UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201-3369

August 16, 2017

Mr. James M. Owendoff
Acting Assistant Secretary for Environmental Management
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

Mr. Edward McGinnis
Acting Assistant Secretary for Nuclear Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

Dear Mr. Owendoff and Mr. McGinnis:

The U.S. Nuclear Waste Technical Review Board (Board) held a meeting in Richland, Washington, on June 21, 2017, to review information on recent U.S. Department of Energy (DOE) research activities related to corrosion and long-term performance of borosilicate high-level radioactive waste (HLW) glass in a repository environment. The meeting included presentations by representatives of three DOE national laboratories and the Vitreous State Laboratory (VSL) of the Catholic University of America on DOE-funded research and development (R&D) activities. In addition, experts from other countries provided their perspectives on the current understanding and remaining challenges in measuring and modeling HLW glass performance. Immediately after the public meeting, a poster session was held during which scientists and engineers from the United States and other countries presented their research related to nuclear waste glass corrosion.

The Board extends its gratitude to your staff members who worked with Board staff to plan the meeting. We also appreciate the investment of time and effort by national laboratory personnel who made presentations or exhibited posters at the meeting. The meeting agenda is attached to this letter, while the presentations, poster abstracts, transcript, and an archived recording of the webcast are available on the Board's website at http://www.nwtrb.gov/meetings/meetings.html.

The Board also thanks your staff, as well as staff from the national laboratories, for supporting a technical fact-finding meeting that was held on May 15, 2017, in Washington, D.C. This fact-finding meeting allowed a more detailed presentation of technical issues related to HLW glass corrosion and long-term performance and enabled the Board to prepare for the June 21 public meeting. The presentations made at the May 15 fact-finding meeting also are available on the Board's website, at the same location as the other June 21, 2017, meeting materials. We also thank your staff, as well as staff from Pacific Northwest National Laboratory (PNNL), for supporting the Board's tour of HLW-related laboratories at PNNL on June 20, 2017.

Background

In the United States and in most other countries, vitrification into borosilicate glass is the technology being used to immobilize liquid HLW destined for disposal in a geologic repository. Borosilicate glass is the preferred waste form because it can accommodate a wide range of HLW compositions, has a structure considered to be less susceptible to radiation damage than crystalline materials, is relatively durable in many geologic disposal environments, and exhibits good thermal and mechanical stability properties. Also, vitrification is a well-demonstrated technology resulting from more than 40 years of industrial experience and is a processing method that can be applied to large volumes of HLW.

During the past few years, DOE has conducted R&D activities on corrosion of borosilicate HLW glass. The purpose of these activities is to improve understanding of glass waste form degradation and to develop a basis for reducing conservatisms in glass corrosion models that are used in disposal system performance assessments.[1] DOE's detailed plan for these R&D activities, which was developed in 2011, included experiments to measure glass corrosion as well as modeling at the atomic and larger scales to help interpret experimental results. The plan also included using the experimental results to develop an improved glass corrosion model and integrating the corrosion model with generic repository system performance assessment calculations. DOE has coordinated its research activities with those being conducted in other countries and also has funded R&D activities on glass corrosion at several U.S. universities through its Nuclear Energy University Program.

The meeting agenda was crafted to guide discussion on the current understanding of glass corrosion mechanisms and rates, the environmental factors that control these mechanisms and rates, the remaining uncertainties and challenges in measuring and modeling the long-term performance of borosilicate HLW glass, and the progress DOE, in collaboration with the international scientific community, has made in addressing those uncertainties and challenges. The meeting focused only on local-scale processes of glass corrosion along surfaces of glass particles or within fractures under conditions of water saturation. Although the long-term durability of glass in a repository environment also will depend on many other factors and interactions, including the transport of water or water vapor through engineered barriers to the waste glass, the extent of fracturing within the waste glass, and the various potential disposal geochemical environments, the limited duration of the meeting precluded discussion of these other factors.

The first technical presentation was by Dr. Bernd Grambow (SUBATECH, France), who discussed alternative approaches to modeling glass corrosion in repository environments and how different countries take account of glass corrosion and radionuclide release in repository performance assessments. In a following presentation, Dr. Carol Jantzen [Savannah River National Laboratory (SRNL)] described DOE's criteria for qualifying borosilicate glass waste forms as being acceptable for disposal in any geologic repository and the technical bases of those

[1] Dr. J.D. Vienna described the motivation for these activities in his May 15, 2017, presentation titled "Summary of Programs and Collaborations."

Telephone: 703-235-4473 Fax: 703-235-4495 www.nwtrb.gov

criteria, including standards, test methods, databases, and models. Then, Dr. Stéphane Gin (French Atomic Energy and Alternative Energies Commission) presented his assessment of the current scientific understanding of the processes responsible for glass corrosion and release of radionuclides into the environment, and the remaining technical challenges to measuring glass corrosion and modeling the long-term performance of borosilicate HLW glasses. Dr. Ian Pegg (VSL) followed with a presentation on glass formulation and durability studies at the VSL and how the results of those studies are used to understand glass corrosion mechanisms and long-term performance in disposal environments.[2] Dr. Joseph Ryan (PNNL) then made a presentation on DOE studies to improve understanding of rate-limiting mechanisms for glass corrosion under varying conditions. Dr. William Ebert (Argonne National Laboratory) followed with a presentation on the DOE HLW glass corrosion model and its implementation in repository post-closure safety analysis. Finally, Dr. Aurélie Verney-Carron (Interuniversity Laboratory of Atmospheric Systems, France) gave a presentation on studies of natural and archeological glasses and what can be learned from these natural and archeological analog studies about long-term HLW glass corrosion.

Board Observations

Borosilicate glass corrosion is a complex process, but there is general consensus that borosilicate glass corrosion follows three main stages: an initial (high) corrosion rate (Stage I) followed by a residual (low) corrosion rate (Stage II), and, under certain conditions, a resumption of a higher corrosion rate that is still less than the initial rate (Stage III).[3] Additional detail on glass corrosion, and its associated stages, is provided in an appendix to this letter.

DOE has used a "bounding" glass corrosion model in repository performance assessments, which was designed to not under-predict the rate of glass corrosion.[4] At the time DOE developed this bounding model in the early 2000s, the conditions triggering Stage III were not well understood. Dr. Ebert explained during his May 15, 2017, presentation that the model represents dependencies on solution composition by using a range of corrosion rates derived from tests conducted over a wide range of pH conditions. Potentially higher glass corrosion rates due to Stage III processes were bounded in the model by using a maximum value that is higher than the rates derived from experiments in which a Stage III resumption of alteration was observed.

Dr. Ebert explained that the model DOE is currently developing incorporates the effects of secondary phase nucleation and growth on glass corrosion rate (*i.e.*, Stage III) deterministically. As Dr. Ebert described, the new model represents DOE's improved understanding of the conditions required to trigger Stage III and provides confidence in using the Stage II (residual)

[2] Dr. Pegg also discussed the performance of low-activity waste glass that DOE plans to create at the Hanford site in Washington State. DOE plans to dispose of low-activity waste glass at the Integrated Disposal Facility, a near-surface disposal facility at the Hanford site.
[3] Based on all of the data that are in the ALTGLASS database, which DOE has developed, Stage III rates are always lower than the Stage I rate for the same glass composition and pH conditions.
[4] Dr. Ebert described the historical basis for the current HLW model in his May 15, 2017, presentation titled "DOE HLW Glass Degradation Model." The Board notes that DOE used this "bounding" model in its performance assessment for the Yucca Mountain repository.

Telephone: 703-235-4473 Fax: 703-235-4495 www.nwtrb.gov

rate if those conditions are not predicted to occur. As DOE continues this model development, and if the resulting model is used for future performance assessments, DOE should consider the following Board observations.

Substantial progress, but significant technical uncertainties remain

The presentations at the Board's public meeting indicate that the R&D activities DOE has conducted in the past few years in collaboration with international scientists have advanced the scientific understanding of HLW glass corrosion. Results are being used to develop mechanistic glass corrosion models for generic repository performance assessment calculations.

Nevertheless, technical uncertainties remain that could be reduced by additional research. For example, the focus of recent studies by DOE and the international community has been on what triggers the resumption of more rapid glass corrosion (Stage III). There has been progress in identifying the glass characteristics and environmental conditions associated with the initiation of Stage III, and DOE-funded researchers have developed a conceptual model of precipitation of secondary phases such as zeolites that drives enhanced corrosion of glass during Stage III. However, significant uncertainties remain, particularly related to the detailed causation mechanisms and timing of Stage III. Establishing what triggers Stage III and how it might be avoided is important because HLW glass will retain radionuclides for a very long time at Stage II corrosion rates whereas the HLW glass radionuclide retention under Stage III corrosion rates will be much shorter.

Effective utilization of state-of-the-art analytical equipment

The advancement of the scientific understanding of HLW glass corrosion mechanisms and rates has been facilitated by new and novel analytical and experimental methods (*e.g*., cryogenic atom probe tomography, *in-situ* monitoring using Raman spectroscopy, energy-filtered transmission electron microscopy, and isotope tagging). These new analytical techniques have allowed a more detailed characterization of the gel and other alteration layers that form on glass surfaces during corrosion. These techniques have led to an improved understanding of glass corrosion mechanisms and have contributed to developing more mechanistic glass corrosion models. DOE's continued support for the development of and use of such techniques and equipment in making measurements to understand the mechanisms that control corrosion of waste repository glass, including examination of existing glass samples from long-term corrosion experiments, would further improve the fundamental understanding of HLW glass corrosion and the predictive capability of glass corrosion models.

Robust international collaboration

It is evident there is an international scientific community that collaborates in investigating HLW glass corrosion, exchanging information, and developing a consensus regarding the mechanisms of corrosion. In his presentation, Dr. Ryan stated that this community meets at least once a year in conjunction with the American Ceramic Society Glass and Optical Materials Division meeting, and at other venues, to exchange data and ideas on glass corrosion models and experiments, and to identify problems and the research needed to solve them. The Board lauds

Telephone: 703-235-4473 Fax: 703-235-4495 www.nwtrb.gov

DOE's support that enables DOE-funded researchers to participate at these mutually beneficial meetings. Dr. Grambow, in his presentation, mentioned that a new European Union-funded project, JOPRAD (Joint Programme on Radioactive Waste Management and Disposal) was initiated in April 2017 and that part of the project will focus on nuclear waste glass corrosion. The Board notes that DOE participation in this European Union initiative would foster increased interaction among the researchers and facilitate continued progress in the development of DOE's new model.

Database enhancement and data analysis

In the U.S. and internationally, there is an immense amount of experimental data on glass corrosion. Some of these data have been incorporated into the ALTGLASS database, discussed by Dr. Jantzen at the meeting. Dr. Jantzen's meta-analysis of the data has resulted in improved understanding of what triggers the resumption of accelerated corrosion in Stage III. Dr. Ebert has used the results of her analyses to develop a modeling approach that could incorporate the mechanisms indicated by her observations into radionuclide source term calculations for repository performance assessment models. These efforts are noteworthy, but as Drs. Pegg and Grambow indicated, there are additional data in the United States and other countries that have not yet been incorporated into the ALTGLASS database. A sustained effort to compile all available data and to develop data analysis tools and techniques, such as Bayesian inference, would enable metadata analysis by researchers in the international collaboration. That effort could be used to identify important empirical correlations between parameters and corrosion rates, reduce duplicative experiments, and identify additional experimental studies needed to reduce uncertainties in model parameters. These efforts could lead to more mechanistic understanding of glass corrosion.

Long-term experiments are important

Several speakers noted how difficult it can be to predict the timing of commencement of Stage III accelerated corrosion and commented that some experiments that were terminated might have entered into Stage III if the tests had continued for a longer time. Given this uncertainty in Stage III initiation, it is impressive that VSL has been able to sustain some tests for 36 years. Long-term experiments appear to have been crucial to providing needed data on Stage III initiation (seventy five percent of the data currently recorded in the ALTGLASS database come from VSL experiments). Additional long-term studies on a wider range of glass compositions could help identify glass formulations that have the potential for entering Stage III corrosion.

Considering model uncertainties

As DOE develops support for a more refined glass corrosion model and adopts a new "consensus" model, it is important to recognize the uncertainties related to these models. In particular, the models may not include phenomena that were deemed unimportant in developing the model, but which may lead to glass corrosion rates higher than the "best estimate" or "consensus" models. For example, the past decade has seen advances in understanding the role that micro-organisms and organic molecules play in mediating and enhancing inorganic chemical processes. The speakers at the meeting felt that micro-organisms would not significantly

Telephone: 703-235-4473 Fax: 703-235-4495 www.nwtrb.gov

influence glass corrosion rates, but this conclusion appears to be based primarily on a few, older studies. Similarly, the impact of radiation emitted by radionuclides immobilized in the HLW glass on its exterior alteration layer and on the precipitation of secondary (*e.g.*, zeolite) phases that could trigger Stage III is not well understood. Since cracking, crack geometry, and surface roughness have been shown to influence glass corrosion rates, understanding glass corrosion dependencies on these factors is also warranted. More generally, it is important to identify and understand processes that may occur in repository environments that could lead to corrosion rates higher than "best estimates."

Natural analogs

Dr. Verney-Carron presented interesting work on archeological and natural glass samples. Characterization of alteration layers in natural analogs and attempts to simulate the observed levels of alteration using geochemical models developed for nuclear waste glasses can provide important tests of the conceptual and rate models that are being used to simulate glass corrosion in geologic repositories. However, using natural analogs to validate models for HLW glass corrosion is challenging because the conditions to which the natural analogs were exposed is poorly known in many cases and the compositions of the natural analog materials do not match the borosilicate compositional range of waste glasses.

Bounding estimates of glass durability

Dr. Jantzen explained that HLW glass is qualified for disposal in a geologic repository by comparing its short-term, laboratory-measured leach rate to that of a reference glass whose properties are utilized in the total system performance assessment. Confirmation that the reference glass corrosion rate is a bounding value is established via accelerated corrosion experiments of the as-manufactured glass using ASTM standard test procedures. A question deserving continued attention, as more becomes known about glass corrosion, is whether the ASTM standard test procedures assure that usage of the reference glass for comparison still provides bounding estimates of glass durability.

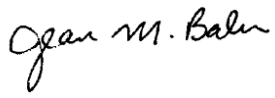
Effective integration of DOE program

At the meeting, the Board observed a notable integration within the DOE program and between the various groups working on the glass R&D program. The presentations and discussions at this Board meeting indicated there has been increasing collaboration among the different groups since the Board's meeting in 2013 on vitrifying HLW stored at the Hanford site. It was also apparent that the U.S. program is integrated with the international community working in this area. Additional coordination within DOE, with the Offices of Science, Environmental Management, and Nuclear Energy working together, is evidenced by the establishment of new Office of Science Energy Frontier Research Centers such as the Center for Performance and Design of Nuclear Waste Forms and Containers (WastePD) at the Ohio State University and the Interfacial Dynamics in Radioactive Environments and Materials (IDREAM) center at PNNL. The Board commends such integration which engenders internal critical review of results.

Telephone: 703-235-4473 Fax: 703-235-4495 www.nwtrb.gov

Thank you again for the participation of DOE staff and technical experts from the national laboratories at our June meeting. In particular, we thank Dr. Patricia Paviet and Ms. Kimberly Gray, both of DOE-NE, for their efforts in coordinating the national laboratory speakers and presentations. We look forward to continuing our ongoing review of DOE's technical activities related to the management and disposal of SNF and HLW.

Sincerely,



Jean M. Bahr
Chair

Attachment

Telephone: 703-235-4473 Fax: 703-235-4495 www.nwtrb.gov

APPENDIX
Glass Corrosion Mechanisms and Kinetics

Borosilicate glass corrosion in water has been studied extensively, resulting in a large database of experimental results. Based on these results, consensus has emerged that borosilicate glass corrosion follows three main stages corresponding to different rate-limiting mechanisms: the initial corrosion rate (Stage I), the residual rate (Stage II), and, under certain conditions, a resumption of increased corrosion (Stage III). Figure 1 illustrates these stages and the proposed rate-limiting mechanisms.

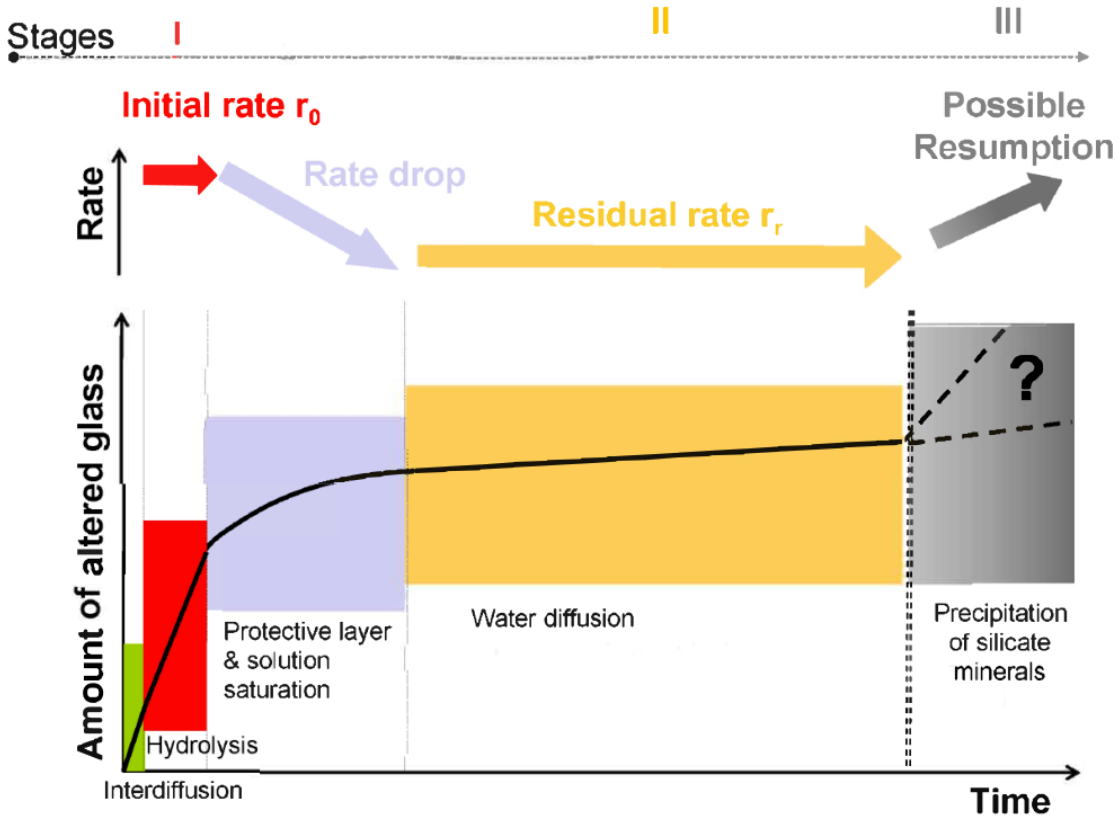


Figure 1. Glass corrosion stages and related rate-limiting mechanisms (modified after Gin *et al.* 2013)

During Stage I, glass corrosion is characterized by diffusion of water into the glass structure, ion exchange, and hydrolysis of the silicate network. Ion exchange, also called interdiffusion, occurs between protonated species in solution (H^+ or H_3O^+) and weakly bound, "glass network-modifier" alkali metal and alkaline earth elements[5] in the glass, which are released into solution as ions (*e.g.*, Na^+ and Ca^{2+}). Hydrolysis (or dissolution) of the glass network-forming elements

[5] In borosilicate glasses, silicon atoms, together with other "glass network-forming" elements (*e.g.*, aluminum, boron, and zirconium) that readily form bridging bonds with oxygen atoms, provide the highly cross-linked glass network. Alkali and alkaline earth elements alter the network structure ("glass network-modifiers"); they are usually present as ions (*e.g.*, Li^+, Na^+, K^+, and Ca^{2+}) and are charge compensated by nearby non-bridging oxygen atoms.

also occurs, which breaks the covalent bonds (Si–O–M, where M = silicon, aluminum, boron, zirconium, *etc*.) that form the glass network and releases into solution the elements constituting the glass (*e.g.*, silicon as H_4SiO_4) as well as radionuclides bound in the glass.

The initial corrosion rate reveals the "forward rate" of the reaction and is relatively high, but the corrosion rate drops as the reaction proceeds. Early studies on glass corrosion attributed this rate drop to an increase in dissolved silica concentration, which decreases the affinity (or driving force) for hydrolysis of the Si–O bonds. Later experiments using various techniques indicated the importance of transport limitation through an alteration layer. In the early 2000s, the European project GLAMOR[6] (Van Iseghem *et al*. 2006, 2007) concluded that two mechanisms must be taken into account to explain the rate drop: the onset of high silica concentration in solution slows down the dissolution of the silicate network (affinity effect) and the formation of a protective alteration layer limits the transport of aqueous species (passivation effect).

The corrosion rate drop does not last indefinitely—the rate tends to stabilize at a relatively constant value, called the residual rate, in Stage II. The residual rate is typically orders of magnitude lower than the Stage I initial rate. Stage II of glass corrosion generally begins once the solution becomes saturated with respect to amorphous silica (Gin *et al.* 2012). During that stage in a closed system, the dissolved silicon concentration reaches a steady state, but the aqueous concentrations of the more soluble glass components (*e.g.*, sodium, calcium, and boron) continue to increase, albeit at a low rate (Ferrand *et al*. 2006; Gin *et al.* 2015a, 2015b). Ion exchange and hydrolysis reactions still occur, but at a much reduced rate controlled by the reactive transport of water species through the alteration layer. This layer acts to diminish the accessibility of water to the unaltered glass. Stage II is considered the most important glass corrosion stage in most geologic disposal performance assessments because the residual rate is thought to be the rate that likely will determine the performance of HLW glasses in a repository at times before the HLW radioactivity decays to negligible levels. If the residual rate is maintained, the glass matrix could have lifetimes of at least several hundreds of millennia (ANDRA 2005).

Under certain conditions (*e.g.*, T > 90 °C and/or pH > 10.5), a sudden increase in glass corrosion rate (Stage III) can occur. The increased rate typically is associated with the precipitation of secondary silicate phases, such as phyllosilicates (*e.g.*, smectite clays), zeolites, phosphates, and calcium-silicate-hydrates. Precipitation of these phases removes dissolved silicon and other glass network-forming elements from the solution, which could increase the driving force for dissolution. Elements may also be removed from the passivating layer, which could result in a loss of its armoring properties.

[6] GLAMOR = A Critical Evaluation of the Dissolution Mechanisms of High-level Nuclear Waste Glasses in Conditions of Relevance for Geological Disposal (Van Iseghem *et al*. 2006).

References

ANDRA (Agence nationale pour la gestion des déchets radioactifs). 2005. *Dossier 2005 Argile: Synthesis—Evaluation of the feasibility of a geological repository in an argillaceous formation*. Paris, France: ANDRA.

Ferrand, K., A. Abdelouas, and B. Grambow. 2006. "Water Diffusion in the Simulated French Nuclear Waste Glass SON68 Contacting Silica Rich Solutions: Experimental and Modeling." *Journal of Nuclear Materials*, Vol. 355, pp. 54–67.

Gin, S., A. Abdelouas, L.J. Criscenti, W.L. Ebert, K. Ferrand, T. Geisler, M.T. Harrison, Y. Inagaki, S. Mitsui, K.T. Mueller, J.C. Marra, C.G. Pantano, E.M. Pierce, J.V. Ryan, J.M. Schofield, C.I. Steefel, and J.D. Vienna. 2013. "An International Initiative on Long-Term Behavior of High-Level Nuclear Waste Glass. *Materials Today*, Vol. 16, pp. 243–248.

Gin, S., X. Beaudoux, F. Angéli, C. Jégou, and N. Godon. 2012. "Effect of Composition on the Short-Term and Long-Term Dissolution Rates of Ten Borosilicate Glasses of Increasing Complexity From 3 to 30 Oxides." *Journal of Non-Crystalline Solids*, Vol. 358, pp. 2559–2570.

Gin, S., P. Jollivet, M. Fournier, F. Angeli, P. Frugier, and T. Charpentier. 2015a. "Origin and Consequences of Silicate Glass Passivation by Surface Layers." *Nature Communications*. Vol. 6, pp. 1–8.

Gin, S., P. Jollivet, M. Fournier, C. Berthon, Z. Wang, A. Mitroshkov, Z. Zhu, and J.V. Ryan. 2015b. "The Fate of Silicon During Glass Corrosion Under Alkaline Conditions: A Mechanistic and Kinetic Study with the International Simple Glass." *Geochimica et Cosmochimica Acta*, Vol. 151, pp. 68–85.

Van Iseghem, P., M. Aertsens, S. Gin, D. Deneele, B. Grambow, P. McGrail, D. Strachan, and G. Wicks. 2007. *A Critical Evaluation of the Dissolution Mechanisms of High-level Waste Glasses in Conditions of Relevance for Geological Disposal (GLAMOR).* Contract No. FIKW-CT-2001-00140 Final report. European Commission.

Van Iseghem, P., K. Lemmens, M. Aertsens, and T. McMenamin. 2006. "Chemical Durability of High-level Waste Glass in Repository Environment: Main Conclusions and Remaining Uncertainties from the GLASTAB and GLAMOR Projects." *Materials Research Society Symposium Proceedings*, Vol. 932, pp. 293–304.

Attachment

AGENDA

Summer Board Meeting

Wednesday, June 21, 2017

Courtyard Richland Columbia Point
480 Columbia Point Drive
Richland, WA 99352
509-942-9400

8:00 a.m. **Call to Order and Introductory Statement**
Jean Bahr, Board Chair

8:15 a.m. **Welcoming Remarks**
Jud Virden, Associate Laboratory Director, Pacific Northwest National Laboratory

8:20 a.m. **Modeling of Glass Performance in Repository Environments—An International Perspective**[7]
Bernd Grambow, SUBATECH, France

i. What are the various approaches to modeling glass corrosion in repository environments and how do different countries take account of glass corrosion and radionuclide release in repository performance assessments?
ii. What are the remaining technical gaps or uncertainties in understanding and modeling of long-term glass performance in repository environments and how important is glass performance to the overall safety case for different repository designs?

8:55 a.m. *Questions, discussion*

9:15 a.m. **Break**

9:30 a.m. **DOE Strategy for Glass Waste Form Acceptance for Geologic Disposal**
Carol Jantzen, Savannah River National Laboratory

i. What are the technical bases, including standards, test methods, and use of databases and models, for DOE's criteria for qualifying borosilicate glass waste forms as acceptable for disposal in a geologic repository?
ii. What is DOE's technical basis for applying the results of short-term tests on reference glasses or glasses with simplified compositions to assessments of the long-term performance of more chemically complex HLW glasses in repository environments?

[7] Note: Questions were provided to the speakers in advance to convey the Board's primary interests in the agenda topics and to aid in focusing their presentations.

iii. What is known about the influence of glass chemistry on crystallite precipitation during glass production and on glass corrosion, and how are crystallites taken into account in DOE's approach to designing glass for disposal in a repository?
iv. Are data on natural and archeological glasses used to support DOE assessments of the long-term performance of HLW glass in a repository and, if so, how?

10:05 a.m. *Questions, discussion*

10:25 a.m. **Current Understanding and Remaining Challenges in Measuring and Modeling Long-term Performance of Borosilicate Nuclear Waste Glasses**
Stéphane Gin, French Atomic Energy and Alternative Energies Commission

i. What is the current understanding of the processes responsible for glass corrosion and release of radionuclides into the environment? What experimental data support this understanding? What are the key parameters affecting the rate of each of the processes and how have these been used in models?
ii. What are the remaining technical challenges to measuring glass corrosion and modeling the long-term performance of borosilicate nuclear waste glasses?

11:00 a.m. *Questions, discussion*

11:20 a.m. **Public Comments**

11:35 a.m. **Lunch Break (1 hour 10 minutes)**

12:45 p.m. **Glass Formulation and Durability Studies at the Vitreous State Laboratory**
Ian Pegg, Catholic University of America

i. Describe the results of studies the Vitreous State Laboratory has conducted for the U.S. program and for other countries and how these are shared and used to understand glass corrosion mechanisms and long-term performance in repository environments.

1:15 p.m. *Questions, discussion*

1:35 p.m. **DOE Studies to Improve Understanding of Rate-Limiting Mechanisms under Varying Conditions**
Joseph Ryan, Pacific Northwest National Laboratory

i. From DOE's perspective, what are the most important remaining technical uncertainties or gaps in data and understanding of the long-term performance of HLW glass? How is DOE addressing those uncertainties or gaps?
ii. What are the status and results of DOE R&D activities to understand and model the long-term performance of borosilicate HLW glass?
iii. Describe the results of recent DOE studies, if any, on natural and archeological analogs of nuclear waste glass. How are the results used to support assessments of the long-term performance of HLW glass?

iv. How is DOE integrating the results of international R&D activities and activities completed at different national laboratories in the U.S. on nuclear waste glass corrosion into its assessments of HLW glass long-term performance?

2:10 p.m. *Questions, discussion*

2:30 p.m. **Break**

2:45 p.m. **DOE High-Level Waste Glass Corrosion Model and Its Implementation in Safety Analysis**
William Ebert, Argonne National Laboratory

i. What are the recent improvements in DOE models for HLW glass corrosion? How are these improvements helpful to the DOE HLW geologic disposal program?
ii. How do the models take account of the important glass corrosion mechanisms and the range of environmental conditions expected for different repository host-rock types and near-field environments? How are environmental conditions such as dissolved organic matter and the presence of microbial life being investigated?
iii. How do the models take account of the wide range in DOE HLW glass compositions to be produced at the Waste Treatment and Immobilization Plant and the Defense Waste Processing Facility?
iv. How are the models and model parameters supported by experimental data, including the large database of glass dissolution experiments managed by DOE personnel?
v. What is DOE's technical basis for using the results of short-term, small-scale tests on glass corrosion to support assessments of long-term glass performance in a repository?
vi. How are the process-level models of glass corrosion and radionuclide release integrated into repository performance assessments? How important is glass performance to the overall safety case for different repository designs?

3:20 p.m. *Questions, discussion*

3:40 p.m. **Studies on Natural and Archeological Glasses—Opportunities to Learn About Long-term High-Level Waste Glass Corrosion**
Aurélie Verney-Carron, University Paris-Est Créteil

i. What have we learned from studies on natural and archeological glasses regarding the corrosion and long-term performance of nuclear waste glasses?
ii. Are the rate-limiting mechanisms the same for natural and for nuclear waste glasses? Have researchers found evidence that natural glasses alter in stages such as those observed for nuclear waste glasses? Is there evidence that corrosion rates increase at late stages in natural systems? What corrosion rates have been estimated for natural glasses?
iii. What causes the large discrepancies between silicate mineral dissolution rates measured in the laboratory and those measured in the field? Is this discrepancy also noted for glassy natural analogs?

iv. Are the kinetic models used for predicting nuclear waste glass corrosion able to take account of glass corrosion on a geological timescale?

4:10 p.m. *Questions, discussion*

4:30 p.m. **Quick Look at Poster Papers**

5:05 p.m. **Public Comments**

5:20 p.m. **Adjourn Public Meeting**

5:30 p.m. **Poster Session: Research Related to Long-Term Performance of Nuclear Waste Glasses**