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Final report: Second generation waste package design study

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SECOND GENERATION WASTE PACKAGE DESIGN STUDY

Final Report
September 1st, 2006 to March 31st, 2007

Task No: ORD-FY06-023

-submitted to-

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Statement of Work

The principal purpose of the cooperative agreement is to develop and continue providing the public and the Office of Repository Development (ORD) of the U.S. Department of Energy's (DOE) Office of Civilian Radioactive Waste Management (OCRWM) with an independently derived, unbiased body of scientific and engineering data concerning the study of Yucca Mountain as a potential high-level radioactive waste repository. Under this agreement, the Nevada System of Higher Education (NSHE), formerly the University and Community College System of Nevada (UCCSN), will perform scientific or engineering research, and maintain and foster collaborative working relationships between government and academic researchers. The following describes the objectives of Project Activity 023 "Second Generation Waste Package Design Study" under the cooperative agreement.

The objectives of this project activity are:

- to review the current YMP baseline environment and establish corrosion test environments representative of the range of dry to intermittently wet conditions expected in the drifts as a function of time.
- to demonstrate the oxidation and corrosion resistance of A588 weathering steel and reference Alloy 22 samples in the representative dry to intermittently dry conditions.
- to evaluate backfill and design features to improve the thermal performance analyses of the proposed second-generation waste packages using existing models developed at UNR.

The work plan for this project activity consists of three major tasks:

Task 1. Definition of expected worst-case environments (humidity, liquid composition and temperature) at waste package outer surfaces as a function of time, and comparison with environments defined in the YMP baseline.

Task 2. Oxidation and corrosion tests of proposed second-generation outer container material.

Task 3. Second Generation waste package thermal analyses.

This project activity is an essential part of the program to enhance the collaborative ongoing research between the NSHE and the ORD during the five-year period of the cooperative agreement.

Progress for the period 10/01/06 – 03/31/07

Estimated percent completion by subtask is summarized below, and in Appendix 1 to this report.

Task	Description	% Complete
1	Definition of expected worst case environments	20 %
2	Oxidation and corrosion tests of proposed second generation outer container material.	15 %
3	Second Generation waste package thermal analyses.	30 %

SUBTASK 1 - DEFINITION OF EXPECTED WORST CASE ENVIRONMENTS

Thermal analysis for a 5000 year period in the Yucca Mountain Waste repository environment is complete. Calculations were performed to determine the maximum oxide thickness that would be formed on the surface of the A588 steels as container wall material in the Second Generation waste packages in the first 5000 year of emplacement. The details are reported in the first and second quarterly reports [1] [2].

SUBTASK 2 – OXIDATION AND CORROSION TESTS

Test Materials

The A588 test material was acquired from the Central Steel Inc. The compositional and mechanical property certificates were provided by the supplier, and independent testing was conducted to verify the alloy content and mechanical properties. Details are reported in the second quarterly report. The Alloy 22 test material along with composition and mechanical property certificates was obtained from ongoing DOE sponsored research programs at the University of Nevada, Reno.

Isothermal Oxidation Tests

A thermal gravimetric apparatus (TGA) was purchased from the Shimadzu Inc. for conducting isothermal oxidation tests in air at elevated temperatures. Isothermal oxidation tests in the TGA and also in box furnace environments, for the both the A588 and the Alloy 22 materials, were ongoing at termination. Microstructure, metallographic and electrochemical characterization studies of the oxide scales were also ongoing. Test data were recorded and retained in project files.

Thermal Gravimetric Analysis

The objective of the TGA testing was to determine the optimum times and temperatures for growing oxide scales that are equivalent in thickness to those which would form during a 10,000 year emplacement in the Yucca Mountain repository. The goal of this effort was to grow oxides of equivalent composition and structure in reasonable times by oxidizing test specimens at significantly higher temperatures than expected in the repository. TGA scoping tests were conducted at 600, 700, 800 and 900 ^{o}C. An important conclusion from these high temperature test data is that temperatures

above 600 ºC are not favorable due to spalling of the iron oxide scale (reported in the second quarterly report).

Subsequent isothermal oxidation tests were performed for 10 to 20 day time periods at 475 to 600 ºC. Results are summarized in Figure 1. Plots of weight gain per unit area vs. square root of time for the A588 steel in the dry air environment at four different temperatures, 475, 500, 575 and 600 ºC show that parabolic oxidation behavior was occurring at temperatures up to 575 ºC. The measured oxidation at 600 ºC was fitted to a second order polynomial. The parabolic oxidation rate constants were determined from the slopes of the data for each temperature. Since the 600 ºC were not linear over the entire time range, the slope for the first 100 hours was used as a pseudo rate constant.

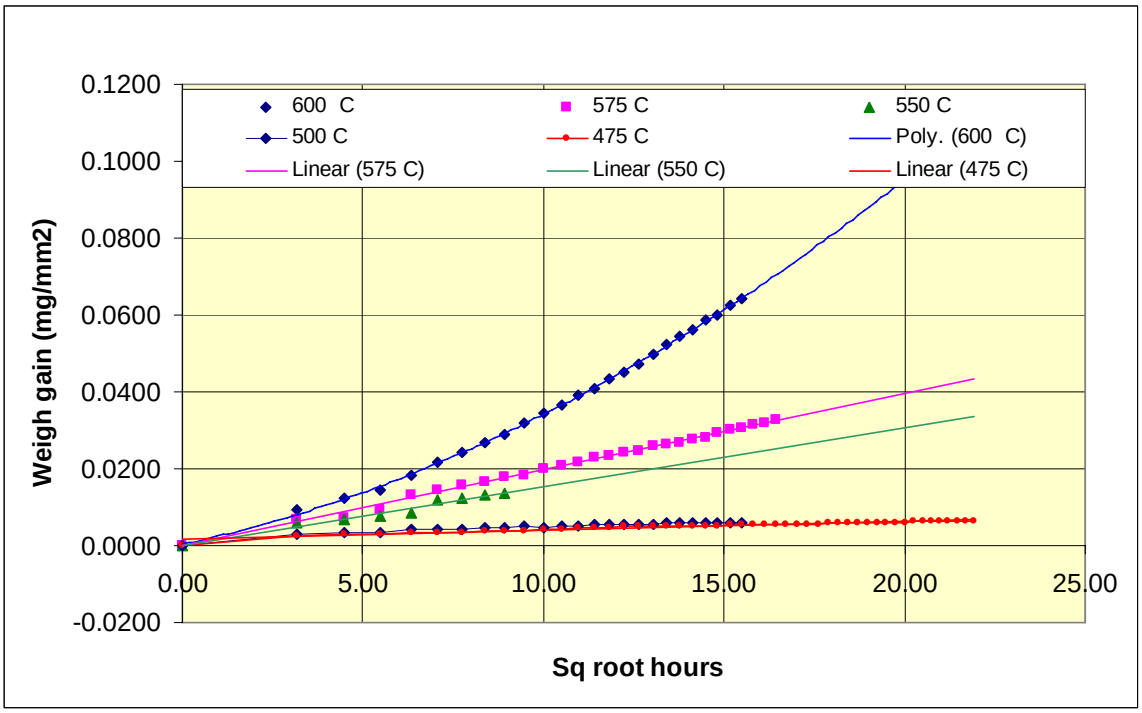

Figure 1. Plot of weight gained per unit area vs. square root of time. Straight line fit can be observed from the data confirming parabolic kinetics at temperatures less than 600.

The logarithm of the rate constants plotted against the inverse of the absolute oxidation temperature, are shown in Figure 2. The slope of the straight line fitting the data multiplied by the gas constant yielded the activation energy for the oxidation of the A588 material in the 475 to 600 ºC regime.

The activation energy, as obtained from these data was 116 kilojoules per mol. This is 30% higher than the value reported in literature Chang [3], i.e. 91 kilojoules per mol. The higher activation energy determined for A588 in the present study is probably more representative since the Chang studies were limited to short term (24 hour) tests compared to the 240 hour to 480 hour tests in this study.

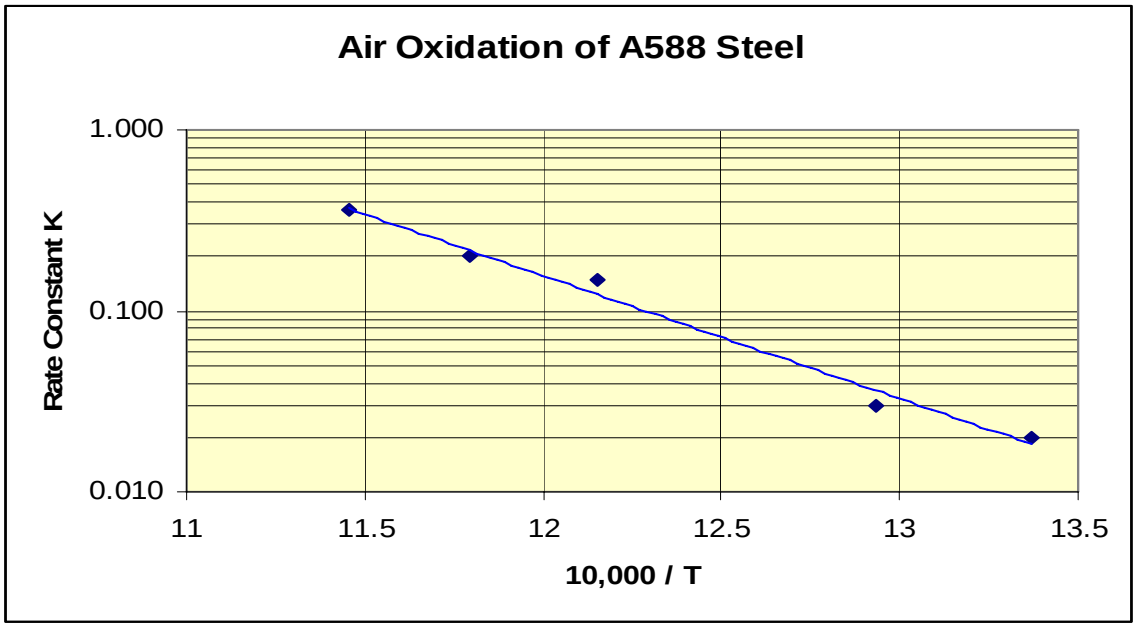

Figure 2. Plot of measured rate constants in ($mg/cm^2\ hour^{½}$) vs. inverse of the absolute temperatures, for dry air oxidation of the A588 steel, at 475, 500, 550, 575 and 600 ºC.

Drip Testing

An initial set of design requirements for the drip corrosion experimental apparatus was developed. Details of the requirements for the apparatus are provided in the first quarterly report. A conceptual design based on these requirements was in progress at project termination

SUBTASK 3 - SECOND GENERATION WASTE PACKAGE THERMAL ANALYSIS

Thermal Analysis

The thermal transient of the Second Generation waste packages was performed for the first 5000 years of emplacement. The waste package thermal analysis demonstrated that above-boiling surface temperatures are sustained for thousands of years and that these favorable dry conditions are extended by incorporation of backfill around the packages. Detailed modeling for determining the thermal history for the first 10,000 years period, with the effect of backfill, has been terminated.

PLANS FOR NEXT QUARTER

The work was discontinued after March 30th due to project termination by DOE. Appendix 1 summarizes details of the completed tasks in a tabular form.

REFERENCES

1. J.S. Armijo, M. Misra, P. Kar, Second Generation Waste Package Design Study, Quarterly Technical Report No. 1, October 1, 2007 to December 31, 2006

2. J.S. Armijo, M. Misra, P. Kar, Second Generation Waste Package Design Study, Quarterly Technical Report No. 2, January 1, 2007 to March 31, 2007

3. Y. N. Chang, "Oxidation behaviors of five low-alloy structural steels at 600 °C", Corrosion, vol. 50 (1), 1994, pp.3-10.

Appendix 1. Second Generation Waste Package Design Study -- Detailed Task Plan

Milestone	Task		Start	Completion	Status 12/31/2006
991	ORD-FY06-023	**Second Generation Waste Package Design Study**	09/25/2006	11/21/2008	Terminated
992		**Subtask 1-Definition of expected worst case environments**	**09/25/2006**	**01/19/2007**	
993		Detailed task plan		11/30/2006	Rev 1 complete
994		Meeting with Office of Chief Scientist		11/30/2006	Terminated
995		Meetings with national laboratories		12/15/2006	Terminated
996		Definition of post closure thermal history		01/12/2007	Complete
997		Definition of post closure humidity		01/12/2007	Terminated
998		Definition of post closure electrolytes		01/12/2007	Terminated
999		Definition of reference test environments for subtask 2		01/19/2007	Premature--will reschedule in Rev 1 of Task plan
1000		**Subtask 2-Oxidation and corrosion tests**	**11/30/2006**	**09/19/2008**	
1001		Detailed task plan		11/30/2006	Rev 1 complete
1002		A588 materials procurement & characterization		02/16/2007	Material received -characterization complete
1003		Alloy 22 materials procurement & characterization		02/16/2007	Certified Materials Procurement complete
1004		Conduct isothermal oxidation tests	04/02/2007	06/28/2007	Terminated
1013		Complete isothermal oxidation tests		06/28/2007	Terminated
1005		Conduct oxide thickness and compensation measurements	04/02/2007	06/29/2007	Terminated
1014		Complete oxide thickness and compensation measurements		06/29/2007	Terminated
1007		Pretest oxidation per simulated thermal history	04/02/2007	06/29/2007	Terminated
1043		Complete oxidation pretests		06/29/2007	Terminated
1006		Drip test equipment design requirement		02/15/2007	Design effort terminated
1008		Drip test equipment preliminary design		05/15/2007	Complete
1009		Drip test equipment fabrication and checkout	07/02/2007	12/21/2007	Terminated
1015		Complete test equipment fabrication and checkout		12/21/2007	Terminated
1010		Procurement of reference test electrolyte	07/02/2007	12/21/2007	Terminated
1011		Pre-test thermal oxidation to prepare test specimens	07/02/2007	12/21/2007	Terminated
1016		Complete test specimen preparation		12/21/2007	Terminated
1012		Metallographic and chemical precharacterization	07/02/2007	03/31/2008	Terminated
1017		Complete metallographic & chemical precharacterization		03/31/2008	Terminated
1018		Initial drip tests series	10/01/2007	03/31/2008	Terminated
1019		Complete initial drip tests		03/31/2008	Terminated

1020		Complete test specimen evaluations		06/27/2008	Terminated
1021		Conduct 2nd drip test series	01/07/2008	06/27/2008	Terminated
1022		Complete 2nd drip test series		06/27/2008	Terminated
1023		Conduct 3rd test series	04/01/2008	09/19/2008	Terminated
1024		Complete 3rd test series		09/19/2008	Terminated
1025		**Subtask 3-Second Generation WP Thermal Analysis**	**12/22/2006**	**06/29/2007**	
1026		Definition of thermal history for reference YMP design		12/22/2006	Complete
1027		Definition of thermal history for2nd generation YMP design		12/22/2006	Complete
1028		Definition of equivalent isothermal history		02/23/2007	
1029		Backfill analysis on peak surface and cladding temperatures		02/28/2007	Complete for 5000 years, analysis for the 10,000 year period terminated
1030		Quantification of dry period extension	01/02/2007	06/29/2007	Terminated
1031		Complete quantification of dry period extension		06/29/2007	Terminated
1032		Analysis of potential thermal optimization techniques	01/02/2007	06/29/2007	Terminated
1040		**Data Submittals**	**09/14/2007**	**09/26/2008**	Terminated
1041		Interim data submittal (FY-2007 data)		09/14/2007	Terminated
1042		Final data submittal		09/26/2008	Terminated
1034		**Reports**	**10/01/2007**	**11/14/2008**	Terminated
1035		FY-2007 Annual Report		10/01/2007	Complete
1036		FY-2008 Annual Report		10/01/2008	Terminated
1037		Final Report		11/14/2008	Terminated
1038		LSN Records submittal		11/21/2008	Terminated
1039		End of funding		09/30/2008	Terminated