforts were also made revising previous milestones in response to NRC technical and programmatic comments (Ofoegbu et al., 2015b; Stothoff et al., 2015c).

2.2 Analysis of Waste Form

The objective of Subtask 2 corrosion studies is to determine dissolution rates of SIMFUEL—a nonradioactive surrogate for spent nuclear fuel (SNF)—under conditions representative of a predominantly chemically reducing environment in a deep underground repository. The reducing conditions of interest include the presence of dissolved hydrogen and small amounts of dissolved oxidizing species such as oxygen and hydrogen peroxide. The oxidizing species are expected to be present due to alpha radiolysis from decay in the SNF, and hydrogen is expected to be generated predominantly from corrosion of the container material, with a small amount from alpha radiolysis. Specifically, the objective of experimental studies conducted this year was two-fold: (i) determine the level of dissolved hydrogen needed to obtain a fractional release rate in the range of 10^{-6}/yr to 10^{-8}/yr and (ii) reconduct some of the fiscal year 2014 experiments in which results were found to be exceptions to the general trends.

During this fiscal year, CNWRA continued experimental studies from the last year. In the previous fiscal year, CNWRA conducted several experiments to determine SIMFUEL dissolution rates as a function of dissolved hydrogen and oxygen levels using an electrochemical cell placed in a glove box. SIMFUEL is an unirradiated, simulated SNF containing chemically equivalent nonradioactive surrogate elements for fission products, activation products, and actinides. The experiments were conducted in contact with a saline simulated groundwater with a composition based on published reference compositions for deep groundwaters in granitic rocks. Experiments involved the following three SIMFUEL types: (i) pure UO_2, (ii) 35 GW-day/MTU burnup equivalent (BU35), and (iii) 60 GW-day/MTU burnup equivalent (BU60). Both BU35 and BU60 SIMFUEL samples contain noble metal inclusions, known as epsilon particles, that are expected to influence the fuel dissolution kinetics under both oxidizing and reducing conditions. The solution was purged with various combinations of compressed air and a mixture of 4 percent hydrogen gas plus 96 percent nitrogen gas. For each SIMFUEL specimen, the electrochemical experiments were conducted under the following conditions:

1. Saturated oxygen
2. Saturated oxygen and hydrogen
3. Unsaturated oxygen and hydrogen

4. Reduced oxygen and saturated hydrogen

Gas partial pressures were not directly measured inside the test cell. The oxygen concentration for each condition was measured and the dissolved hydrogen concentration was estimated for Conditions 2, 3, and 4. Electrochemical impedance spectroscopy and potentiodynamic polarization curves were used to record the electrochemical response of the SIMFUEL samples for various combinations of the purging rate of gas and the solution temperature. The collected electrochemical impedance spectroscopy data were analyzed using an electrical circuit model to estimate dissolution rates. The potentiodynamic polarization curves also were analyzed to obtain the dissolution rates.

The estimated dissolution rates of the SIMFUEL samples in the electrochemical experiments ranged from 0.06–15.5 mg/m^2-day under the four conditions. Based on the experimental data, two primary factors affect the dissolution rates: (i) burnup and (ii) dissolved oxygen concentration. Dissolution rates increased with increasing burnup under the same conditions, except for Condition 4. Under Condition 4, the dissolution rate of the BU60 sample was lower than the BU35 sample. Potential factors affecting these patterns were investigated.

SIMFUEL dissolution rates decreased with decreasing dissolved oxygen concentration. The dissolution rate of an sample under Condition 1 {i.e., 1.02 atmg [15 psig] air} was the highest compared to the other three conditions. The dissolution rates for Conditions 2 and 3 were generally between Conditions 1 and 4 for a given sample. The experimental work in this fiscal year suggests that SNF dissolution rates depend on the dissolved oxidizing species concentration along with the hydrogen concentration under reducing conditions in a geologic repository. More specifically, the experimental results for the three SIMFUEL specimens indicate that the dissolution rate under oxidizing conditions (i) increases with increasing burnup and (ii) decreases with decreasing oxygen concentration. Under reducing conditions, the dissolution rate decreases with increasing burnup.

The dissolution rate data acquired under the reducing Condition 4 were analyzed to estimate the fractional release rate, which is a parameter commonly used in performance assessment models. The fractional release rate is related to dissolution rate via a conversion factor that is dependent on the surface area to volume ratio of a fuel particle. The fractional release rate under reducing conditions is reported in the literature to be in the range of 10^{-6}/yr to 10^{-8}/yr. An analysis of our dissolution rate data indicated that the lowest value of the fractional release rate from the experimental data in this work is 4×10^{-6}/yr. Therefore, the dissolution rates measured using the electrochemical methods are higher than reported values.

In addition to the electrochemical tests, leaching experiments were conducted with BU35 and BU60 to determine dissolution rates using the leachate concentrations. The objective of these experiments was to measure the dissolution rate with a dissolved hydrogen concentration near 1 mM. This concentration of dissolved hydrogen could be achieved when fugacity of the hydrogen is near 1.3 atm [19.1 psi], which is elevated compared to the electrochemical tests. These experiments were conducted using two pipe reactors pressurized with 4 percent H_2 plus 96 percent N_2 gas mixture at approximately 30.6 atmg [450 psig] and were run for 30 days. The leaching test solutions are being analyzed, so are not available at the time of writing this report. These and related experiments will help determine the level of dissolved hydrogen needed to effectively decrease SNF dissolution such that the release fraction rate is in the range of 10^{-6}/yr to 10^{-8}/yr.

This work was documented in an intermediate milestone (Shukla et al., 2015a) and a revision to a prior report (Shukla et al., 2015b). Other activities included preparation of a paper and accompanying presentation for the 2015 International High-Level Radioactive Waste Management Conference (Shukla and Ahn, 2014; 2015) and participation in the buffer workshop (Pickett, 2015a).

2.3 Analysis of Waste Package

Experimental studies, augmented by literature review, continued to provide a more in-depth understanding of copper and carbon steel general corrosion in anoxic conditions. The experimental studies focused on the following areas: (i) copper corrosion under anoxic conditions in granitic groundwater and in pure water, (ii) carbon steel repassivation at open circuit conditions, and (iii) carbon steel hydrogen-induced cracking (HIC) tendencies. These topics are critical for evaluating the long-term performance of copper and carbon steel waste packages. Test setups were improved to reduce the residual oxygen concentration further to achieve an anoxic condition. The residual oxygen concentration was measured with two types of oxygen probes and was found to be extremely low. Literature studies and the CNWRA experimental studies show that copper corrosion is very sensitive to O_2 concentration in the test solution and the surrounding environment. Copper corrosion rates were in the range of 0.5–0.9 µm/yr [0.02–0.04 mils/yr] measured by electrochemical impedance spectroscopy, consistent with measurements from weight loss and with some literature studies in anoxic environments with extremely low O_2 concentrations. However, our measured copper corrosion rates are higher than some literature data documenting corrosion rates indirectly determined from H_2 generation in pure water. Further work is continuing to characterize the effect of chemical species, such as chloride in groundwater, on copper corrosion behavior. The measured corrosion potentials are also consistent with literature data for anoxic conditions and predictions from Pourbaix stability diagrams.

Carbon steel exposed to an anoxic simulated alkaline solution was susceptible to localized corrosion, predominantly in the form of pitting and crevice corrosion under galvanic coupling to the same material, with or without the addition of strong oxidant at 50 °C [122 °F]. Over a testing period of up to 30 days, there was no indication of repassivation under open circuit conditions, but the test was complicated by the initiation of multiple crevice sites. Tests with better controlled crevices are continuing to assess repassivation at open circuit conditions. Carbon steel single U-bend specimens were exposed to the same deaerated alkaline solution at 50 and 80 °C [122 and 176 °F] for up to 6 months under atmospheric conditions. Minor pitting was observed, but no cracking was detected in surface and cross section micrographs. Tests with double U-bends, which are more susceptible to corrosion because of the formation of crevices, are planned to assess HIC tendency. Other methods, such as cathodic charging, may be used in the future to evaluate the potential for HIC.

An intermediate milestone was prepared at the end of this fiscal year to summarize the literature review and independent test results for both carbon steel and copper as potential waste package materials (He and Ahn, 2015a). Early in this fiscal year, the intermediate milestone prepared at the end of fiscal year 2014 was revised to address NRC comments and incorporate some test results obtained at the beginning of this year (He et al., 2015a). A paper summarizing some important results on copper corrosion was presented at the 2015 International High-Level Radioactive Waste Management Conference (He et al., 2014; 2015b). A paper highlighting results on carbon steel corrosion was presented at the annual Corrosion conference (He and Ahn, 2015b). Relevant information and feedback obtained at the conferences were discussed with NRC staff and the test program was adjusted accordingly.

2.4 Analysis of Alternative Geologic Media

Work under this subtask assessed the thermomechanical behavior of salt host rock in a hypothetical underground repository housing heat-generating radioactive waste. Activities during fiscal year 2015 focused on implementation of the FZK-INE creep model as a user-defined function in the FLAC computer code for modeling the thermomechanical behavior of salt. The FZK-INE creep model, developed for the European Commission, is well-suited for modeling salt mechanical behavior because it includes a separate model for three creep deformation mechanisms—transient, steady-state, and damage—and provides for separate representations of creep and noncreep deformation mechanisms for numerical implementation by developing interfaces for user-defined material modeling in FLAC. Triaxial creep tests of cylindrical specimens of Waste Isolation Pilot Plant (WIPP) salt conducted at Sandia National Laboratories at ambient and elevated temperatures were modeled using FLAC to simulate the laboratory strain-time data. The FZK-INE creep model was calibrated and parameter values were determined that closely matched laboratory test data for the WIPP salt. FLAC with the calibrated FZK-INE creep model was used to numerically model two *in-situ* experiments (Rooms B and D) at the WIPP site. Rooms B and D are rectangular openings in homogeneous halite at a depth of about 200 m [650 ft] below the ground surface. Long term convergence was measured in Room D (ambient condition) and Room B (heated). The FLAC model results did not show time dependency of room convergence that was similar to the measured data, indicating that creep alone does not explain the magnitude and rate of the observed convergences. The model needs to be modified to include other inelastic deformation mechanisms, such as shear deformation, dilation, and compaction. A framework for the plasticity model to include these deformations was developed. Future work will involve implementation of the inelastic deformation mechanisms in the FZK-INE creep model and incorporation of horizontal clay seams, geological features that were not included in the current model of the field experiments. This year's modeling work was documented in an intermediate milestone (Ofoegbu and Dasgupta, 2015). During presentations and discussions at the NRC-CNWRA Thermal-Hydrological-Mechanical Modeling of Geologic Media workshop on salt and clay held during this fiscal year (Pickett, 2015b), further activities on salt were identified for future considerations. These future tasks could involve obtaining information on: the differences between fluid inclusions in bedded salts and in domal salts; the temperature limit for a repository affected by the presence of fluid inclusions; retrievability concerns in a salt repository; and salt repository performance assessment.

2.5 Buffer and Near Field Performance Assessment

Activities during fiscal year 2015 centered on improvements to process abstractions included in the SOAR code, particularly with respect to the near field component. Conceptualization and abstraction of processes associated with the buffer material and interactions at the interface between the buffer and the waste package were identified as topics for a buffer performance assessment workshop early in the fiscal year. Based on a review of past project workshops, technical reports, and international repository programs, key uncertainties and knowledge gaps were identified and used in developing the topical issues for the workshop. NRC and CNWRA staff members held a series of planning meetings to finalize the workshop agenda, which included four presentations and three facilitated discussion sessions.

The buffer performance assessment workshop (Pickett, 2015a) was held February 24, 2015, at NRC headquarters. CNWRA staff members presented summaries of the current state of knowledge and key technical gaps regarding buffer coupled processes, canister corrosion, geochemical conditions, and performance assessment modeling. The subsequent discussion sessions defined a nominal scenario and identified key processes to support conceptualization and generic abstraction of buffer performance needed for enhancing the capabilities of the SOAR code. A summary report on the workshop was transmitted to NRC as an IM (Osidele et al., 2015). Included in this report were CNWRA's suggestions for future work on the SOAR code, particularly the abstraction of time- and temperature-dependent processes affecting buffer performance and waste package corrosion.

Following the buffer performance assessment workshop, a series of updates was conducted to support the next public release of the SOAR code. These updates produced the SOAR Version 1.1β code and a draft User Guide document, both transmitted as an intermediate milestone (NRC and CNWRA, 2015). The updated SOAR code includes the U-238 decay chain abstraction developed in fiscal year 2014 and minor code revisions documented in fiscal year 2013 milestones. This fiscal year, a new buffer degradation model was implemented using piecewise linear functions of buffer damage fractions and explicit linear interpolation, and a new hazard curve based on user-defined recurrence rates was developed to represent multiple waste package failure events. On NRC staff directions, the model abstraction for time-dependent waste package corrosion was retained in SOAR as an experimental code, but not documented in the draft User Guide. The SOAR dashboard was also modified to facilitate ease of use. Parameters for waste form degradation and waste package corrosion documented in SOAR User Guide Appendix A (Default Input Parameters) were reviewed and updated as needed. A revised Microsoft Access® database was developed to transfer the default input parameter values into the SOAR code. Also under this task, a journal article titled Effects of Flow Uncertainty and Variability on Performance Assessment of a Generic Geologic Repository was completed and transmitted to NRC for programmatic review (Stothoff, 2015).

3 SUMMARY AND CONCLUSIONS

Task Order 9 activities during fiscal year 2015, conducted in close collaboration with NRC staff, continued CNWRA contributions to the understanding of risk-significant processes in geologic disposal of SNF and high-level radioactive wastes. Technical work was topically organized around coupled process modeling for DECOVALEX, waste form, waste package, salt host rock, and buffer conceptualization in performance assessment and related SOAR updates.

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APPENDIX

CNWRA Deliverables, Fiscal Year 2015, Disposal-Related Integrated Spent Nuclear Fuel Regulatory Activities—Identification and Analysis of Key Regulatory and Technical Issues for Disposal of Spent Nuclear Fuel and High-Level Waste

CNWRA Deliverables, Fiscal Year 2015, Disposal-Related Integrated Spent Nuclear Fuel Regulatory Activities—Identification and Analysis of Key Regulatory and Technical Issues for Disposal of Spent Nuclear Fuel and High-Level Waste

Deliverable Number	Title	Authors	Year	Type
Administrative Items				
AI17860.09.001.416	Copper Corrosion in Simulated Anoxic Granitic Groundwater	He, X., T. Ahn, and J. McMurry	2014	IHLRWMC Paper
AI17860.09.001.417	Effects of Dissolved Hydrogen on Dissolution Rate of SIMFUEL in High-Level Waste Repositories with Reducing Conditions	Shukla, P., and T. Ahn	2014	IHLRWMC Paper
AI17860.09.001.418	Constitutive Model Developments for Bentonite Buffer Behavior	Stothoff, S., C. Manepally, and R. Fedors	2014	IHLRWMC Paper
AI17860.09.001.419	Modeling Thermohydrological-Mechanical Behavior of Granular Bentonite	Manepally, C., S. Stothoff, G. Ofoegbu, B. Dasgupta, and R. Fedors	2014	IHLRWMC Paper
AI17860.09.001.501	Trip Report: 6th DECOVALEX-2015 Workshop, November 10–13, 2014	Stothoff, S., and R. Fedors	2014	Trip Report
AI17860.09.001.502	Trip Report: 7th DECOVALEX-2015 Workshop, April 13–16, 2015	Manepally, C., and R. Fedors.	2015	Trip Report
AI17860.09.011.501	Modeling Thermohydrological-Mechanical Behavior of Granular Bentonite	Stothoff, S., C. Manepally, G. Ofoegbu, B. Dasgupta, and R. Fedors	2015	IHLRWMC Presentation
AI17860.09.011.502	Constitutive Model Developments for Bentonite Buffer Behavior	Stothoff, S., C. Manepally, and R. Fedors	2015	IHLRWMC Presentation
AI17860.09.011.511	Modeling the Mechanical Behavior of Unsaturated Expansive Soils Based on Bishop Principle of Effective Stress	Ofoegbu, G., B. Dasgupta, C. Manepally, S. Stothoff, and R. Fedors	2015	Journal Paper
AI17860.09.012.501	Effects of Dissolved Hydrogen on Dissolution Rate of SIMFUEL in High-Level Waste Repositories with Reducing Conditions	Shukla, P., and T. Ahn	2015	IHLRWMC Presentation
AI17860.09.013.501	Carbon Steel Corrosion in Anoxic Alkaline Solution	He, X. and T. Ahn	2015	NACE Presentation
AI17860.09.013.502	Copper Corrosion in Simulated Anoxic Granitic Groundwater	He, X., T. Ahn, and J. McMurry	2015	IHLRWMC Presentation

CNWRA Deliverables, Fiscal Year 2015, Disposal-Related Integrated Spent Nuclear Fuel Regulatory Activities—Identification and Analysis of Key Regulatory and Technical Issues for Disposal of Spent Nuclear Fuel and High-Level Waste				
Deliverable Number	**Title**	**Authors**	**Year**	**Type**
Intermediate Milestones				
IM17860.09.001.315 Revised	Thermal-Hydrological-Mechanical Modeling of a Saturated Clay Shale—Report on HE-D Test Modeling	Ofoegbu, G., B. Dasgupta, C. Manepally, and R. Fedors	2015	Report
IM17860.09.001.405	Summary of Fiscal Year 2014 Activities: Disposal-Related Integrated Spent Nuclear Fuel Regulatory Activities—Identification and Analysis of Key Regulatory and Technical Issues for Disposal of Spent Nuclear Fuel and High-Level Waste	Pickett, D., C. Manepally, O. Pensado, P. Shukla, O. Osidele, X. He, and A. Ghosh	2014	Report
IM17860.09.001.410 Revised	Modeling Thermohydrological-Mechanical Behavior of Granular Bentonite in a Laboratory Column Test	Stothoff, S., C. Manepally, G. Ofoegbu, and B. Dasgupta	2015	Report
IM17860.09.001.430 Revised	Hydrogen Effects on Dissolution of Spent Nuclear Fuel in Reducing Repository Conditions—Literature Review and Laboratory Experiments	Shukla, P., T. Ahn, J. McMurry, M. Rubal, D. Daruwalla, Y. Pan	2015	Report
IM17860.09.001.440 Revised	Literature Review and Experiments on Waste Package Corrosion—Copper and Carbon Steel	He, X., T. Ahn, and J. McMurry	2015	Report
IM17860.09.001.455	Effects of Flow Uncertainty and Variability on Performance Assessment of a Generic Geologic Repository	Stothoff, S.	2015	Journal Paper
IM17860.09.001.505	Software: Source Code of xFlo, User Documentation, and Installation Test Problems for NRC Testing and Verification in Windows	Pickett, D.	2014	Software

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Deliverable Number	Title	Authors	Year	Type
IM17860.09.010.500	Disposal-Related Integrated Spent Nuclear Fuel Regulatory Activities—Identification and Analysis of Key Regulatory and Technical Issues for Disposal of Spent Nuclear Fuel and High-Level Waste Mid-Year Summary Report and Table Summary of Documentary Deliverables and Information Items From Fiscal Year 2012 Through 2014	Pickett, D., C. Manepally, P. Shukla, X. He, B. Dasgupta, and O. Osidele	2015	Report
IM17860.09.011.500	Modeling and Analyses of the Thermohydrological-Mechanical Behavior of Bentonite Buffer and Clay Host Rock in the HE-E Test	Manepally, C., S. Stothoff, G. Ofoegbu, B. Dasgupta, and R. Fedors.	2015	Report
IM17860.09.011.510	Workshop: Thermal-Hydrological-Mechanical Modeling of Geologic Media	CNWRA and NRC	2015	Workshop
IM17860.09.012.500	Hydrogen Effects on Dissolution of Spent Nuclear Fuel Under Reducing Repository Conditions—Literature Review and Laboratory Experiments	Shukla, P., T. Ahn, J. McMurry, M. Rubal, D. Daruwalla, and Y. Pan	2015	Report
IM17860.09.013.500	Experiments on Corrosion of Copper and Carbon Steel Waste Containers—Progress Report	He, X., and T. Ahn	2015	Report
IM17860.09.014.500	Implementation of a Creep Model in FLAC to Study the Thermomechanical Response of Salt as a Host Repository Medium—Progress Report	Ofoegbu, G., and B. Dasgupta	2015	Report
IM17860.09.015.500	Workshop on Buffer Conceptualization for Performance Assessment	CNWRA and NRC	2015	Workshop
IM17860.09.015.505	Summary Report: Workshop on Buffer Conceptualization for Performance Assessment	Osidele, O., J. Gwo, O. Pensado, T. Ahn, R. Fedors, X. He, C.	2015	Workshop Report

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Deliverable Number	**Title**	**Authors**	**Year**	**Type**
		Manepally, C. Markley, S. Mohanty, P. Shukla, and S. Stothoff		
IM17860.09.015.510	SOAR: A Model for Scoping of Options and Analyzing Risk Version 1.1: User Guide	NRC and CNWRA	2015	Software and Report