EPA-SAB-12-xxx

The Honorable Lisa P. Jackson
Administrator
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, N.W.
Washington, DC 20460

Subject: Advisory on EPA's Draft Technical Document entitled *Considerations Related to Post-Closure Monitoring of Uranium In-Situ Leach/In-Situ Recovery (ISL/ISR) Sites*

Dear Administrator Jackson:

The EPA is considering the need to update the environmental protection standards for uranium mining. The current regulations, promulgated in response to the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA), do not address the relatively recent process of *in-situ* leaching (ISL) of uranium from underground ore bodies. In the ISL process, an extraction fluid is pumped underground through a set of injection wells to solubilize uranium, is retrieved at a central extraction well, and is then processed to remove the uranium and recycle the fluid back into the ground for further uranium extraction. Because the ISL process affects groundwater quality, the EPA's Office of Radiation and Indoor Air (ORIA) requested advice from the Science Advisory Board on issues related to design and implementation of groundwater monitoring at ISL mining sites.

The ORIA prepared a draft technical report, *Considerations Related to Post-Closure Monitoring of Uranium In-Situ Leach/In-Situ Recovery (ISL/ISR) Sites* (dated June 2011), that describes a proposed general approach to monitoring at ISL sites and provides case studies and key issues associated with post-closure monitoring. In the charge to the SAB, the agency requested comments on the technical aspects of designing and implementing the groundwater monitoring networks at ISL uranium mines, including wells within the production area to compare post- and pre-operational groundwater quality, and wells outside the mine production area to detect the presence or absence of excursions of the leachate solution from the production zone.

In the attached report, the SAB comments on issues concerning monitoring to characterize baseline groundwater quality prior to the start of mining operations, monitoring to detect any leachate excursions during mining, and monitoring to determine when groundwater quality has stabilized after mining operations have been completed. The SAB also reviews the advantages and disadvantages of alternative statistical techniques to compare groundwater quality before and after uranium mining activities. The objectives of such comparisons are to demonstrate that post-operating groundwater quality is stabilized at levels near pre-mining conditions and that mine operations have not adversely impacted groundwater supplies.

The EPA draft technical report presents an excellent preliminary framework of considerations applicable to groundwater monitoring at ISL uranium mines. It emphasizes the relevance of *Groundwater Monitoring Requirements for Treatment, Storage, and Disposal Facilities (TSDF's)* in 40 CFR Part 264, Subpart F, in response to the Resource Conservation and Recovery Act (RCRA). The report also gives examples of ISL groundwater monitoring data and of statistical techniques for comparing post- and pre-operational monitoring data. The SAB advises the EPA to expand greatly this technical report so that it reaches its potential to serve as a useful guide for developing and applying EPA standards for ISL uranium mining. Although all pertinent topics are touched upon in the draft report, only a few topics contain sufficient detail to guide setting and implementing these standards.

In response to the charge, the SAB recommends that the draft technical report be expanded so that it is at the same time protective and realistic in guiding the monitoring program and evaluating its results. To be a guide for decisions that are based on knowledge of both the general behavior of groundwater constituents and the conditions at the mine under consideration, the technical report should include detailed discussion of the following critical activities:

- Survey the extensive monitoring data available for ISL uranium mines to identify data sets suitable for building an evidence base that could inform EPA's regulatory decisions.
- Compile and systematically analyze these data sets to support modeling of the interactions between pertinent groundwater constituents and associated geologic media.
- Apply environmental models to provide realistic predictions of the rates at which groundwater constitutents approach stable conditions following the cessation of mining operations, for a range of realistic bounding conditions.
- Describe systematic approaches for determining the optimal number, location, and sampling frequency of monitoring wells.
- Specify criteria for selecting groundwater analytes of primary and secondary importance for monitoring by emphasizing the linkages between analytes and monitoring objectives.

The SAB advises the EPA to organize the technical report by applying the EPA's Data Quality Objectives process. Further, it advises the EPA to optimize the quality and timeliness of the technical report by inviting cooperation by the other regulators and participation by the scientific community in addressing the activities identified in the enclosed report.

The SAB appreciates the opportunity to provide advice on the draft technical report and engage in thoughtful dialogue on this topic, and looks forward to your response.

Sincerely,

Dr. Deborah L. Swackhamer	Dr. Bernd Kahn
Chair	Chair, Augmented Radiation Advisory Committee
Science Advisory Board	Science Advisory Board

Enclosure

NOTICE

U.S. Environmental Protection Agency
Science Advisory Board
Radiation Advisory Committee (RAC)
Augmented for Uranium In-Situ ISL/ISR Advisory

CHAIR

Dr. Bernd Kahn, Professor Emeritus, Nuclear and Radiological Engineering Program, and Associate Director, Environmental Radiation Center, GTRI, Georgia Institute of Technology, Atlanta, GA

MEMBERS

Dr. Susan M. Bailey, Associate Professor, Colorado State University, Department of Environmental and Radiological Health Sciences, Fort Collins, CO

Dr. Thomas B. Borak, Professor, Department of Environmental and Radiological Health Sciences, Colorado State University, Fort Collins, CO

Dr. Shih-Yew Chen, Senior Environmental Systems Engineer, Environmental Science Division, Argonne National Laboratory, Argonne, IL

Dr. Faith G. Davis, Senior Associate Dean and Director of Graduate Studies, Professor of Epidemiology, Division of Epidemiology and Biostatistics, School of Public Health, University of Illinois at Chicago, IL

Dr. R. William Field, Professor, Department of Occupational and Environmental Health, College of Public Health, University of Iowa, Iowa City, IA

Dr. Jonathan M. Links, Professor and Deputy Chair, Department of Environmental Health Sciences, Bloomberg School of Public Health, Johns Hopkins University, Baltimore, MD

Dr. William F. Morgan, Director of Radiation Biology and Biophysics, Biological Sciences Division, Fundamental & Computational Sciences Directorate, Pacific Northwest National Laboratory, Richland, WA

Mr. Bruce A. Napier, Staff Scientist, Radiological Science & Engineering Group, Pacific Northwest National Laboratory, Richland, WA

Dr. Dale L. Preston, Principal Scientist, Hirosoft International, Eureka, CA

Dr. Daniel O. Stram, Professor, Department of Preventive Medicine, Division of Biostatistics and Genetic Epidemiology, Keck School of Medicine, University of Southern California, Los Angeles, CA

INVITED EXPERTS

Dr. Thomas Borch, Associate Professor, Environmental Chemistry & Biochemistry, Department of Soil & Crop Sciences, Joint Position in Department of Chemistry, Colorado State University, Fort Collins, CO

Dr. Douglas B. Chambers, Vice President and Director of Risk & Radioactivity, Senes Consultants, Ltd., Ontario, Canada

Dr. June T. Fabryka Martin, Earth Observations Systems Group, Los Alamos National Laboratory, Los Alamos, NM

Dr. Thomas E. Johnson, Assistant Professor, Department of Environmental and Radiological Health Sciences, Colorado State University, Fort Collins, CO

Dr. Brian A. Powell, Assistant Professor, Department of Environmental Engineering & Earth Sciences, L. G. Rich Environmental Laboratory, Clemson University, Anderson, SC

SCIENCE ADVISORY BOARD STAFF

Dr. K. Jack Kooyoomjian, Designated Federal Officer, Radiation Advisory Committee (RAC) Augmented for Uranium In-Situ ISL/ISL Advisory, US EPA, Science Advisory Board (1400R), 1200 Pennsylvania Avenue, NW, Washington, DC 20460

U.S. Environmental Protection Agency
Science Advisory Board

CHAIR

Dr. Deborah L. Swackhamer, Professor and Charles M. Denny, Jr., Chair in Science, Technology and Public Policy, Hubert H. Humphrey School of Public Affairs and Co-Director of the Water Resources Center, University of Minnesota, St. Paul, MN

SAB MEMBERS

Dr. George Alexeeff, Acting Director, Office of Environmental Health Hazard Assessment, California Environmental Protection Agency, Oakland, CA

Dr. David T. Allen, Professor, Department of Chemical Engineering, University of Texas, Austin, TX

Dr. Pedro Alvarez, Department Chair and George R. Brown Professor of Engineering, Department of Civil & Environmental Engineering, Rice University, Houston, TX

Dr. Joseph Arvai, Svare Chair in Applied Decision Research, Institute for Sustainable Energy, Environment, & Economy, Haskayne School of Business, University of Calgary, Calgary, Alberta, Canada

Dr. Claudia Benitez-Nelson, Full Professor and Director of the Marine Science Program, Department of Earth and Ocean Sciences, University of South Carolina, Columbia, SC

Dr. Timothy J. Buckley, Professor and Chair, Division of Environmental Health Sciences, College of Public Health, The Ohio State University, Columbus, OH

Dr. Patricia Buffler, Professor of Epidemiology and Dean Emerita, Department of Epidemiology, School of Public Health, University of California, Berkeley, CA

Dr. Ingrid Burke, Director, Haub School and Ruckelshaus Institute of Environment and Natural Resources, University of Wyoming, Laramie, WY

Dr. Thomas Burke, Professor, Department of Health Policy and Management, Johns Hopkins Bloomberg School of Public Health, Johns Hopkins University, Baltimore, MD

Dr. Terry Daniel, Professor of Psychology and Natural Resources, Department of Psychology, School of Natural Resources, University of Arizona, Tucson, AZ

Dr. George Daston, Victor Mills Society Research Fellow, Product Safety and Regulatory Affairs, Procter & Gamble, Cincinnati, OH

Dr. Costel Denson, Managing Member, Costech Technologies, LLC, Newark, DE

Dr. Otto C. Doering III, Professor, Department of Agricultural Economics, Purdue University, W. Lafayette, IN

Dr. Michael Dourson, President, Toxicology Excellence for Risk Assessment, Cincinnati, OH

Dr. David A. Dzombak, Walter J. Blenko, Sr. Professor of Environmental Engineering , Department of Civil and Environmental Engineering, College of Engineering, Carnegie Mellon University, Pittsburgh, PA

Dr. T. Taylor Eighmy, Vice President for Research, Office of the Vice President for Research, Texas Tech University, Lubbock, TX

Dr. Elaine Faustman, Professor and Director, Institute for Risk Analysis and Risk Communication, School of Public Health, University of Washington, Seattle, WA

Dr. John P. Giesy, Professor and Canada Research Chair, Veterinary Biomedical Sciences and Toxicology Centre, University of Saskatchewan, Saskatoon, Saskatchewan, Canada

Dr. Jeffrey K. Griffiths, Professor, Department of Public Health and Community Medicine, School of Medicine, Tufts University, Boston, MA

Dr. James K. Hammitt, Professor, Center for Risk Analysis, Harvard University, Boston, MA

Dr. Barbara L. Harper, Risk Assessor and Environmental-Public Health Toxicologist, and Division Leader, Hanford Projects, and Program Manager, Environmental Health, Department of Science and Engineering, Confederated Tribes of the Umatilla Indian Reservation (CTUIR), West Richland, WA

Dr. Kimberly L. Jones, Professor and Chair, Department of Civil Engineering, Howard University, Washington, DC

Dr. Bernd Kahn, Professor Emeritus and Associate Director, Environmental Radiation Center, Georgia Institute of Technology, Atlanta, GA

Dr. Agnes Kane, Professor and Chair, Department of Pathology and Laboratory Medicine, Brown University, Providence, RI

Dr. Madhu Khanna, Professor, Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign, Urbana, IL

Dr. Nancy K. Kim, Senior Executive, Health Research, Inc., Troy, NY

Dr. Cecil Lue-Hing, President, Cecil Lue-Hing & Assoc. Inc., Burr Ridge, IL

Dr. Floyd Malveaux, Executive Director, Merck Childhood Asthma Network, Inc., Washington, DC

Dr. Judith L. Meyer, Professor Emeritus, Odum School of Ecology, University of Georgia, Lopez Island, WA

Dr. James R. Mihelcic, Professor, Civil and Environmental Engineering, University of South Florida, Tampa, FL

Dr. Christine Moe, Eugene J. Gangarosa Professor, Hubert Department of Global Health, Rollins School of Public Health, Emory University, Atlanta, GA

Dr. Horace Moo-Young, Dean and Professor, College of Engineering, Computer Science, and Technology, California State University, Los Angeles, CA

Dr. Eileen Murphy, Director of Research and Grants , Ernest Mario School of Pharmacy, Rutgers University, Piscataway, NJ

Dr. James Opaluch, Professor and Chair, Department of Environmental and Natural Resource Economics, College of the Environment and Life Sciences, University of Rhode Island, Kingston, RI

Dr. Duncan Patten, Research Professor, Hydroecology Research Program , Department of Land Resources and Environmental Sciences, Montana State University, Bozeman, MT

Dr. Stephen Polasky, Fesler-Lampert Professor of Ecological/Environmental Economics, Department of Applied Economics, University of Minnesota, St. Paul, MN

Dr. C. Arden Pope, III, Professor, Department of Economics, Brigham Young University , Provo, UT

Dr. Stephen M. Roberts, Professor, Department of Physiological Sciences, Director, Center for Environmental and Human Toxicology, University of Florida, Gainesville, FL

Dr. Amanda Rodewald, Professor of Wildlife Ecology, School of Environment and Natural Resources, The Ohio State University, Columbus, OH

Dr. Jonathan M. Samet, Professor and Flora L. Thornton Chair, Department of Preventive Medicine, Keck School of Medicine, University of Southern California, Los Angeles, CA

Dr. James Sanders, Director and Professor, Skidaway Institute of Oceanography, Savannah, GA

Dr. Jerald Schnoor, Allen S. Henry Chair Professor, Department of Civil and Environmental Engineering, Co-Director, Center for Global and Regional Environmental Research, University of Iowa, Iowa City, IA

Dr. Gina Solomon, Senior Scientist, Health and Environment Program, Natural Resources Defense Council, San Francisco, CA

Dr. Daniel O. Stram, Professor, Department of Preventive Medicine, Division of Biostatistics, University of Southern California, Los Angeles, CA

Dr. Peter Thorne, Professor and Head, Occupational and Environmental Health, College of Public Health, University of Iowa, Iowa City, IA

Dr. Paige Tolbert, Professor and Chair, Department of Environmental Health, Rollins School of Public Health, Emory University, Atlanta, GA

Dr. John Vena, Professor and Department Head, Department of Epidemiology and Biostatistics, College of Public Health, University of Georgia, Athens, GA

Dr. Robert Watts, Professor of Mechanical Engineering Emeritus, Tulane University, Annapolis, MD

Dr. R. Thomas Zoeller, Professor, Department of Biology, University of Massachusetts, Amherst, MA

SCIENCE ADVISORY BOARD STAFF

Dr. Angela Nugent, Designated Federal Officer, U.S. Environmental Protection Agency, Science Advisory Board (1400R), 1200 Pennsylvania Avenue, NW, Washington, DC, Phone: 202-564-2218, Fax: 202-565-2098, (nugent.angela@epa.gov)

TABLE OF CONTENTS

ACRONYMS, SYMBOLS AND ABBREVIATIONS

ACLs	Alternate Concentration Limits
$Ca_2UO_2\text{-}(CO_3)_3$	Calcium Uranyl Carbonate Ternary Complex
CFR	U.S. Code of Federal Regulations
COC	Contaminant of Concern
CREM	Council for Regulatory Environmental Modeling
CrunchFlow	Software package for multicomponent reactive flow and transport
Δ	Delta (differences) for a given criterion or allowed value; or a null value
δ	Del; measured difference
DQO	Data Quality Objective
Eh	Oxidation/reduction potential compared to that of hydrogen
EPA	Environmental Protection Agency (U.S. EPA)
HA	Health Advisories
ISL	In-Situ Leach
ISR	In-Situ Recovery
MCL	Maximum Concentration Level
MCLG	Maximum Concentration Level Goals
MKB	Models Knowledge Base
NACEPT	National Council for Environmental Policy and Technology
NAS	National Academy of Sciences
ND	North Dakota
NM	New Mexico
NRC	Nuclear Regulatory Commission (U.S. NRC)
ORIA	Office of Radiation and Indoor Air (U.S. EPA/ORIA)
ORNL	Oak Ridge National Laboratory
ORP	Oxygen/reduction potential
p	Probability values (p1, p2, ….p_n)
pH	Negative Log Concentration of Hydrogen Ions
PHREEQC	U.S. Geological Survey computer code for speciation, batch-reaction, one-dimensional transport and inverse geochemical calculations
PPAs	Production Authorization Areas
RCRA	Resource Conservation and Recovery Act
RSL	Regional Screening Levels
SAB	Science Advisory Board (U.S. EPA/SAB)
SMCL	Secondary Maximum Concentration Level
TAC	Texas Administrative Code
TSDF	Treatment, Storage and Disposal Facilities
TX	Texas
UMTRCA	Uranium Mill Tailings Radiation Control Act of 1978

1. EXECUTIVE SUMMARY

The EPA is currently reviewing its regulations that establish environmental protection standards for uranium and thorium mill tailings (40 CFR Part 192) to determine if revisions are necessary in light of current mining practices. The standards are promulgated by EPA under the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA). The Nuclear Regulatory Commission (NRC), or the NRC Agreement State in which the mine is located, issues and oversees the mine operating licenses. The original UMTRCA regulations, written in 1983 and revised in 1995, focused on surface and underground mining of uranium, which at that time were the prevalent types of uranium extraction. Currently, *in situ* leaching (ISL) is a common method of uranium extraction. ISL operations involve injection of uranium extraction fluids into subsurface ore bodies. Hence, the EPA is considering establishing standards applicable to groundwater monitoring systems at and around ISL facilities.

The EPA's Office of Radiation and Indoor Air (ORIA) has prepared a draft technical report, *Considerations Related to Post-Closure Monitoring of Uranium In-Situ Leach/In-Situ Recovery (ISL/ISR) Sites,* dated June 2011. The draft technical report provides background information concerning the objectives, design, and implementation of groundwater monitoring systems for ISL/ISR operations. Monitoring wells positioned outside the production area are used to detect excursions of leach solution from the production area during the operational phase. Monitoring wells within the production area are used pre-operationally to establish baseline conditions and post-operationally to determine when physical and chemical conditions in groundwater have been restored and stabilized. Part 1 of the EPA draft technical report presents the overall approach, including the regulatory context for EPA's standards under UMTRCA; Part 2 provides details on specific issues associated with the approach, including monitoring at existing ISL facilities, establishing post-operation steady state, performing statistical analyses to compare pre- and post-operation conditions, and describing encountered post-closure performance issues.

The EPA requested that the Science Advisory Board (SAB) provide feedback on the draft technical report and respond to four charge questions. The first charge question requests comments on the technical aspects of designing and implementing the groundwater monitoring networks described in the report, and identification of any omitted or mis-characterized technical considerations. The remaining questions relate to characterization of baseline groundwater quality in pre-operational monitoring and the monitoring duration needed; approaches for monitoring the post-operation and restoration phases and determining when groundwater quality has stabilized adequately based on post-operational monitoring data; and statistical techniques and data requirements to compare post- to pre-operational monitoring for determining whether groundwater quality has met the applicable regulatory standards.

The SAB finds the draft technical report to be an excellent framework of considerations applicable to groundwater monitoring at ISL uranium mines. Every aspect of monitoring and associated activities appears to be mentioned (e.g., planning, well locations, sampling frequency, analytes, and modeling). Missing is sufficient detail on most important topics; only application of statistics and Resource Conservation and Recovery Act (RCRA) regulations to groundwater monitoring are discussed in such detail.

The SAB recommends that the EPA greatly expand its discussion of specified topics in the technical report to provide a more substantive foundation for developing and evaluating EPA standards related to

ISL uranium mining. The technical report should be a guide for effectively and realistically protecting the environment and human health by combining general information on the behavior of groundwater constituents with specific information on their concentrations and concentration changes at the mine.

Two critical interrelated aspects of the draft technical report that would benefit from enhancement concern the availability of environmental data and application of models. To build an evidence base adequate for informing EPA's regulatory decisions, the agency is encouraged to survey the extensive data collected at ISL uranium mining sites by monitoring, regulatory, and research groups, and to compile systematically those data that are of suitable scope and quality to support modeling interactions between pertinent groundwater constituents and associated geologic media. A closely-related topic is the application of environmental models to predict the groundwater's approach to stable conditions following the end of mining operations. Examples of applying such models for a range of realistic bounding conditions would be a useful addition to the technical document. Another modeling topic that could be enhanced is the application of statistical models to support decisions concerning the optimal number, location, and sampling frequency of monitoring wells.

A fifth topic is identifying criteria for selecting analytes of primary and secondary importance for monitoring and listing their required detection limits and data precision. The examples of groundwater monitoring data sets presented in attachments to the draft technical report will be far more instructive when accompanied by agency comments concerning their virtues, shortcomings, and applicability beyond the specific mine to the broad category of monitoring ISL uranium mines. In an integrated program of monitoring and modeling with built-in feedback, monitoring results are used to validate the model, while model output is used to assure appropriate monitoring system design.

The EPA is encouraged to address its technical objectives systematically by applying the EPA's Data Quality Objectives approach, and to address them efficiently by including participants from other regulatory agencies and the research community. In the near term, the EPA can develop a set of guiding principles and assumptions to specify its concept of an appropriate groundwater monitoring system, within the limitations of the information currently available to the agency. Over the long term, e.g., a 3- to 5-year period, a reasonable target would be to have in place a systematic data base and validated models with defined precision and limitations that can be used as a basis for ISL uranium mine standards and decisions concerning post-mining stability of groundwater quality.

In support of this general advice, the SAB offers the following specific recommendations to the EPA, identifying the Sections in which the recommendations are made and noting the overlap and interconnection among the charge questions and the responses to them.

Designing and Implementing a Monitoring Network (Charge Question 1):

- Develop a long-term (3-5 year) program of data analysis and model development for evidence-based standards setting (Section 3.2);
- In the near-term, articulate a set of guiding principles and assumptions for standards setting (3.3);
- Identify indicators, both chemical and radioactive, for establishing conditions pre- and post-operationally (3.4, 4.3);
- Distinguish between primary and secondary indicators on basis of risk, return to pre-operating conditions, and information concerning other constituents (3.4);

- Discuss in detail the many factors that affect interactions and transformations during and after operation (3.5);
- Obtain and analyze geological and mineralogical data to support decisions based on groundwater monitoring (3.5, 5.5);
- Before adequate modeling has been developed, specify a sufficiently dense spatial and temporal monitoring system to assure collecting sufficient data for pre- and post- mining comparison (3.6);
- Consider applying available relevant groundwater models to ISL uranium mines (3.7, 7.5);
- Support research for providing both empirical values and model coefficients for understanding the approach to stability after ISL uranium mining (3.7);
- Develop individual modules if needed to reduce the complexity of groundwater models (3.7);
- Devote at least as much effort to defining baseline groundwater conditions as to post-operational trend monitoring (3.8, 5.6);
- Prepare a glossary of uniform definitions for use by pertinent regulatory agencies and mine operators (3.10).

Establishing Baseline Conditions (Charge Question 2):

- Define monitoring objectives of baseline characterization within the framework of the Data Quality Objective (DQO) approach (4.2, 7.3);
- Identify groundwater constituents and parameters pertinent for monitoring, not limited to those with regulatory limits but also including non-hazardous constituents that can affect the behavior of, or serve as surrogates for, constituents of interest (4.3);
- Consider challenging and fluctuating ambient circumstances in baseline characterization (4.5, 3.4);
- Build in flexibility to modify the design and implementation of monitoring programs as new information becomes available (4.6);
- Apply consistent sample collection techniques, record keeping, and data compilation (4.7).

Post-Mining and Restoration Monitoring (Charge Question 3):

- Carefully qualify the meaning of “return to pre-operational groundwater quality” (5.2, see also 3.10);
- Develop a set of guiding principles for crafting standards (5.2, 3.3);
- Combine the extensive existing data sets with knowledge of constituent interactions in the rock/water system to model post-mining approach to stability (5.3, 3.2);
- Match sampling frequency and duration to information needs for model confirmation (5.5);
- Collect sufficient pre-operational groundwater monitoring data to support reliable post-operational decision making (5.6, 3.8);
- Discuss implications of data presented in tables in the Attachments to the draft technical report (5.7);
- Apply a risk-weighting system in determining acceptability of groundwater quality at ISL uranium mines (5.7, 3.4).

Statistical Techniques (Charge Question 4):

- Present a survey of methods to determine sufficient well number and density (6.1, 3.6);
- Select statistical evaluation approach in terms of strengths and weaknesses to suit questions to be answered (6.2).

Additional Advice Beyond the Charge

The SAB also commented on several topics beyond the charge to support preparation of the enhanced technical report. These topics concerned:

- Monitoring media other than groundwater for potential contaminants (7.1);
- Considering plans for groundwater use that may be impacted by ISL uranium mining (7.2);
- Elaborating on recommendations for applying the DQO framework to establishing technical approaches to standard setting (7.3);
- Adding other considerations for integrating EPA requirements with existing EPA regulatory programs (7.4);
- Tapping available resources for the recommented modeling (7.5);
- Encouraging the working relation of EPA staff with NRC or state agency staff (7.6);
- The importance of this regulatory review and update (7.7).

2. INTRODUCTION

2.1. Background on ISL Mining

Uranium mining by *in-situ* leaching (ISL) was developed during the past 50 years (U.S. Bureau of Mines, 1981; Charbeneau 1984; U.S. EPA 2008) and the first commercial ISL mine was licensed in 1975. Currently, ISL mining is preferred to surface and underground mining for a suitably contiguous ore body located in a porous aquifer between effective aquitards. Although uranium mining in the United States has been quiescent during the past decade, potential mine operators have expressed renewed interest in uranium mining by ISL. A meeting participant provided a list of 32 former or currently active ISL mines and 16 ISL mines with license applications.

In the ISL mining process, a uranium-solubilizing extraction fluid (i.e., lixiviant) is delivered to the subsurface ore body through a set of injection wells and is withdrawn at a central recovery well. A mine consists of many such units. The recovered lixiviant is contacted at a surface facility with ion-exchange or solvent extraction media to extract the dissolved uranium, restored to its initial extraction strength, and returned through the injection wells for further uranium dissolution and extraction.

The mining process is terminated after a period of time (that may exceed 10 years) when the operator deems that production no longer is profitable. The lixiviant then is replaced by groundwater (possibly with suitable reagents) that initially is cycled through the injection and recovery wells ("pump and treat") to restore the site groundwater to its pre-operational quality.Water from early restoration cycles that contains residual lixiviant is withdrawn for evaporation in ponds or pumping to disposal wells.

According to a simplified concept, the uranium-solubilizing reagents in the lixiviant function by oxidizing uranium(IV) to uranium(VI) and forming soluble complexes with the resulting uranium ion; reagents such as oxygen plus carbon dioxide gases or soluble bicarbonate salts are used to minimize the impact of added ions on the aquifer. Restoring groundwater quality after mining by flushing the aquifer with water is considered to be natural attenuation. If additional restoration efforts are needed, reagents may be added to reduce uranium to its original insoluble uranium(IV) form, and to make insoluble any other ions, such as arsenic and molybdenum, that were dissolved or released by the lixiviant. In practice, the ongoing processes in the ground during mining and restoration are considerably more complex, as must be the efforts to return the system to its original form.

2.2. The Regulatory Framework

Regulation of radiological and non-radiological hazards associated with uranium and thorium ore processing involves multiple federal agencies. Under the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA), the EPA establishes health and environmental protection standards in 40 CFR Part 192. The NRC in 10 CFR Part 40—or an agency in its Agreement State—controls mine operation under UMTRCA at active (Title II) sites by license conditions and guidance (U.S. NRC 2003). The U.S. Department of Energy (DOE) is responsible for control of inactive (Title I) mining and milling sites.

To operate, a mine must receive from the EPA an Underground Injection Control aquifer exemption to exempt the site from the requirements for protection of groundwater as an underground source of drinking water. The mine operator must monitor groundwater before operation to establish the groundwater quality baseline within and around the site, and during and after operation to detect pollutant excursion beyond the site. Post-operation groundwater quality then must be monitored on site until steady state in water quality is observed. This finding signals that no further monitoring is needed to detect constituent instability within the mining area. The EPA, in support of revising Part 192, intends to establish standards for determining the duration of monitoring for those substances of which steady-state attainment and/or return to pre-operational quality is required.

2.3. The Charge to the SAB

The EPA requested technical advice in the form of an Advisory Review from the SAB to support revision of 40 CFR Part 192 regarding issues relevant to groundwater monitoring for both stable and radioactive substances at ISL uranium mining sites. The charge from the EPA (Appendix A) focuses on achieving reliable analyte results -- both radiological and non-radiological -- in groundwater monitoring before, during, and after ISL mining. In particular, the charge asks for advice on important aspects that contribute to confidence in data reliability: (1) monitoring network design; (2) effective baseline monitoring; (3) restoration-phase monitoring to define trends in groundwater constituents and ultimate arrival at stability; and (4) use of appropriate statistical techniques and data processing for reliable conclusions.

As background for the SAB, the agency developed a draft technical document, *Considerations related to post-closure monitoring of uranium in-situ leach/in-situ recovery (ISL/ISR) sites* (dated June 1, 2011), to describe the proposed overall approach and specific monitoring issues. The draft technical report addresses groundwater monitoring for both stable and radioactive substances. It is concerned principally with designing a monitoring program and comparing post- and pre-operational monitoring data. It specifies 5 successive phases of groundwater monitoring: baseline (pre-operational), mining (operational), restoration (immediate post-operational), steady state attainment (post-treatment) and long-term stability assurance (post-closure). For the crucial action of comparing post- and pre-operational data, the report discusses applicable statistical techniques for indicating that the two data sets are or are not identical. Some data sets submitted by mine operators to the licensing agency are attached as examples.

To respond to the EPA charge, the SAB's Radiation Advisory Committee augmented with additional experts held public meetings on July 12, July 18-19, September 6, and October 5, 2011 to receive technical briefings from the agency, hear public comments, and deliberate on the charge questions. Public commenters, notably Dr. Elise Striz, hydrogeologist for the NRC, identified useful sources of information from groundwater monitoring at ISL uranium mines. The augmented RAC's draft advisory report was provided to the chartered SAB in November for review and disposition in a December 21, 2011 public meeting.

The SAB's responses to the four charge questions follow in Sections 3 to 6. Section 7 contains additional comments by the SAB beyond the charge questions.

3. DESIGNING AND IMPLEMENTING A MONITORING NETWORK

Charge Question 1: Comment on the technical areas described in the report and their relative importance for designing and implementing a monitoring network. Identify any technical considerations that have been omitted or mis-characterized.

3.1. Introduction

For purposes of this report, the SAB treats the concept of a "monitoring network" as:

- a spatially-distributed network of monitoring wells;
- a time-dependent series of measurements via those wells;
- a set of constituent indicators that are quantified;
- additional geophysical and geochemical measures made or assumed; and
- underlying conceptual and/or kinetic models that:
  - provide the technical basis for network design and implementation, and
  - make use of the data collected from wells in the network.

The SAB makes two general recommendations – one long-term, and one for the near term – and the specific recommendations detailed below.

3.2. Evidence-Based Decision-Making

The SAB recommends that the scientific/technical approach to designing and implementing a monitoring network for ISL uranium mining sites be evidence-based, or at least evidence-informed. The discussion with EPA staff, NRC staff, and members of the public associated with ISL uranium mining operations during the face-to-face meeting suggested that considerable monitoring data pertinent to designing and implementing groundwater monitoring networks are available but that only a limited fraction of this information was incorporated into the draft technical report. Empirical site-specific approaches form the basis of discussions in the draft technical report and were emphasized during the presentations. Data would need to be collected, organized, and analyzed in a comprehensive and standardized way (e.g., via standardized reporting protocols) in order to build the evidence base to inform the regulatory approach, as sketched in a flow chart in Figure 1.

Accordingly, the SAB recommends for the long term that EPA initiate and maintain a formal process to build this evidence base in, say, 3 to 5 years. Ideally, the data to be collected should include (1) the constituents used for baseline characterization, (2) constituent concentrations observed immediately upon completion of mining but prior to restoration, and (3) concentrations observed as restoration is approached. Data from monitoring wells, including information on excursions during operation and subsequent recovery, should be gathered to provide examples of the groundwater situation.

The extensive data reported to be available are not in one place or in one format. Mining companies have accumulated baseline data to support the mining license applications and to justify the proposed monitoring network design to the regulator. These data can be used for validation in hydro-geochemical modeling efforts to aid in determining system behavior during baseline, operational, and post-operational stages. Even for hydro-geochemical systems that differ widely, physical and chemical principles that apply universally will allow application of such modeling. Ready accessibility of the available information to the public will facilitate analysis and modeling by the scientific/technical community. As seen for other data sets (e.g., RadNet following the recent nuclear power plant accidents in Japan), the scientific community is eager to perform some of the work that the EPA would otherwise be expected to do. Hence, results will be available sooner because of the distributed, parallel effort.

3.3. Guiding Principles and Assumptions for Regulatory Monitoring

The SAB recommends for the near term, until the needed large evidence base is accumulated and systematized, that the EPA articulate a set of guiding principles and assumptions on which to base regulations. The proposed standards can be based on these assumptions during the next several years, and superceded if evidence of their unsuitability becomes available. For example, assumption of seasonality in groundwater quality will require seasonal measurements for at least one year, and preferably longer. If the reviewed data, for example, show that no seasonality is observed, or that the concept of seasonality should be replaced by groundwater quality response to monthly rainfall or major rain events, the sampling frequency specification would be changed.

3.4. Indicators of Interest

The SAB recommends that the EPA identify, in addition to pertinent groundwater constituents, sets of indicators to assist in establishing baseline conditions and post-closure monitoring conditions, with direct linkage between the baseline and post-closure indicators. Indicators can include: (1) specific radionuclides, by mass concentration or radioactivity, as appropriate; (2) gross radioactivity, by alpha-particle, beta-particle, and gamma-ray activity; (3) water quality (e.g., total dissolved solids); and (4) geophysical and geochemical variables. The latter can indicate groundwater status, serve as surrogates of status or prognostic indicators, or influence constituent values (e.g., pH, flow). Where appropriate, the physico-chemical form (e.g., speciation/oxidation state, solubility) of the constituents should be determined.

Because this list of indicators could be extensive, the SAB recommends that the EPA specify criteria by which to distinguish between primary and secondary indicators. Such categorization can be helpful in risk-weighting the indicators for use in regulatory decision-making (see Section 5.7). Not all indicators will behave the same way post-closure compared with baseline conditions. Risk from a given groundwater constituent is itself dependent on both its intrinsic toxicity and its concentration, so that what constitutes a primary *versus* secondary indicator may depend on the locality.

Calculating average baseline values may be inappropriate for some constituents if, for example, the ISL uranium mine is located within a roll-front deposit, where concentrations of some constituents show sharp trends over short distances reflecting the onset of reducing conditions that precipitate uranium minerals. Hence, baseline measurements should include those made outside the proposed production zone, beyond the uranium deposits (also see Section 4.5, fifth bullet).

3.5. Constituent Interactions and Environmental Transformations

The SAB recommends that the EPA technical report discuss how the composition of groundwater and minerals in the production zone may be modified by:

- mass balance issues of the lixiviant/extraction fluid, particularly the fate of excess lixiviant injected into production areas;
- changes in microbial activity;
- environmental transformations associated with lixiviant flow and composition; and

- impacts of external changes caused, for example, by nearby activities or groundwater movement.

These effects arise from interactions among constituents, environmental transformations, and other processes acting on the constituents and aquifers that produce (potentially linked) changes in indicators over time in mining and restoration processes that should be anticipated and documented. Some of this information for a site can be derived from experience at other sites, but other information will require on-site monitoring data and possibly specific studies.

The SAB recommends that geological monitoring information also be obtained from samples of formation material collected pre- and post-mining to characterize mineralization because the ability to solubilize or oxidize constituents will depend on the geochemistry of the solid phase. Also collected should be information relevant to modeling the aquifer for understanding groundwater flow and predicting future concentrations of constituents both on- and off-site. The information collected can be utilized to evaluate the potential for mobilizing constituents off-site that may impact human health.

3.6. Spatial and Temporal Sampling Densities

Ultimately, the purpose of monitoring is to determine the concentration distribution (in space and time) of constituents or indicators of interest at baseline, during mine operation, post-closure, and post-restoration. The space and time patterns of the indicators, the sampling scheme, and the regulatory requirements must match. That is, monitoring should reflect the expectations implied by the regulations, which themselves should reflect the underlying anticipated geo-physico-chemical behavior of the constituents.

A crucial aspect of monitoring is the detailed spatial and temporal sampling scheme. Sampling is often performed in a regular pattern (i.e., on a grid in space and at equal intervals in time). The optimum spacing required in space and time (i.e., that spacing which accurately reflects the underlying distribution) – or conversely, the sampling density – is ultimately determined by the distributions of the constituents of interest. A fundamental approach to determining sampling is by the Nyquist sampling theorem (Oppenheim and Schafer 2010), which states that sampling must occur at twice the highest frequency (spatial or temporal) present in the signal. In this case, the "signal" is the spatial and temporal distribution of the constituents of interest. If constituent concentration changes slowly across space or time, then fewer samples, spaced further apart, are appropriate. If the concentration changes more rapidly in space or time, then sampling density must correspondingly increase.

While the Nyquist sampling theorem will indicate the sampling needed to portray accurately the space and time distribution of any constituent, it can result in collecting more data than necessary if the regulations do not require fully mapping the space and time distribution of constituents of interest. Accordingly, the Nyquist sampling theorem should be viewed as giving the upper bound on sampling density, not the required scheme *per se*.

The above considerations lead to a paradox: to determine the optimum sampling scheme, the space and time distributions of the constituents have to be known in advance. In practice, the SAB recommends that a combination of existing data and modeling be used to obtain some information about the general behavior of constituents in space and time. That is, models can be developed that incorporate the anticipated variation across mine sites; model development will be aided by existing data from a variety of active and closed mine sites at hydro-geochemically similar locations. The models can be validated initially with those existing data. Models can then be used to predict the range of constituent behaviors likely to be observed at subsequent mine sites as a basis for setting sampling requirements.

For example, sampling in time can reflect the anticipated time-varying time constants of the anticipated temporal kinetics. Because much of the rapid change in post-closure conditions occurs immediately post-closure, more frequent sampling should occur during that initial period. This is consistent with, for example, an assumption of first-order rather than zero-order kinetics.

The SAB recommends that the EPA provide additional discussion in its technical document on the following important monitoring issues:

- Spatial or temporal hotspots (and distinguishing from random outliers);
- Behavior of individual wells *vs*. the average behavior of the pooled wells;
- Seasonality or other periodicity;
- Trends related to environmental factors (e.g., groundwater flow, rainfall);
- Measurement accuracy and precision; and
- Extreme weather events during baseline or post-closure monitoring.

3.7. The Role of Hydro-geochemical Modeling

During the face-to-face meeting and teleconferences, much time was spent discussing the need or desire to have a modeling component that can predict the chemical and physical (and possibly biological) processes occurring during ISL uranium mining and the post-mining restoration phase. Concern was expressed that models capable of capturing the complex kinetic and thermodynamic behavior, particularly immediately following the end of active mining, are mentioned but not presented in detail in the draft technical report. This issue is particularly significant given the reliance on natural attenuation processes to restore groundwater to an acceptable and sustainable quality within a reasonable time frame. The SAB recommends that the EPA expand its draft technical document to (a) summarize current capabilities and gaps in the use of models to predict the effectiveness of natural attenuation at sites spanning a range of operational conditions (such as type and amount of lixiviant injected) and restoration practices (such as sweep volumes), and (b) discuss how an ISL uranium mine operator could design a site-specific monitoring strategy to confirm that natural attenuation processes are at least as effective as predicted.

The SAB recommends that the EPA technical report discuss the applicability of available models that have been developed and used to address similar situations. Such models have been used by the EPA, by industries other than ISL uranium mines, and in different applications (see Section 7.5). For example, numerous geochemical modeling software packages are readily available with the capability for modeling equilibrium fluid speciation, and redox, sorption, and precipitation reactions for specific hydrogeochemical conditions. Examples of these models include PHREEQC (Parkhurst and Appelo 1999), The Geochemist's Workbench® (Bethke and Yeakel 2009) and CrunchFlow (Steefel 2009).

The SAB recognizes limitations in existing models, such as the inability of most models to capture chemical reaction kinetics. At the relatively low groundwater flow-rates for many ISL uranium mines, it might be reasonable to assume local equilibrium with respect to aqueous complexation and sorption reactions, thereby allowing use of thermochemical modeling databases for those reactions. The kinetics of mineral dissolution, precipitation and transformation remain unknown for many systems, but should be considered to the extent possible.

Knowledge gained from modeling the geochemical evolution of a site is valuable and worth the effort to the extent that the considerations listed above can be addressed. At a minimum, the EPA can consider adapting these existing models for application to the ISL technology to gain technical insight into the performance of ISL operations and their associated monitoring networks. The feasibility of modeling can be evaluated by comparing predicted results with monitoring data, which appear to be abundant. The modeling efforts will complement the monitoring data to support assessment of the impacts of site operations on groundwater quality, and will provide lessons learned for future licensing of similar operations.

The SAB recommends that research be undertaken to obtain empirical values of time-frames and (spatial and temporal) rate constants/reaction rates to validate kinetic models. These models should include components (both causal and mediating), interconnections, and sensitivity (e.g., by perturbation analysis) and consider the following areas (at a minimum level):

- Geochemical modeling using chemical reaction kinetic equations and equilibrium thermodynamic equations, as appropriate;
- Evaluation of an appropriate kinetic model (e.g., first order for both spatial and temporal kinetics);
- Incorporating natural attenuation processes such as adsorption and the formation of secondary minerals, and the effects of redox conditions and microbial activities on these processes (EPA 2010);
- Need for a conceptual (physical) model (or not); and
- Interplay between data collection and modeling (see Figure 1).

As noted above, the technical report should describe in detail the needed efforts, recognizing that the regulator can provide licensing conditions and guidance for operating a specific mine. The SAB views modeling as a tool to assist in the design of remediation and monitoring strategies. For example, a reliable model may help identify the areas at risk and in need of monitoring at baseline and after restoration attempts, and in interpreting monitoring results. Modeling can assist in developing a good monitoring design, but cannot make up for poor design. Modeling also can help to inform and formulate the sampling requirements to be included in the regulation.

The primary comparison between baseline conditions and post-operation conditions is the concentration of various analytes in the groundwater and other water quality parameters. The SAB acknowledges that practical considerations must be taken into account when performing baseline determinations and evaluating post-closure performance of a site. For example, a complete mineralogical characterization of the site during baseline and post-closure periods provides complete evidence of long-term site stability, but this level of characterization is impractical from physical and economic viewpoints. Therefore, a reliable validated model that can predict the evolution of the groundwater chemistry based on the behavior of the entire system (aqueous and solid phase components) will be helpful. If a single integrated model cannot be developed to serve this purpose, an alternative approach is to develop and test individual modular models that can be used collectively to achieve the same objective.

The SAB recommends that, based on these considerations, the EPA develop or apply a geochemical model (or a series of individual modules) that can reproduce observed data from an existing ISL mine. The intent of this modeling effort will be for the EPA to have a model that can be validated by field measurements and then used to predict the likelihood that a site will achieve its restoration objectives within a given time frame. An important unknown is how long post-restoration monitoring must occur before the site is released for other uses. A reliable model would be capable of making this prediction and, if valid kinetic data are incorporated, show that the groundwater quality at a site will or will not maintain a steady state similar to that of the baseline.

This information will give the EPA the ability to set a fixed time or guiding principles for post-restoration monitoring at various sites. The current common practice of setting a default one-year monitoring period, subject to extension if post-closure monitoring goals have not been met, is not based on scientific knowledge supporting the adequacy of such a requirement. A reliable model also will give the EPA a technically defensible method for establishing guiding principles for the number of wells for groundwater characterization and monitoring required at a site and the frequency with which the wells must be sampled.

The power of the modeling efforts described above will be in the knowledge gained to craft the regulation. Due to the high degree of variability the modeling programs may have, it seems technically burdensome to require a complete hydro-geochemical model of every site and it is unclear at this early stage how the parameters of the modeling efforts would be regulated (e.g., the choice of modeling code). That site specific considerations must be applied is well understood due to the heterogeneity across ISL uranium mines. For this reason, model development has to rely heavily on field information gathered from the sites.

The modeling effort is closely related to the effort for ascertaining ground truth; the better the information, the more accurate the model prediction. The wealth of site data should be incorporated into the modeling effort. Conversely, any limitation identified in modeling should become a topic for future research. The real intent is to understand fully the physical/chemical processes occurring within a site. To accomplish that, modeling can be used effectively in combination with site characterization and environmental surveillance. With such level of understanding, the EPA will be capable of producing a consistent set of guiding principles that are technically defensible.

3.8. Establishing Baseline Groundwater Chemistry

The RAC recommends that at least as much effort should be devoted to establishing baseline conditions as is put into post-closure monitoring. Critical considerations include:

- Spatial and temporal patterns (e.g., seasonality, annuality),
- Effects of changes in groundwater vo*lume per se* on baseline conditions, and
- Identify key geochemical constituents that control the mobility of hazardous constituents.

This topic is discussed in detail in Section 4.

3.9. Post-Closure Monitoring

The issues inherent in establishing baseline conditions also pertain to post-closure monitoring. In addition, the mining process itself creates spatial and temporal instabilities. While the restoration process is intended to return the aquifer to its pre-mining state, restoration is a dynamic process that itself introduces spatial and temporal instabilities. Considerations include:

- Spatial and temporal extent of perturbations to the aquifer,
- Comparability (e.g., same monitoring wells) to baseline,
- Modeling trend of return to stability,
- Indicators and their concentrations used as acceptability criteria.

This topic is discussed in detail in Section 5.

3.10. Standardized Terminology

The SAB recommends that the EPA pursue cross-agency adoption of standardized definitions for key terms such as excursion, contamination, and "return to pre-operational groundwater quality." For example, the term "excursion" has been defined in different regulations and guidance documents related to ISL monitoring as:

- transport of contaminants beyond the exempted portion of the aquifer (U.S. EPA 2011a, Section 2.3);
- an elevated reading within the mining field (that indicates the potential for contamination) (U.S. NRC 2011);
- the movement of mining solutions, as determined by analysis for control parameters, into a designated monitor well (Texas Administrative Code, TAC Rule §§331.2).

The SAB similarly found various definitions of the term "contamination" in regulatory requirements, guidance, and site operating licenses. The NRC applies this term to the detection of contaminants or elevated constituents at a well beyond the boundaries of the mining field (see also Section 5.2).

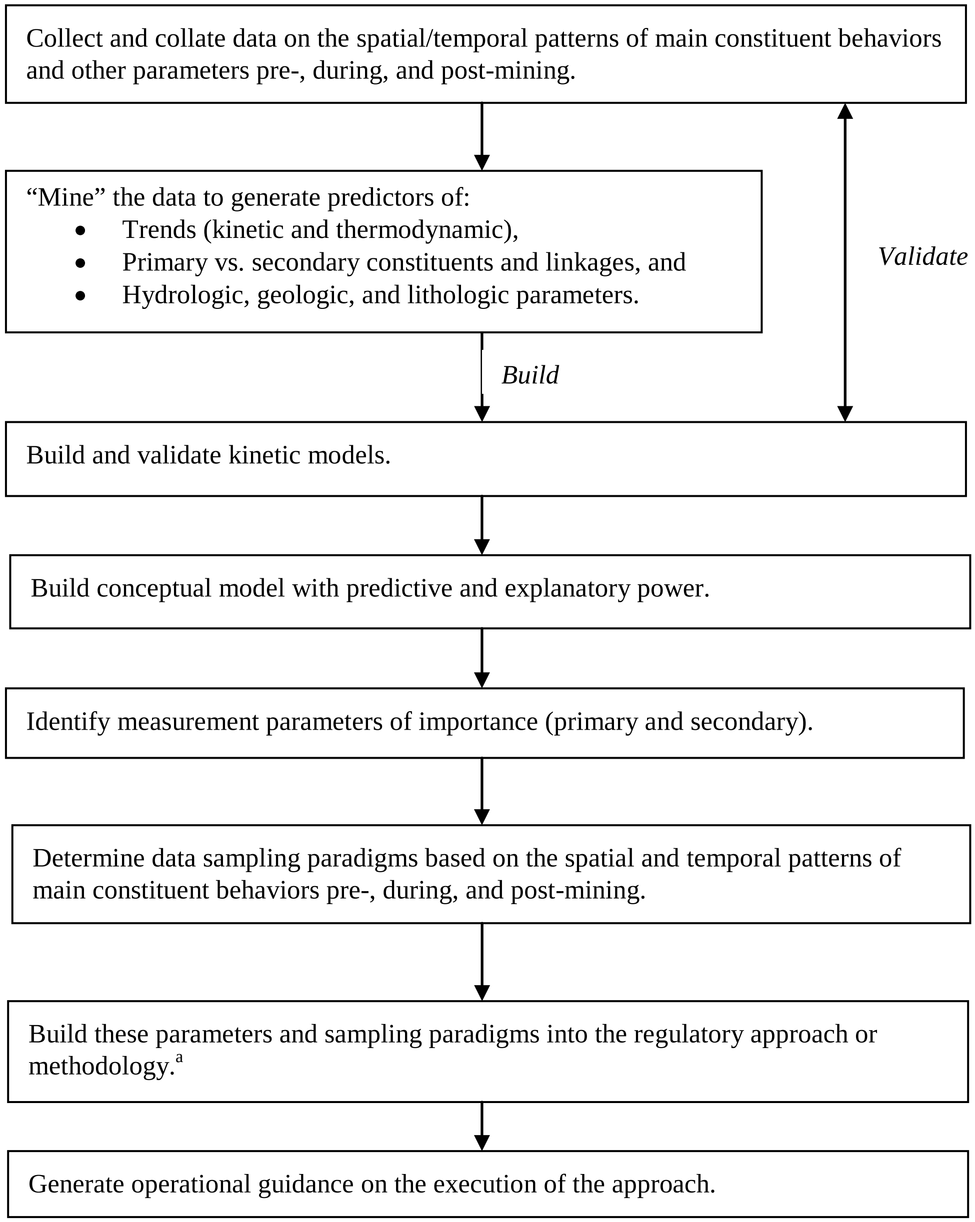

Figure 1. Flowchart representing the coupling of data and modeling analyses to generate an evidence-informed regulatory approach and methodology. ([a] The terms "parameters and sampling paradigms" refers to a consistent approach/methodology for determining the monitoring requirements at a given site, while recognizing that the requirements themselves are site-specific.)

4. PRE-OPERATIONAL MONITORING

Charge Question 2: Comment on the proposed approaches for characterizing baseline groundwater chemical conditions in the pre-mining phase and proposed approaches for determining the duration of such monitoring to establish baseline conditions.

4.1. Background Information Considered by the SAB

In responding to the EPA discussion of establishing baseline conditions in Section 4.2 of its draft technical report (EPA 2011a), the SAB considered geologic settings of current and potential ISL operations and the inter-relationships among geologic, hydrologic and water-quality conditions. The following observations about characterization during the pre-mining phase are based upon EPA and NRC presentations and regulatory guidance documents, selected permit applications for proposed ISL operations, and license conditions established by the NRC (or by one of its Agreement States) for ISL uranium mining operations.

4.2. Defining Data Quality Objectives for Baseline Characterizaion

The SAB recommends that the proposed approach to groundwater monitoring for pre-mining chemical and radiological characterization be defined in the context of the DQOs for baseline characterization. For example, the most basic DQO may be to establish zone-specific statistical distributions of baseline concentrations for key hazardous constituents that may be released to groundwater during mining or restoration operations. Regulations require these distributions to be based on independent and representative water samples collected from zones in which baseline wells are located by a statistically valid sampling design:

- Mine-area monitor wells completed within the proposed production zone;
- Mine-area nonproduction wells that comprise the monitor well ring to monitor for excursions; and
- Mine-area non-production monitor wells completed in any freshwater aquifers that overlie or underlie the production zone.

Additional DQOs such as the following also may be appropriate:

- Demonstrate correlations among key geochemical constituents that may support optimization of the characterization approach (e.g., identifying and monitoring surrogates, such as conductance, for key constituents);
- Identify key geochemical constituents that control the mobility of hazardous constituents during the recovery phase (e.g., redox couples that define the Eh-pH field);
- Understand the hydrologic and geologic controls responsible for producing localized mineralization of uranium and other hazardous trace metals in the ore deposit;
- Identify optimal physico-chemical indicators for excursions, considering both reliability and cost-effectiveness of analytical methods;

- Establish spatial variability of key geochemical constituents as the basis for determining the extent to which the mean or upper concentration limit of baseline concentrations is a function of location, e.g., upgradient, downgradient and offgradient of the mine deposit, or in the near-field versus the far-field of structural controls and potential pathways;
- Assess the presence or absence of temporal variations in groundwater chemistry;
- Obtain data needed for geochemical modeling of water/rock interactions to predict re-equilibration trends and rates during the recovery phase (e.g., Bain et al. 2001); and
- Identify the most critical or vulnerable pathways (e.g., Striz 2011). Generally, vertical excursions into overlying or underlying aquifers are of greater concern than are horizontal excursions. Thus, for ISL operations in confined aquifers, the primary consideration should be no likelihood of breaching the confining beds conditions.[1]

The key point for consideration is that each DQO may require a different approach to the design and implementation of a baseline characterization program, as illustrated in the following section in which baseline characterization parameters are mapped to relevant DQOs.

4.3. Baseline Characterization Parameters

The EPA is encouraged to emphasize the importance of evaluating and presenting water-quality data within the context of their geochemical interrelationships, not solely as independent variables. The SAB recommends that baseline chemical conditions be defined broadly to encompass transport flow paths and conceptual models of mineralogic controls not only for hazardous constituents (e.g., trace metals) but also for associated parameters. Iron serves as a prime example of the potential complexity of geochemical interrelationships in an aquifer. Iron-bearing minerals buffer the redox chemistry of the groundwater, and iron (oxy) hydroxides not only constitute one of the most important sorbents for trace metals but also are one of the most important sources because of their potential to release these sequestered constituents into the groundwater when reducing conditions are restored.

Based on this broad perspective, the SAB recommends that analytes be included in baseline characterization to meet the following objectives:

- Establish baseline conditions for key hazardous constituents with the potential to be released to the groundwater during mining or recovery operations;
- Characterize baseline conditions of chemical and secular equilibrium as one measure of mineralogic stability (e.g., mineral saturation indices). This is an alternative approach to defining concentration ranges as the sole measure of baseline chemistry;
- Collect data needed to define the Eh-pH fields for the mine production area as well as for the adjacent aquifers.

[1] Failure of unlined (#S3) ponds at the Oak Ridge National Laboratory (ORNL) provides one example of the consequences of failing to recognize the vulnerability of a confining layer serving as a barrier for contaminant transport (Kim et al. 2009; Wu et al. 2006). The ponds were unlined because they were situated above a clay layer (saprolite). A fatal flaw in this design was that the clay was fractured and allowed releases of constituents into the subsurface.

- Include aluminum in the background characterization suite because of its utility for normalizing metal concentrations and fingerprinting trace-metal sources (Myers and Thorbjornsen 2004; Thorbjornsen and Myers 2008), which may include formation solids/colloids, contamination, or residual annular-fill bentonite in the vicinity of the well screen.

- Apply effective statistical methods and develop effective graphical techniques to delineate geochemical fingerprints, such as Piper and Stiff diagrams (Striz 2011) and plots presented in the EPA technical support document, "Fingerprint Analysis of Contaminant Data" (Power 2004).

Tables B-1 and B-2 in Appendix B of this report are intended to illustrate how the above criteria might provide a basis for developing site-specific lists of analytes and groundwater quality parameters to be monitored during baseline, mining, remediation, and closure operations. Not all parameters listed in these tables would be applicable to a specific site; not all applicable parameters would need to be measured at a site; nor would all parameters selected for measurement at a given site need to be sampled with the same frequency. Although an exhaustive set of data might be desirable to allow evaluation of all parameters, a more practical approach is to limit data collection to a set of high-priority primary parameters determined for a site, augmented, if necessary, by a second set of lower-priority parameters. Because this is a site-specific consideration, no attempt has been made to prioritize the parameters listed in Tables B-1 and B-2.

The inclusion of redox speciation of the analytes of interest in Table B-2 differentiates this list from a typical RCRA analyte list in which only concentrations of the analytes are to be measured. If properly sampled and measured, the redox speciation data will provide invaluable information regarding the state of the aquifer. This will be important for determining the baseline conditions as well as for demonstrating that the aquifer has been restored after mining is complete. For example (see Section 5.3), the sulfide/sulfate ratio will help to understand and explain aqueous concentrations of radium; and the distribution of uranium between its tetravalent and hexavalent states, uranium(IV) and uranium(VI), respectively, has a direct relationship to the measured aqueous concentrations of uranium due to the low solubility of uranium(IV) relative to uranium(VI). Although measuring analyte redox speciation has practical limitations, notably in preserving the redox state of a field sample, under most subsurface conditions simple pH and redox potential measurements are possible.

Coupling these field measurements with the hydro-geochemical modeling discussed above can be useful for predicting analyte redox speciation. Whenever possible the redox potential and oxidation state information of the analytes of interest should be considered based upon the availability of data collected from the analyte lists (Tables B-1 and B-2). The stability lines for site-specific redox couples of interest (e.g., iron(II)/(III), sulfide/sulfate, molybdenum(II)/(IV), manganese(II)/(IV)/(VII), and uranium(IV)/(VI)) should be plotted and analyzed with the relationships described by Borch et al. (2010) and Lindsay (1979).

Clarification or guidance is needed concerning whether baseline concentrations should be determined for filtered and/or unfiltered samples, particularly in the case of trace metals. Although filtered groundwater concentrations are more appropriate for modeling geochemical speciation, mineral/water interactions, and mineral saturation indices, unfiltered concentrations also have relevance for characterization. For example, comparison of filtered and unfiltered concentrations may establish the extent to which samples collected from the well may be biased by formation solids, annular-fill material, or metal corrosion products. In addition, some regulatory standards for trace metals apply to total concentrations (e.g., arsenic, mercury, selenium).

4.4. Drilling and Well Construction Practices

Little discussion is provided in the draft technical report about potential effects of drilling, well construction and development activities on the capability of the monitoring well to provide water-quality samples that will be adequately representative of baseline conditions. Regulatory requirements and guidance generally focus on the mechanical and physical integrity of the well and annular seals to prevent undesirable vertical migration of groundwater from one strata to another. The EPA is encouraged to consider how drilling, construction and development activities may affect or bias concentrations of water-quality parameters of interest, and to identify protocols that might be used to detect or minimize such biases. Three examples are:

- Physical changes to formation minerals induced by drilling may increase concentrations of colloids and suspended solids in the vicinity of the screened interval, causing an upward bias in concentrations of trace metals in filtered and unfiltered samples. Use of bentonite drilling muds or improper placement of bentonite annular-fill and seals also may have the potential to bias the concentrations of strongly-sorbing metals. These effects may be minimized by proper development of the screened interval while monitoring trends in turbidity.

- Introduction of oxidizing fluids into the reducing ore zone during drilling, well construction or development may chemically alter formation minerals in the vicinity of the screened interval, leading to elevated concentrations of, for example, uranium, other trace metals, radioactive uranium daughter products, and sulfate. Oxidation of the ore zone may be minimized if wells are drilled with reducing fluids and not developed with air-purging (Abitz and Darling 2010; Sass 2011). Changes to baseline redox conditions may be detected in the field by monitoring trends in redox indicators during well development or during purging of the screened interval prior to sample collection.

- Oxidizing conditions might also affect groundwater at a monitoring well as a result of new exploration boreholes drilled nearby. Collecting representative groundwater samples within the proposed production zone thus requires that baseline water quality be established early in the exploration phase (Abitz and Darling 2010; Sass 2011).

For these reasons, the EPA should consider expanding its technical report to include guidance on best practices (a) for conducting and documenting drilling, well completion, and development activities at wells used to establish baseline conditions, and (b) for evaluating the capability of the well to provide reliable and representative groundwater samples.

4.5. Challenges for Background Characterization

The EPA draft technical report properly emphasizes that the design and implementation of a baseline characterization program will be driven by site-specific factors. Some additional discussion and guidance may be needed to emphasize that the location of the baseline wells must be based on a statistically valid sampling design developed following the DQO process.

A systematic grid is one example of a statistically valid approach for locating baseline wells. However, even a statistically valid distribution of sampling wells does not eliminate complications for establishing baseline conditions in the context of site-specific factors such as those described below.

- *Intersecting or adjoining deposits* near mine leases. Mining companies often submit applications to expand the area of ISL operations or to establish satellite ISL wellfields. Consequently, environmental impacts of operations may overlap but not be coincident in time, and complicate defining baseline groundwater chemistry for a proposed mine. Such overlap also may cause ambiguity about which mining operation is the source of any future excursions.

- *Groundwater contamination in adjacent abandoned mine shafts and tunnels* could complicate the definition of baseline chemistry and specification of restoration target concentrations. If operations at an ISL mine that intersects these mine workings subsequently chemically alter the groundwater in the workings, then an argument could be made that less restoration effort should be required than for the native sandstone leached in other areas.

- *Dewatering effects of old mine workings* in or near a proposed ISL operation may subject the formation to oxidizing conditions that may extend for some distance around the old mine workings (i.e., into areas that were not mined by the underground operation). Such dewatering may have diminished or eliminated reducing conditions in the aquifer, and uranium may move a longer distance than would normally be predicted before it encounters reducing conditions in the aquifer.

- *Improper selection of sampling horizons* creates an invalid bias in the water-quality parameters, e.g., by collecting samples from ore horizons relative to samples collected from the entire thickness of the formation.

- *Limited knowledge about site mineralogy*, particularly related to trace metals, may undermine the reliability of geochemical modeling to predict the types and rates of water/rock interactions controlling groundwater chemistry and hence post-mining rehabilitation. Uranium distributions are generally determined from downhole gamma logs; chemical assays are not always performed, and presumably performed rarely on cuttings from barren holes.

- *Changes occurring in the groundwater environment during mine operation* but for reasons unrelated to the mine itself could have the potential to invalidate the use of pre-operational monitoring data as a comparison for post-operational monitoring data. One approach to mitigate this possibility would be to ensure that two or more baseline monitoring wells are located outside the mining area, and that these wells continue to provide baseline monitoring data throughout the mining operational phase.

The SAB recommends that the EPA consider the above items in its technical report. Corollary topics for consideration in the technical report are to (1) summarize the various types of mineralogical characterizations desirable for baseline characterization; (2) ensure that the approach proposed for baseline characterization is sufficiently flexible to accommodate other characteristics encountered at future mines; and (3) include models and coefficients for monitoring networks where available.

4.6. Frequency and Duration of Monitoring to Determine Background

The SAB recommends adopting a phased approach to baseline characterization that takes into account the following:

- Need for additional background locations can be informed by the level of uncertainty in the range and spatial variability of constituents in the groundwater;
- Need for additional data from a particular well (or the need to resample a well) can be informed by the consistency of the data with concentrations predicted from geochemical modeling of the site; and
- Need to continue sampling an individual well can be based on testing for trends in the data indicating the extent to which the well has recovered from drilling and construction activities.

The adequacy of development and re-equilibration time of baseline wells should be confirmed prior to sampling. The EPA is encouraged to consider how best to test for steady-state geochemical conditions at baseline wells, and to evaluate whether samples represent water-quality data from these wells. The baseline data ultimately will provide the technical basis for establishing action levels for exceedances observed during the post-restoration monitoring phase. As such, it is critical that the data represent the natural variability of each analyte, unbiased by variability resulting from residual effects of drilling, construction and development. Under some conditions, residual impacts from drilling can dominate the concentrations of some groundwater constituents (particularly trace metals) in the vicinity of the well screen for months (if not years).

The EPA is encouraged to include in its technical report guidance on best practices for groundwater sampling, including the following:

- Document the volume of water purged before sample collection and field parameter data measured during purging (e.g., pH, Eh, conductivity, turbidity) to provide a basis for assessing whether the groundwater sample is representative of predrilling conditions.
- Collect additional water-quality samples during purging that may provide additional insights on well performance issues. For this purpose, a time-series suite could be defined that involves collecting water-quality samples in increments of one to two casing volumes during purging to be analyzed for major ions, trace metals and nonmetals, and total organic carbon. These data would then be evaluated for trends that might indicate residual drilling or construction products, mixing of groundwaters from different hydrologic zones, or disequilibrium with formation mineralogy.
- Other approaches for evaluating representativeness are to plot redox-couple data on phase diagrams and to use geochemical modeling to determine the extent to which measured water-quality parameters are in equilibrium or disequilibrium with mineral phases known to be present in the formation.

A single sample from each well is insufficient to determine whether water-quality parameters are stable and representative of the groundwater at the sample location. Background chemistry should be based on a statistical analysis of groundwater chemistry data from a sufficiently large set of wells sampled over a period of time. The RCRA requirements (40 CFR 264 Subpart F) for the frequency of sampling are appropriate and applicable for this purpose:

> §§192.32(g)(1). A sequence of at least four samples, taken at an interval that assures, to the greatest extent technically feasible, that an independent sample is obtained, by reference to the uppermost aquifer's effective porosity, hydraulic conductivity, and hydraulic gradient, and the fate and transport characteristics of the potential contaminants.

Examples of calculations for determining the length of time (or distance, in the case of neighboring wells) required to ensure samples will be independent, and examples of how to test for independence, would be useful additions to the technical report.

4.7. Standardized Data Collection

The SAB recommends that the EPA adopt a standardized data collection process for groundwater monitoring data from ISL uranium mines in order to develop a national information-sharing compilation. This step will provide the EPA with a more complete and accurate picture of activities in response to regulations in this field.

5. POST-OPERATIONAL MONITORING AND RESTORATION

Charge Question 3: Comment on the approaches considered for monitoring in the post-mining/restoration phase and the approaches considered for determining when groundwater chemistry has reached a "stable" level.

5.1. Introduction and Overview

The draft technical report points to two primary objectives for post operation and restoration monitoring. The first is to provide comments on how the monitoring program during the post-mining and restoration phases should be organized and carried out; the second is to discuss approaches for determining when the groundwater chemistry has reached a "stable" state. Considerable reliance is placed on the method for determining baseline conditions that is addressed in the response to Charge Question 2.

5.2. Defining Restoration Goals

The SAB recommends that the EPA provide careful qualification about its meaning of "return to pre-operational groundwater quality." Restoration activities may not fully or precisely restore the aquifer to pre-operational quality; consequently some quantitative measure of how close is close enough will have to be developed to support a decision. Examples of alternative approaches to defining remedial goals include returning the aquifer to pre-operational conditions based on statistical comparison with pre-established criteria *versus* the use of a risk-informed basis. A glossary of definitions should be included in the draft technical report for terms that may have somewhat different definitions within the scientific community and hence can be open to interpretation. These words include: colloid, steady state, irreversible (in the context of a chemical reaction), stability/stable, baseline, and heterogeneity.

The SAB recommends that the EPA develop a set of guiding principles that will be used to craft restoration standards. The draft technical report suggests that many considerations are highly site-specific. However, the EPA can provide generic guidance with provisions to be adapted to site-specific conditions (i.e., geology, groundwater flow, groundwater chemistry). One critically important aspect for which little discussion is provided in the draft technical report concerns guidance on adopting alternative concentration limits (ACLs) as restoration goals. Such ACLs are particularly important for post-operation monitoring of ISL facilities because adoption of ACLs appears to be the norm, rather than the exception. In a sense, ACLs serve as *de facto* regulatory standards that vary from site to site. Thus, in considering standards that apply to ISL uranium mines, the EPA can apply its guidance on ACLs (U.S. EPA 1987).

For effective generic guidance, available data must be analyzed. Many of the specific recommendations below are intended for developing a consistent set of physical and chemical parameters to be monitored, a uniform database of available data, and public dissemination of the data. The latter will give the academic and research community the opportunity to evaluate the data and apply them to hydro-geochemical modeling as a means for predicting post-closure behavior through universally applicable principles of chemistry and physics. Modeling will provide an opportunity to combine knowledge of physical/chemical processes with what is known about a site. In this way, monitoring data can test the model and suggest the likely effectiveness or alternative remediation schemes.

5.3. Evaluation of Existing Datasets

The SAB recommends that the EPA seek out and collate data sets of sufficient scope and quality to provide information relevant for setting the standards under consideration. Such data sets are available from existing and former sites during the baseline evaluation, operation, and restoration stages. Because geochemical, biological and physical conditions are highly variable among ISL uranium mines, a corollary activity is to use the existing data to identify fundamental transferable concepts among the sites. Some examples to illustrate this point are:

- Correlations among various chemical and physical parameters may provide general descriptions of the systems:
  - The valence state of uranium and arsenic should correlate with their total measured aqueous concentrations. For uranium, this relationship is due to the increased solubility of the hexavalent state, uranium(VI), relative to the tetravalent state, uranium(IV) (Borch et al. 2010). The measured redox potential (when little or no dissolved oxygen is present) should be related to the valence state of uranium and arsenic. Rigorous analysis of the redox kinetics and speciation of the system may be needed because many geochemical redox reactions do not achieve an equilibrium state. Complexation with dissolved ions may provide thermochemical gradients that favor an oxidized state of a metal or metalloid despite the presence of reducing conditions[2];
  - Due to the relatively low solubility of radium sulfate, $RaSO_4$(solid), aqueous concentrations of radium-226 and radium-228 should be inversely related to the sulfate concentration; and
  - Iron (oxy) hydroxides and clay minerals are generally expected to be the dominant sorbents of uranium and radium in the ore deposits. Consequently, aqueous uranium and radium concentrations should be inversely related to the amount of iron (oxy) hydroxide and clay minerals in the subsurface (Catalano and Brown 2005; Moyes et al. 2000).
- The existing datasets can be used to demonstrate use of hydro-geochemical modeling for predicting behavior of the system during operation, restoration, and post-closure. Numerous modeling programs currently are available at varying degrees of sophistication (see Sections 3.7 and 7.5). These models can incorporate chemical speciation models with hydrologic flow models to predict spatial and temporal concentrations of analytes in aqueous and solid phases. A feasibility study employing the modeling program PHREEQC was commissioned by the NRC (U.S. NRC 2007; also see Parkhurst and Appelo 1999). The study examined three techniques for estimating the volume of water that must be passed through the aquifer system to achieve restoration standards. A model that considers hydrology, contaminant transport, and geochemical reactions provided a qualitative estimate of the geochemical conditions and estimated the behavior of the system during post-closure operations. Because

[2] An example of this phenomenon has been clearly demonstrated by Wan et al. (2005) during a uranium bioreduction study. After amending uranium-contaminated sediments with lactate, uranium reduction was seen up to 80 days but after >100 days uranium was reoxidized despite the fact that a microbial population capable of reducing uranium was maintained. It was found that the oxidation was due to the formation of thermodynamically favorable aqueous uranyl carbonate ternary complexes such as Ca_2UO_2-$(CO_3)_3$. Oxidation of uranium(IV) to uranium(VI) is highly undesirable because of the enhanced environmental mobility of uranium(VI) relative to uranium(IV).

in-situ mining is a major perturbation of the system, a quantitative model in support of site measurements can provide confidence that the restoration goal of site stability after closure has been met. The U.S. NRC (2007) emphasized that development of a justifiable conceptual model that captures the major chemical and physical phenomena at each site is required. This approach will allow for site-specific flexibility.

- Information on solubility, aqueous speciation, and sorption affinity may be found to guide extrapolation to aqueous concentrations near equilibrium. Prediction of temporal trends by hydro-geochemical modeling is difficult due the lack of kinetic data for some relevant systems. The very act of in situ mining takes a system far from an equilibrium state during normal operation. The thermodynamics and kinetics during the early phase of restoration are likely to be important. In most cases, aqueous complexation reactions and sorption reactions may reach at least a local equilibrium. Therefore, the major focus should be on incorporating kinetics of mineral precipitation and dissolution into the modeling efforts. An example is provided in Attachment B of the draft technical report when discussing transitions from ferric (oxy) hydroxides to soluble ferrous iron to ferrous sulfide minerals.

- The EPA has case studies from sites that have completed restoration and post-closure monitoring (U.S.EPA 2008). These may be pertinent to discussions in the draft technical report on the use of confidence levels for determining if restoration goals have been achieved.

- A uniform database can be prepared from the collected site data that were used to characterize baseline, operation, restoration, and post-closure conditions. This database can be made publically available so that the academic/research community can evaluate the data and help to develop conceptual and quantitative models which can be used to further refine the regulations and monitoring activities for in-situ mining.

5.4. Criteria for Collection and Analysis of Monitoring Data

Development of a set of guiding principles discussed above for use in forming standards will be an improvement on the current practices primarily guided by site-specific metrics, which allow for a high degree of variability. A set of general principles that considers variable site conditions within a broadly consistent approach can ensure that consistent standards are applied for all sites. Several relevant principles are:

- The data gathered during restoration will be valuable for determining if the restoration activities are effective. A feedback loop should be implemented that requires a change in restoration activities if the data indicate that the goals will not be met. This can be a simple projection of groundwater chemistry based on the extrapolation procedures outlined in the draft technical report or a more complex coupled hydro-geochemical model of the system that considers relevant reaction kinetics;

- Pertinent data incorporated into the consistent, publically available, database discussed above will encourage interrogation of the data to refine future monitoring during *in-situ* mining activities;

- Several approaches are available to analyze the large sets of data generated from sites with multiple wells at multiple times. While a site-averaging technique is a simple approach, the key to understanding outliers and spatial variability is to look at the data for individual wells. Therefore, unless specifically guided by a statistical test, chemical parameters should not be reported or evaluated as a site-wide average value. (See Section 6.2).

5.5. Duration of Post-Mining/Restoration Monitoring

Mining by ISL drastically alters the subsurface physical and chemical environment. When mining ends and no further anthropogenic actions influence the groundwater, then the groundwater and the minerals with which it is in contact begin to shift toward a new geochemical steady state. Proposing methods of returning to baseline hydrological and chemical conditions during restoration activities implies that the system will return to steady state conditions comparable to pre-operational baseline conditions. However, although groundwater conditions may be sufficient to satisfy license requirements, the SAB is not aware of available data indicating that mineralogical and hydrological conditions can be fully restored. Examination of post-closure/restoration data from existing ISL uranium would be useful to determine the extent to which return to baseline conditions has indeed been achieved. The examples in the draft technical report appear to focus primarily on analyte concentrations.

In addition to water quality data, mineralogical data can be used to evaluate the long-term stability of the system. Because complete mineralogical characterization is unrealistic or economically infeasible, alternative approaches are needed. Data from existing facilities can be used to propose a technically reliable time frame for post-closure monitoring. This is a case in which hydro-geochemical modeling can be a valuable tool for predicting how long a system will take to return to baseline conditions. Combining a validated model with the data from a relatively limited number of sites that have proceeded completely through the restoration and closure process will provide an estimate of technically reliable time frames for post-operational and post-restoration phase monitoring.

The SAB recommends the following actions regarding sampling frequency and duration:

- Increased frequency of groundwater monitoring immediately after termination of mining operations. The system is expected to return rapidly from its status far from equilibrium during mining to nearer its natural state after the lixiviant is flushed out. Measuring this rapid change with great frequency will provide valuable data regarding the trajectory of aquifer parameters and analyte concentrations for validating and verifying hydro-geochemical models;

- Statistical testing to verify that baseline conditions, once reached, are maintained (see Section 6.2); and

- Application of hydro-geochemical models to data sets from ISL uranium mines that have been restored to indicate magnitude of duration needed to attain restoration, as defined by consistent criteria.

5.6. Grouping Constituents for Monitoring Activities

To verify that baseline conditions have been achieved by site restoration activities, the SAB recommends that the list of analytes and groundwater parameters to be monitored before, during, and after operation be established pre-operationally. The analyte lists provided in Appendix B include the analytes and groundwater parameters that the SAB considers potentially relevant for baseline determination and evaluation of post-closure stability.

5.7. Hazard Quotient or other Risk-Weighting Scheme for Determining Relevant Analytes

The SAB recommends that the EPA discuss the implications of the data on restoration activities at mines included in attachments to the draft technical report. Listing measured analytes and water quality parameters without pertinent discussion is of limited utility. For example, would it matter if the calcium concentration is above the baseline concentration but uranium and radium concentrations are all at or below baseline?

The SAB recommends that the EPA consider developing a risk-weighting scheme to apply to the analytes being monitored during baseline and restoration activities. Such weighting can show the relative risk from a given analyte that is out of compliance. This will prevent the scenario that a site must continue restoration activities even though it has met the goals defined by risk analysis. This scheme can be combined with the recommended primary and secondary list discussed above where the analytes on the primary list must meet the restoration goals while the secondary list contains analytes of little risk that provide information on the extent of restoration.

One approach to consider is the hazard quotient, which is the ratio of the measured analyte concentration to the analyte concentration at which no adverse effect is expected (Fjeld et al. 2007). According to this approach, constituent concentrations in groundwater may be acceptable with regard to health risk provided the sum of their hazard quotients is <1. Accordingly, a site at which an analyte has not met a restoration goal but does not present an unacceptable health risk can use a hazard quotient approach to demonstrate that there is little potential for adverse health effects. In the example above considering calcium, uranium, and radium, if the calcium concentration had not reached the baseline levels during restoration but the overall groundwater composition had a hazard quotient less than one, then the site could be released despite the fact that the restoration goal for calcium has not been attained.

6. STATISTICS, DATA REQUIREMENTS, AND USE

Charge Question 4: Comment on statistical techniques that would be applicable for use with ISL/ISR mining applications (particularly for the areas in Charge Questions 2 and 3), as well as the subsequent data requirements for their use.

6.1. <u>Design of Well Placement and Sampling Program</u>

Many issues concerning the design and execution of monitoring plans for pre- and post-mining/restoration are difficult to address in full in a brief technical document. Each site is unique geologically, and effects of ISL uranium mining on hydrodynamics and water chemistry are complex. The draft technical report presents a reasonable general approach to statistical analysis of data from a monitoring program. However, the statistical analysis can only be as reliable as the overall design of the study, which must ensure that the monitoring wells will be representative of the aquifers at risk of contamination.

The problem of designing a monitoring system with adequate site locations and densities is not directly discussed in the draft technical report, although other EPA reports may cover this issue in other contexts. The monitoring system must be designed to provide adequate coverage for all aquifers deemed to be affected by ISL uranium mining according to the hydrological survey and hydro-geochemical modeling. The term"adequate coverage" implies both selecting locations with most affected groundwater (e.g., potential hotspots) and overall assessment of pre- and post-mining/restoration aquifer conditions. Any appearance of "cherry-picking" affected locations for underestimating long-term changes due to mining and recovery operations must be avoided.

The SAB recommends that the technical report give a summary of methods to determine the number and density of monitoring wells. A basic approach can specify monitoring an initial number of wells that will be adequate under a presumed standard physical model for groundwater pollutant concentrations (based on prior standard practice). After an initial (perhaps one year) interval, heterogeneity (and periodicity, see below) can be evaluated; if the coefficient of variation (comparing different wells) of key potential constituents is unexpectedly high, additional wells can be added to the system prior to the start of the ISL operations, in time to collect several months of baseline data for those wells before operations begin.

The draft technical report gives a sample size formula (U.S. EPA 2011a, page 52) that is relevant for testing whether a single analyte differs in the post- *versus* pre-period for a single well; this is highly relevant for predicted "hotspot" regions that would be most affected by ISR activities. The formula should be supplemented with a discussion of finding sample size needed for characterizing whether the average value of an analyte of interest over an entire aquifer is comparable in the post-ISL period compared to the pre-ISL period. Here, both the number of wells and the number of readings per well are relevant, and the among-well variance in analyte value determines the number of wells required. Care must be taken in deciding over how large an aquifer or spatial area to average, because including wells in aquifer regions unaffected by ISL activities will attenuate the apparent effects of ISL mining. Once the region of interest is defined, standard sample size considerations (similar to the formula given in U.S. EPA 2011a, page 52, but with the variance term now involving a sum of within- and among-well variability) can be applied to this problem.

6.2. Statistical Analysis Discussion

The statistical analyses discussed in the draft technical report assume that monitoring wells provide measurements during both pre- and post-mining/restoration, and describe a set of statistical analyses to determine the following:

- Whether measurements of a single given pollutant concentration in the pre- and post-periods for a single well are temporally stable (e.g., not subject to trends in either the pre- or post-period);
- Whether the data from a given well (if temporally stable in both periods) provides statistical evidence that differences in pollutant level (post – pre period) are not greater than a given allowed value, Δ;
- Whether a group of wells are heterogeneous in either their temporal trends or in their post – pre period differences in concentration levels; and
- Whether, in longer follow-up, trends are evident in individual wells or overall in a group of wells.

The draft technical report mainly discusses non-parametric statistical methods to test for trends, post - pre differences and heterogeneity It recommends the Mann-Kendall test to test for unexpected trends (U.S. EPA 2011a, Sections 8.3.2, 8.3.3, 8.5, and Attachment D, sections D.2 and D.3), the Wilcoxon test for comparing baseline and post-restoration samples for statistical differences for a single well (U.S. EPA 2011a, Sections 8.4.1.1, 8.5, and Attachment D, section D.5), It also recommends a test for heterogeneity among the pooled set of wells based on the Wilcoxon test for trend (U.S. EPA 2011a, Sections 8.4.1.2, 8.5, and Appendix D, section D.4). Also given is an approximation to the sample size needed to test for pre - post differences so that power and Type I[3] error of the statistical analysis are controlled (U.S. EPA 2011a, Appendix E, Table E-4).

The SAB recommends the technical report consider the complications that arise in practice when applying this relatively simple and straightforward approach to data from ISL uranium mining. A few of these complications are discussed in the following subsections.

6.2.1. Strengths and Weaknesses of Non-Parametric Approach

The general non-parametric approach taken has weaknesses as well as strengths. While robustness to outliers, non-detects, and data blunders such as mis-recording values is greater with the non-parametric procedures, something is lost in terms of modeling flexibility. For example, a linear model framework can more readily incorporate correlations between measurements by specifying models for both the means and the variances of the measurements. Also, repeated measurements (same well, same time) can be properly handled whether or not they are available consistently (taken at each time period) or only sporadically.

[3] In statistics, a Type I error may be compared with a false positive. It is an error of the first kind and is the wrong decision that is made when a test rejects the null hypothesis.

The proposed test for heterogeneity (across wells) based on using the z-scores[4] from the Wilcoxon test assumes that all z-scores are constructed to be equally informative about the overall post - pre differences. This would not be the case if some wells have more measurements than do other wells. Wells with larger z scores may simply have more observations available (and hence more power) to detect the post - pre level changes. If all wells have the same number of pre and post measurements then the proposed method of testing for heterogeneity should be appropriate. The linear model framework, when it applies, provides a more general test for heterogeneity not dependent upon having the same number of observations per well.

6.2.2. Implications of Heterogeneity

The draft technical report does not propose what actions might be taken if heterogeneous results are found for the post - pre differences for different wells. What actions are likely to be triggered if there is evidence of a single well (or of several wells) in which post - pre difference criteria have not been met?

6.2.3. Grouping of Wells

The draft technical report pays little attention to deciding how wells should be grouped to test for either overall patterns or heterogeneity, and whether all wells in a grouping should be treated the same in such tests. For example, it makes little sense to analyze distant wells or wells that are up gradient in the same way as the wells most proximal to the aquifers or injection locations of interest. Including unaffected wells in the analysis tends both to attenuate the overall estimate of post-pre mining differences and to reduce the ability to detect heterogeneity. If heterogeneity is detected, it would be reasonable to specify additional analyses that relate the levels to factors such as distance from injection points and groundwater gradients. Again, this can be done more readily in the framework of linear models than with nonparametric tests.

6.2.4. Periodic Patterns and Trends

Seasonality, or whatever underlying factor it represents, complicates the proposed analyses. Sufficient data must be collected to estimate seasonal trends and account adequately for seasonality in the statistical analysis. This requires at least two years of data (a minimum of one year pre- and one year post-operation) under the assumption that only the overall level of contamination and not the seasonal pattern has been disturbed by the mining/restoration process. Seasonal patterns in concentration levels that are dominated by very short-term but intense events (e.g., heavy rainfall events that recharge aquifers with oxygenated water over just a few days in the summer months) require both more measurements per year and more years of data to determine the response of the post-mining/restoration water system to these events.

A carefully designed monitoring plan in which each well has equivalently timed measurements (quarterly or monthly measurements taken at the same dates in each period) will largely eliminate the need for seasonal adjustment because the seasonality terms can be "subtracted out" when statistical tests of post-pre differences are performed. Again, if sporadic but intense events dominate seasonal differences, more years of data and or more measurements per year are required to capture differences (post – pre mining) in response to these events. Based on comments provided to the RAC (E. Striz,

[4] In statistics, z-scores are standard scores, normal scores, or standardized variables. The z-score allows comparison of observations from different normal distributions.

personal communication), such events (or seasonal patterns generally) rarely markedly affect the deep aquifers of interest.

6.2.5. Role of Modeling in Assessment

Modeling of groundwater and geochemical dynamics plays a crucial role in assessing which aquifers are at risk, the dimensions of the affected areas, the constituents most affected by the long-term effects of ISL mining and restoration, and the time required for restoration. Modeling of aquifer conditions and chemical dynamics is crucial in designing an appropriate assessment of pre-mining groundwater constituents, including spatial and temporal extent of monitoring. In addition, modeling can define constituents that should be monitored closely because of the risk attributed to them directly, and because of their role in the underlying chemistry that may be affected by ISL mining and restoration. Modeling also plays an important role in interpreting restoration monitoring results, especially when monitoring shows that certain analytes are not returned to baseline or predefined concentrations. This can be seen in several of the examples given in the appendix to the draft technical report.

Overall, modeling assists in designing monitoring and interpreting its results, but cannot make up for poor monitoring design. A certain margin of safety for each spatial, temporal, and chemical dimension of a monitoring program for the pre- and post-mining/restoration periods needs to be adopted so that the long-term effects of ISL mining and recovery on all chemical constituents of groundwater relevant to public health will be well characterized even in situations when models are incomplete or assumptions are not met.

6.2.6. Multiple Comparisons

The hypothesis-testing framework described in the draft technical report gives a rather different context for discussions of multiple comparisons than is typical, and the discussion of multiple comparisons seems a bit off focus from the hypothesis testing framework. In the draft technical report, the null hypothesis is that the post – pre mining differences for a given potential pollutant are at or above a given criterion, Δ. In usual multiple comparisons analysis, one is concerned with making the experiment-wide Type I error of concluding that ANY of the post – pre differences, δ, are different than the null value Δ, when they are all in fact truly at the null value. In such analysis, one is interested in controlling the probability that the minimum value of a set of p-values {p_1, p_2, … , p_n} is less than some fixed value alpha (each p_k corresponds to the overall p-value for some potential pollutant).

Here, things are a bit different; because the site will not be regarded as clean unless all potential pollutants are significantly below each Δ criteria (which may be different for each pollutant), an "experiment-wide" error would only occur if all {p_1, p_2, … , p_n} were below alpha. It is this probability that should be controlled under the null hypothesis. However, the null hypothesis of interest now is not the global null hypothesis (i.e., that all post – pre differences, δ, are at or above Δ, in which case we could allow a very relaxed p-value). Rather, the composite null hypothesis is that at least one of the δ are equal or above Δ. In particular, for the null hypothesis that exactly one of the δ is equal to Δ and all other δ are so far from Δ that the power to reject δ=Δ is close to 1, then testing each hypothesis at the nominal level alpha does indeed control the experiment-wise false positive rate at this same alpha level.

For all other possible null hypotheses (more than one δ equal to Δ), the nominal level provides a conservative test. In this setting, control of the experiment-wide Type I error rate is accomplished by simply ignoring the fact that more than one comparison has been made while testing each hypothesis in turn.

In this arrangement, the concern with multiple comparisons is not loss of control of a global Type I error rate, but rather, loss of control of power. Because the site is released only if all null hypotheses are rejected, then the sample size needs to be set so that a reasonable probability exists that all null hypotheses can be rejected, assuming that they are all false.The site operators' interest lies in performing a careful power analysis to provide enough measurements to decrease considerably the nominal Type II[5] error for each test, while keeping the Type I error rate at a traditional (e.g., 5 or 10 percent) value in each analysis.

6.2.7. Bayesian Approaches

Another option which the EPA might consider is the use of Bayesian methodology to determine the efficacy of post-operational restoration. For example, pre-operational monitoring data may lend themselves to the formation of robust, realistic and informative prior distributions of groundwater constituents. An analysis using these data to estimate parameters of the prior distributions is similar to an Empirical Bayes method and can be viewed as an approximation to the complete hierarchical Bayesian analysis (Martz 2000; Gelman et al. 2009). If this methodology were to be adopted, then a decision-making process that uses Bayesian posterior densities to determine whether or not groundwater restoration has been completed would need to be developed.

[5] In statistics, a Type II error may be compared with a false negative. It is an error of the second kind and is the wrong decision that is made when a test fails to reject a false null hypothesis.

7. ADDITIONAL ISSUES BEYOND THE CHARGE

7.1. Monitoring Beyond Groundwater

The following situations may only indirectly affect post-closure groundwater monitoring, but can impact efforts to protect public health and the environment. For this reason, the EPA may wish to mention in the technical report these potential events, the efforts responsive to them, and the range of actions considered by the EPA to control possible adverse environmental consequences. Any impacts addressed in 40 CFR Part 192 in connection with surface or underground mining can be referenced.

- Release of liquid, solid, and airborne contaminants during routine operation from surface structures, pipelines, evaporation ponds, well drilling, and sample collection,
- Effect of accidents, incidents, and natural disasters on distributing lixiviant-borne contaminants or disturbing post-closure groundwater contents, and
- Contribution by nearby mining, abandoned mines, and waste sites to the constituents of post-closure groundwater.

7.2. Potential Impacts on Groundwater

Alterations of the ore body aquifer chemistry are expected to be minor if the aquifer is confined, is not a potential drinking water source, and will be restored to preoperational baseline quality. The EPA needs to assure that ISL uranium mining does not occur in aquifers that are currently used or planned for use by local populations for domestic use, livestock watering and agricultural uses. Uranium mining by ISL could permanently and significantly alter such use patterns.

7.3. Establishing DQOs

The SAB recommends in Sections 4.2 and 4.5 that the EPA define explicitly the DQO framework in the technical report. The adequacy and technical accuracy of information in the EPA's draft technical report—specifically, information related to the four charge questions for this advisory activity—can best be assured if the agency implements the DQO process for this project to define its objectives and its options for meeting those objectives. The absence of succinct definitions of these critical details complicated the SAB's ability to identify the information and actions needed by the agency to review the adequacy of existing regulatory standards in 40 CFR Part 192. For example, the compliance points for the standards are not consistently clear, the extent to which the existing standards are being met cannot be assessed, and the alternative technical approaches for meeting objectives are not explicit. This presents difficulties to relate DQOs to potential options being considered within the existing draft document.

7.4. Integration with Other EPA Regulatory Programs Applicable to Groundwater Quality

The EPA may wish to address explicitly in the technical report how the agency will integrate the ISL uranium mining standards with the long-established and well-documented requirements and guidance for other EPA regulatory programs that are also applicable to groundwater quality and that address many of the same groundwater monitoring challenges. The discussion in the draft technical report concerning the applicability of RCRA is a good example.

7.5. Tapping Existing Resources for Environmental Modeling

Modeling is complementary to monitoring in attaining a full understanding of groundwater quality at ISL uranium mines and the EPA can draw upon existing modeling efforts for this task. For example, ORIA has undertaken cooperative multiagency modeling efforts to support regulatory programs, including enviromental pathway models for groundwater modeling to inform remediation at sites contaminated with radioactive material and hazardous waste (EPA 1993a, 1993b, 1993c).

Another source of information is the EPA SAB's review of the EPA's 2003 draft guidance on the development, evaluation, and application of regulatory environmental models and Models Knowledge Base (MKB) (U.S. EPA 2003), prepared by the EPA Council for Regulatory Environmental Modeling (CREM). In the SAB review, the panel emphasized a number of ways in which the *Draft Guidance* and *MKB* can be improved (US EPA SAB 2006). The following points from that review may be relevant to technical guidance supporting the regulatory program for uranium ISL sites:

- Care in articulating the audience to which the *Draft Guidance* is directed;
- The need to develop and apply models within the context of a specific problem;
- Caution in the way that information on modeling uncertainty is evaluated and communicated, and the need for *Draft Guidance* to fully discuss uncertainty and sensitivity analysis methods;
- Consistency in conforming the terminology used in the *Draft Guidance* to previous uses and meanings of these terms in other environmental modeling activities; and
- The need to gather, and in many cases to develop, additional information to be included in the modeling database, including the framework, evaluation, and limitations of individual models; and to implement a mechanism that allows the community of model users to submit feedback on their experiences and suggestions for model improvement.

The EPA (U.S. EPA/ORD Office of the Science Advisor) and the U.S. Dept of Transportation were co-sponsors of a National Academy of Sciences study (NAS 2007) on the use of models to inform the regulatory decision-making process. The report prepared by the NAS Committee on Models in the Regulatory Decision Process recommended that evaluation of a regulatory model should continue throughout the life of a model, including throughout regulatory applications and revisions of the model. The NAS committee observed that the one-time peer review of a model that is typically seen in the published literature is insufficient for many models used in the environmental regulatory process, and that more time, effort, and variety of expertise is required to conduct and respond to peer review at different stages of the life cycle, especially for complex models. The NAS committee also noted that a wide range of possibilities is available for performing model uncertainty analysis and that, in some cases, presenting results from a small number of model scenarios will provide an adequate uncertainty analysis. In many instances, however, probabilistic methods will be necessary to characterize properly at least some of the uncertainties and that there is a need to communicate clearly all of the uncertainties. The NAS Committee report touched on communicating uncertainty, the interdependence of models and measurements, principles for model development, the selection and application of models, the issue of proprietary models, model management in the rule-making context, improving model accessibility, and related topics.

The EPA CREM published its guidance (U.S. EPA 2009a) following the reviews of modeling evaluations by the SAB, the NAS and NACEPT (U.S. EPA NACEPT 2008). The CREM guidance provides an overview of the best practices for ensuring and evaluating the quality of environmental models.

7.6. Working Relationship with the NRC

During its face-to-face meeting, the RAC observed what appeared to be insufficient communication between ORIA and NRC staff concerning the accessibility groundwater monitoring data and its regulatory implications for ISL uranium mining. As a result, the EPA draft technical report suffered from a lack of operational details and delineation of present-day guidelines for monitoring. The EPA is encouraged to conduct a cooperative dialog and to consider the establishment of a working group—perhaps similar to the MARSSIM Working Group—to coordinate its review of the uranium mining standards.

7.7. Importance of Uranium Mining Standards Review and Update

As noted in the EPA's draft technical report, protocols for establishing baseline groundwater quality (as well as for monitoring groundwater before, during, and after mining) are established in the facility license issued by the NRC or applicable Agreement State (U.S. EPA 2011a, p. 26). Regarding this practice, the SAB agrees with the statement made by the NRC's Center for Nuclear Waste Regulatory Analyses (U.S. NRC. 2001, p. 1-1):

> *Widespread use of license conditions is not an optimum regulatory framework. Since these license conditions are subject to rejection or modification through legal challenge, they add substantial uncertainty and economic and operational risk to ISL operations. Ensuring consistency of requirements for all licensees is also difficult with widespread use of license conditions.*

In summary, the SAB believes that the critical review and update of the EPA ISL uranium mine standards are necessary and timely.

REFERENCES

Abitz, R. and B. Darling. 2010. *Anthropogenic Induced Redox Disequilibrium in Uranium Ore Zones*. Geological Society of America Abstracts with Programs, Vol. 42, No. 5, p. 56. http://pbadupws.nrc.gov/docs/ML1103/ML110320700.pdf. (Accessed October 31, 2011).

Ablequist, E. W. 2008. Dose Modeling and Statistical Assessment of Hot Spots for Decommissioning Applications, A Dissertation Presented for the Degree of Doctor of Philosophy, The University of Tennessee, Knoxville, August 2008.

Bain, J.G., K.U. Mayer, D.W. Blowes, E.O. Frind, J.W.H. Molson, R. Kahnt and U. Jenk. 2001. Modeling the closure-related geochemical evolution of groundwater at a former uranium mine. *J. Contaminant Hydrology* 52:109-135.

Bethke C.M. and S. Yeakel. 2009. The Geochemist's Workbench®, Release 8.0, Reference Manual. Hydrogeology Program, University of Illinois, Urbana, IL. Software and associated documentation are distributed by RockWare; accessible at http://www.rockware.com/product/overview.php?id=132

Borch, T., R. Kretzschmar, A. Kappler, P.V. Cappellen, M. Ginder-Vogel, A. Voegelin and K. Campbell. 2010. Biogeochemical redox Processes and their impact on contaminant dynamics. *Environ. Sci. Technol.* 44:15-23.

Catalano, J.G. and G.E. Brown Jr. 2005. Uranyl adsorption onto montmorillonite: Evaluation of binding sites and carbonate complexation. *Geochim. Cosmochim. Acta* 69:2995-3005.

Charbeneau, R.J. 1984. Groundwater Restoration with In Situ Uranium Leach Mine, in *Groundwater Contamination*, National Academies Press, Washington DC.

Fjeld, R. A., N.A. Eisenberg and K.L. Compton. 2007. Quantitative Environmental Risk Analysis for Human Health. John Wiley and Sons Inc: Hoboken, 2007. 390 pages.

Gelman, A., J.B. Carlin, H.S. Stern and D.B. Rubin. 2009. *Bayesian Data Analysis*. Chapman & Hall / CRC Texts in Statistical Science.

Hall, S. 2009. Groundwater Restoration at Uranium In-Situ Recovery Mines, South Texas Coastal Plain, U.S. Department of the Interior, U.S. Geological Survey, Open File Report 2009-1143.

Kim, Y.J., J.W. Moon, Y. Roh and S.C. Brooks. 2009. Mineralogical characterization of saprolite at the FRC background site in Oak Ridge, Tennessee. *Environ. Geol.* 58:1301-1307.

Lindsay, W.L. 1979. Chemical Equilibria in Soils. John Wiley and Sons Ltd: New York. 449 pages.

Martz, H.F. 2000. An Introduction to Bayes, Hierarchical Bayes and Empirical Bayes Statistical Methods in Health Physics, in *Applications of Probability and Statistics in Health Physics*, T.B. Botak ed. Medical Physics Publishing, Madison WI.

Moyes, L.M., R.H. Parkman, J.M. Parkman, D.J. Vaughan, F.R. Livens, C.R. Hughes and A. Braithwaite. 2000. Uranium uptake from aqueous solution by interaction with goethite, lepidocrocite, muscovite, and mackinawite: An x-ray adsoprtion spectroscopy study. *Environ. Sci. Technol.* 34:1062-1068.

Myers, J. and K. Thorbjornsen. 2004. Identifying Metals Contamination in Soil: A Geochemical Approach. *Soil & Sediment Contamination* 3:1-16.

NAS (National Academy of Sciences). 2007. *Models in Environmental Regulatory Decision Making*, Committee on Models in the regulatory Decision process, Board on Environmental Studies and Toxicology, Division of Earth and Life Sciences, National Research Council of the National Academies, The National Academies Press, Washington, D.C.

Oppenheim, A.V. and R.W. Schafer. 2010. Discrete-Time Signal Processing. Third Edition. Pearson Prentice Hall, Upper Saddle River NJ. Pp. 160-161.

Parkhurst D. L. and C.A.J. Appelo. 1999. "Users Guide to PHREEQC (Version 2) – A Computer Program for Speciation, Batch-Reaction, One-Dimensional Transport, and Inverse Geochemical Calculations," United States Geological Survey, Water-Resources Investigations Report 99-4259, Denver, CO. Web link http://wwwbrr.cr.usgs.gov/projects/GWC_coupled/phreeqc/html/final.html

Power, R.H., Jr. 2004. Fingerprint Analysis of Contaminant Data: A Forensic Tool for Evaluating Environmental Contamination. EPA/600/5-04/054. May 2004.

South Dakota Codified Laws (SDCL). Chapter 45-6B Mined Land Reclamation (web link http://legis.state.sd.us/statutes/DisplayStatute.aspx?Statute=45-6B&Type=Statute). Chapter 74:55:01 Underground Injection Control—Class III Wells (Web link http://legis.state.sd.us/rules/DisplayRule.aspx?Rule=74:55&Type=All) (Accessed October 22, 2011).

Sass, R.L. 2011. *Uranium Mining in Texas: Why Is It Done That Way?* James A. Baker III Institute for Public Policy, Rice University, Houston, Texas. http://bakerinstitute.org/publications/GCC-pub-SassUraniumMining-032811.pdf (Accessed October 31, 2011).

Steefel, C.I. 2009. CrunchFlow: Software for Modeling Multicomponent Reactive Flow and Transport. User's Manual. October 12, 2009. Web link http://www.csteefel.com/CrunchPublic/CrunchFlowManual.pdf

Striz, E. A. 2011. *ISR Application and Licensing Actions: Hydrogeology Lessons Learned*, Presentation by Elise A. Striz, Ph.D., Hydrogeologist in the Uranium Recovery and Licensing Branch of the U.S. NRC, given at the public MNA/NRC Uranium Recovery Workshop in Denver CO, January, 2011. Available from the U. S. NRC Website at www.nrc.gov/materials/uranium-recovery/public-meetings/ur-workshops/estriz- nrc.pdf-2011-03-31

Texas Administrative Code (TAC). Title 30 Environmental Quality, Part 1 Texas Commission on Environmental Quality, Chapter 331 Underground Injection Control. Posted on the web site http://info.sos.state.tx.us/pls/pub/readtac$ext.ViewTAC?tac_view=5&ti=30&pt=1&ch=331&sch=E&rl=Y (Accessed October 22, 2011).

Thorbjornsen, K. and J. Myers. 2008. Geochemical Evaluation of Metals in Groundwater at Long-Term Monitoring Sites and Active Remediation Sites. *Remediation*, Spring 2008, pp 99-114.

U.S. Bureau of Mines. 1981. In Situ Mining Research. Bureau of Mines Information Circular 8852. U. S. Dept. of the Interior.

U.S. EPA. 40 CFR Part 192, Subpart A – Standards for the Control of Residual Radioactive Materials from Inactive Uranium Processing Sites, July 1, 2002 edition

U.S. EPA. 1987. Alternative Concentraion Limit Guidance. Part I. ACL Policy and Information Requirements (Interim Final). July 1987. OSWER Directive 9481.00-6C. EPA/530-SW-87-017. Web site http://www.epa.gov/epawaste/hazard/correctiveaction/resources/guidance/gw/acl.htm

U.S. EPA. 1993a. Environmental Pathway Models—Ground-Water Modeling in Support of Remedial Decision-Making at Sites Contaminated with Radioactive Material, EPA 402-R-93-009, March, 1993

U.S. EPA. 1993b. Environmental Characteristics of EPA, NRC, and DOE Sites Contaminated with Radioactive Substances, EPA 402-R-93-011, March 1993.

U.S. EPA. 1993c. Computer Models Used to Support Cleanup Decision-Making at Hazardous and Radioactive Waste Sites, EPA 402R-93-005, March 1993.

U.S. EPA. 2003. *Draft Guidance on the Development, Evaluation, and Application of Regulatory Environmental Models*, Prepared by The Council for Regulatory Environmental Modeling (CREM), November 2003, 60 pages.

U.S. EPA. 2008. Technologically Enhanced Naturally Occurring Radioactive Materials From Uranium Mining, Volume 1: Mining and Reclamation Background, and Volume 2: Investigation of Potential Health, Geographic, and Environmental Issues of Abandoned Uranium Mines, Office of Radiation and Indoor Air, Radiation Protection Division (6608J), Washington, DC, EPA-402-R-08-005, April 2008.

U.S. EPA. 2009a. Guidance on the Development, Evaluation, and Application of Environmental Models, Office of the Science Advisor, Council for Regulatory Environmental Modeling (CREM), EPA/100K-09/ 003, March 2009.

U.S. EPA. 2009b. Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, Unified Guidance, EPA 530/R-09-007, EPA Office of Resource Conservation and Recovery, March 2009

U.S. EPA. 2010. Monitored Natural Attenuation of Inorganic Contaminants in Ground Water, Volume 3: Assessment for Radionuclides Including Tritium, Radon, Strontium, Technetium, Uranium, Iodine, Radium, Thorium, Cesium, and Plutonium-Americium, Edited by Robert G. Ford, Land Remediation and Pollution Control Division, Cincinnati, Ohio, and Richard T. Wilkin, Ground Water and Ecosystems Restoration Division, Ada Oklahoma, National Risk Management Research Laboratory, Office of Research and Development, U.S. EPA, Cincinnati, Ohio, EPA/600/R-10/093, September 2010.

U.S. EPA 2011a. Considerations Related to Post-Closure Monitoring of Uranuim In-Situ Leach/In-Situ Recovery (ISL/ISR) Sites, Draft Technical Report, U.S. Environmental Protection Agency, Office of Air and Radiation, Radiation Protection Division, June 2011. Web link http://www.epa.gov/radiation/docs/tenorm/post-closure-monitoring.pdf

U.S. EPA. 2011b. 2011 Edition of the Drinking Water Standards and Health Advisories. EPA 820-R-11-002. January 2011. Web link http://water.epa.gov/action/advisories/drinking/upload/dwstandards2011.pdf U.S. EPA. *Models Knowledge Base* (MKB, or KBase). Link is available at: http://cfpub.epa.gov/crem/crem_report.cfm?deid=74913

U.S. EPA NACEPT. 2008. *White Paper on Integrated Modeling for Integrated Environmental Decision Making*, National Council for Environmental Policy and Technology (NACEPT), Sept. 22, 2008, 11 pages

U.S. EPA Regions 3, 6, and 9. 2011. Regional Screening Levels for Chemical Contaminants at Superfund Sites. http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm

U.S. EPA SAB. 1989. *Resolution on Use of Mathematical Models by EPA for Regulatory Assessment and Decision-Making*, Report of the Environmental Engineering Committee, EPA-SAB-EEC-89-012, January 13, 1989

U.S. EPA SAB. 2006. Review of Agency Draft Guidance on the Development, Evaluation, and Application of Regulatory Environmental Models and Models Knowledge Base, by the Regulatory Environmental Modeling Guidance Review Panel of the EPA Science Advisory Board, EPA-SAB-06-009, August 22, 2006

U.S. NRC. 2003. Standard Review Plan for In Situ Leach Uranium Extraction License Applications: Final Report. NUREG-1569. June 2003.

U.S. NRC. 2004. Materials License SUA-1580 Amendment No. 2. Licensee Hydro Resources, Inc. (HRI) for the Crownpoint Uranium Project. Dated August 16, 2004. ADAMS Accession Number ML042330776. Accessible at http://www.nrc.gov/reading-rm/adams.html

U.S. NRC. 2007. Consideration of Geochemical Issues in Groundwater Restorations at Uranium In-Situ Leach Mining Facilities, NUREG/CR-6870, Authors: J.A. Davis and G.P. Curtis. January 2007. ML070600405. Accessible through ADAMS: http://wba.nrc.gov:8080/ves/

U.S. NRC. 2011. Request for review of restoration action plan revisions, Hydro Resources, Inc., Crownpoint Uranium Project. Letter dated October 14, 2011, from K.I. McConnell (NRC) to M.S. Pelizza (HRI). Docket No. 040-08968. License No. SUA-1580. ADAMS Accession Number ML112140558. Accessible at http://www.nrc.gov/reading-rm/adams.html

U.S. NRC. 10 CFR Part 40 Appendix A to Part 40 - - Criteria Relating to the Operation of Uranium Mills and the Disposition of Tailings orWastes Produced by the Extraction or Concentration of Source Material From Ores Processed Primarily for Their Source Material Content, NRC Library Document Collections.

Wan, J. M., T.K. Tokunaga, E. Brodie, Z.M. Wang, Z.P. Zheng, D. Herman, T.C. Hazen, M.K. Firestone, and S.R. Sutton. 2005. Reoxidation of bioreduced uranium under reducing conditions. *Environ. Sci. Technol.* 39 (16):6162-6169.

Wu, W.M., J. Carley, M. Fienen, T. Mehlhorn, K. Lowe, J. Nyman, J. Luo, M. E. Gentile, R. Rajan, D. Wagner, R.F. Hickey, B. Gu, D. Watson, O.A. Cirpka, P.K. Kitanidis, P.M. Jardine, and C.S. Criddle. 2006. Pilot-Scale in Situ Bioremediation of Uranium in a Highly Contaminated Aquifer. 1. Conditioning of a Treatment Zone. *Environ. Sci. Technol.* 40:3978-3985.

APPENDIX A. THE CHARGE FROM THE AGENCY TO THE SAB

June 2, 2011

MEMORANDUM

SUBJECT: Advisory Review of the Draft Technical Report: *Considerations Related to Post-Closure Monitoring of Uranium In-Situ Leach/In-Situ Recovery (ISL/ISR) Sites*

FROM: Michael P. Flynn, Director /S/
Office of Radiation and Indoor Air

TO: Vanessa Vu, Director
Science Advisory Board

This is to request that the Science Advisory Board's augmented Radiation Advisory Committee (RAC) conduct an advisory review of the attached draft *Technical Report: Considerations Related to Post-Closure Monitoring of Uranium In-Situ Leach /In-Situ Recovery (ISL/ISR) Sites* (Technical Report).

Background

In accordance with the Uranium Mill Tailings Radiation Control Act (UMTRCA) section 206, the Environmental Protection Agency (EPA) is authorized to develop standards for the protection of public health, safety, and the environment from radiological and non-radiological hazards associated with residual radioactive materials. Regulatory standards implementing UMTRCA (40 CFR Part 192 Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings) were originally issued in 1983, and last revised in 1995. EPA is currently conducting a review of its regulations for uranium and thorium milling to determine if the existing standards in 40 CFR Part 192 should be updated.

While the existing regulatory standards apply to both conventional mills and unconventional ore processing methods, they were not written in anticipation of new technologies such as heap leaching and in-situ leach/in-situ recovery (ISL/ISR). With ISL/ISR operations expected to be the most common type of new uranium extraction facility in the U.S., and the potential for these facilities to affect groundwater, EPA has prepared the attached draft Technical Report, which addresses considerations involved in establishing groundwater monitoring systems around uranium ISL/ISR operations.
There are several objectives for monitoring an ISL/ISR uranium extraction operation, specifically:

1) to establish baseline (pre-mining) groundwater chemical compositions;
2) to detect excursions of the injected and mobilized components beyond the well field; and
3) to determine when the post-mining/restoration phase groundwater chemistry has "stabilized," *i.e.*, reached concentration levels that are expected to remain constant over time.

EPA is considering including groundwater monitoring requirements as a component of the regulatory standards included in any revision of 40 CFR Part 192. The draft Technical Report is intended to support the technical considerations about monitoring requirements (*e.g.*, sampling protocols, timeframes, statistical tools and techniques) that may be included in revisions to 40 CFR Part 192.

Specific Request

At this time, EPA is seeking advice from the RAC on the technical considerations relevant to establishing monitoring plans to achieve the objectives described above. The Technical Report focuses on these considerations for designing and implementing a monitoring network. After receiving the advisory review, EPA plans to revise the Technical Report and use the information as a basis for updating 40 CFR Part 192 to explicitly address ISL/ISR extraction processes.

Specifically, EPA requests that the RAC provide comments on the following:

1) The technical areas described in the report and their relative importance for designing and implementing a monitoring network. Identify any technical considerations that have been omitted or mischaracterized.
2) The proposed approaches for characterizing baseline groundwater chemical conditions in the pre-mining phase and proposed approaches for determining the duration of such monitoring to establish baseline conditions.
3) The approaches considered for monitoring in the post-mining/restoration phase and the approaches considered for determining when groundwater chemistry has reached a "stable" level.
4) Suitable statistical techniques that would be applicable for use with ISL/ISR mining applications (particularly for the areas in Items 2 and 3 above), as well as the subsequent data requirements for their use.

If you have any questions about this request, please contact Mary E. Clark of my staff at (202) 343-9348.

Attachment

cc: Carl Mazza, OAR

APPENDIX B. WATER QUALITY PARAMETERS FOR GROUNDWATER MONITORING AT ISL URANIUM MINING SITES

Table B-1. Primary and secondary water-quality parameters

Parameter[a,b]	Primary Relevance for Baseline Determination and Post-Operational Monitoring[c]	Mentioned in NRC guidance and/or baseline data reported by operator or applicant				Mentioned in Regulations or EPA Screening Level Guidance	
		NRC 2003	Crownpoint License (NM)	Production Authorization Areas (PAAs) (TX)	Dewey-Burdock (ND)	Applicable EPA and NRC regulations[d]	Other EPA groundwater standards or screening levels[e]
Major Ions							
Bicarbonate	Excursion indicator, geochemical modeling, source fingerprint	●	●	●	●	–	–
Calcium	Source fingerprint, geochemical modeling	●	●	●	●	–	–
Carbonate	Geochemical modeling	●	●	●	●	–	–
Chloride	Excursion indicator, geochemical modeling, source fingerprint	●	●	●	●	–	SMCL
Fluoride	Source fingerprint, geochemical modeling	●	●	●	●	–	SMCL, RSL
Magnesium	Source fingerprint, geochemical modeling	●	●	●	●	–	–
Nitrate	Redox indicator, source fingerprint	●	●	●	●	–	MCL
Potassium	Source fingerprint, geochemical modeling	●	●	●	●	–	–
Silica	Well performance indicator, geochemical modeling	–	–	●	●	–	–
Sodium	Source fingerprint, geochemical modeling	●	●	●	●	–	–
Sulfate	Excursion indicator, geochemical modeling, source fingerprint	●	●	●	●	–	SMCL
Trace Nonmetal Constituents							
Ammonia	Redox indicator, geochemical modeling	●	●	–	●	–	RSL, HA
Phosphate	Geochemical modeling	–	–	–	–	–	–
Sulfide	Redox indicator, geochemical modeling	–	–	–	–	–	–
General Water Chemistry							
Alkalinity	Excursion indicator, geochemical modeling, source fingerprint	●	●	●	●	–	–
Total Dissolved Solids	Excursion indicator, well performance indicator	●	●	●	●	–	SMCL
Total Organic Carbon	Well performance indicator	–	–	–	–	–	–

Parameter[a,b]	Primary Relevance for Baseline Determination and Post-Operational Monitoring[c]	Mentioned in NRC guidance and/or baseline data reported by operator or applicant				Mentioned in Regulations or EPA Screening Level Guidance	
		NRC 2003	Crownpoint License (NM)	Production Authorization Areas (PAAs) (TX)	Dewey-Burdock (ND)	Applicable EPA and NRC regulations[d]	Other EPA groundwater standards or screening levels[e]
Total Suspended Solids	Well performance indicator	–	–	–	–	–	–
Field Parameters							
Dissolved Oxygen	Redox indicator, well performance indicator	–	–	–	–	–	–
Oxidation Reduction Potential	Redox indicator, well performance indicator	–	–	–	●	–	–
pH	Excursion indicator, geochemical modeling, source fingerprint	●	–	●	●	–	SMCL
Conductivity	Excursion indicator, well performance indicator	●	●	●	●	–	–
Temperature	Well performance indicator	–	–	–	–	–	–
Turbidity	Well performance indicator	–	–	–	–	–	–
Water level	Excursion indicator, well performance indicator	–	–	–	–	●	–
Trace Metals							
Aluminum	Well performance indicator, geochemical modeling, source fingerprint for trace metals	●	–	–	●	–	SMCL, RSL
Antimony	–	–	–	–	●	●	MCLG, RSL
Arsenic	Mobilized COC, redox indicator	●	●	●	●	●	MCL
Barium	Mobilized COC, geochemical modeling, source fingerprint	●	●	–	●	●	MCL
Beryllium	–	–	–	–	●	●	MCL
Boron	Source fingerprint	●	●	–	●		HA, RSL
Cadmium	–	●	●	●	●	●	MCL
Chromium	Mobilized COC, redox indicator, geochemical modeling	●	●	–	●	●	MCL
Cobalt	–	–	–	–	–	–	RSL
Copper	Mobilized COC, geochemical modeling	●	●	–	●	–	MCLG, SMCL
Iron	Well performance indicator, redox indicator, geochemical modeling	●	●	●	●	–	SMCL, RSL
Lead	Mobilized COC, geochemical modeling	●	●	●	●	●	MCL

Parameter[a,b]	Primary Relevance for Baseline Determination and Post-Operational Monitoring[c]	Mentioned in NRC guidance and/or baseline data reported by operator or applicant				Mentioned in Regulations or EPA Screening Level Guidance	
		NRC 2003	Crownpoint License (NM)	Production Authorization Areas (PAAs) (TX)	Dewey-Burdock (ND)	Applicable EPA and NRC regulations[d]	Other EPA groundwater standards or screening levels[e]
Manganese	Well performance indicator, redox indicator, geochemical modeling	●	●	●	●	–	HA, SMCL, RSL
Mercury	Mobilized COC	●	●	●	●	●	MCL
Molybdenum	Mobilized COC, excursion indicator, redox indicator, geochemical modeling	●	●	●	●	●	HA, RSL
Nickel	Mobilized COC	●	●		●	●	HA, RSL
Selenium	Mobilized COC, excursion indicator, redox indicator, geochemical modeling	●	●	●	●	●	MCL
Silver	–	●	●	–	●	●	HA, SMCL, RSL
Strontium	Geochemical modeling, source fingerprint	–	–	–	●	–	HA
Thallium	–	–	–	–	●	●	MCL
Thorium	Mobilized COC	●	–	–	●	●	–
Uranium	Mobilized COC, excursion indicator, redox indicator, geochemical modeling	●	●	●	●	●	MCL
Vanadium	Mobilized COC, excursion indicator, redox indicator, geochemical modeling	●	●	–	●	●	RSL
Zinc	Mobilized COC, geochemical modeling	●	●		●		HA, SMCL, RSL
Radiological parameters							
Gross alpha	Excursion indicator, mobilized COC	●	●		●	●	MCL
Gross beta + gross gamma	Excursion indicator, mobilized COC	●	●		●		MCL
Radium-226	Excursion indicator, mobilized COC	●		●	●		MCL
Radium-228	Excursion indicator, mobilized COC	●	●			●	MCL
Radon	Mobilized COC				●		MCL
Additional site-specific parameters							
Constituents in injected solutions, e.g., lixiviants, antiscalants, pH adjustment, chemicals used during groundwater restoration		●					●
Constituents likely to be present in spills or leaks, e.g., acids, bases, salts, oxidants, reductants, pregnant lixiviant							

[a] This list was compiled based on examination of parameters listed in EPA's draft technical document (U.S. EPA 2011a, Section 4.2 and Appendix A), 40 CFR Part 192, EPA's Drinking Water Standards and Health Advisories (U.S. EPA 2011b), and Table 2.7.3-1 in U.S. NRC 2003.

[b] Parameters may be added to, or removed from, this list based on site-specific considerations.

[c] "Source fingerprint" indicates the parameter is commonly used to distinguish among different types of groundwater, such as the field in which the sample is plotted on a trilinear (Piper) diagram. "Geochemical modeling" indicates this parameter is commonly used to model the rates and interdependencies of water-chemistry reactions in geologic media, principally redox reactions, mineral-dissolution/precipitation reactions, sorption and ion-exchange reactions. "Mobilized COC" indicates the parameter is a contaminant of concern (COC) that may be released into the groundwater as a direct or indirect result of mining or restoration activites.

[d] Applicable EPA and NRC regulations include 10 CFR Part 40, 40 CFR Part 192, and 40 CFR Part 264.

[e] Other relevant EPA groundwater standards and screening levels include maximum concentrations levels (MCLs), secondary MCLs (SMCLs), MCL goals (MCLG) and health advisories (HA) for drinking water (U.S. EPA. 2011b), and EPA regional screening levels (RSLs) for tapwater (U.S. EPA Regions 3, 6, and 9. 2011).

Table B-2. Other Water-Quality Characterization Parameters

Parameter	Comments
Redox couples	
Ammonia (aq)/nitrate	–
Arsenic (III)/(V)	–
Chromium (III)/(VI)	–
Iron (II)/(III)	–
Sulfide/sulfate	–
Manganese (II)/(IV)/(VII)	–
Selenium (-II)/(0)/(IV)/(VI)	Data reported for selenium (IV) and selenium (VI) for Dewey-Burdock site (U.S. EPA. 2011, Table A-1). Measurement of selenium oxidation states would be helpful from an analysis standpoint but due to analytical limitations may not be necessary. Also, there are certainly practical limitations in sampling frequency.
Uranium (IV)/(VI)	–
Stable Isotope Ratios	
Carbon-13/Carbon-12	Potential tracer of sources, groundwater mixing, kinetic rates of geochemical processes, microbial activity
Hydrogen and oxygen isotopes	Potential tracer of sources, groundwater mixing
Sulfur-34/Sulfur-32	Potential tracer of sources, groundwater mixing, kinetic rates of geochemical processes, microbial activity
Uranium-decay series	
Lead-210	Data reported for Dewey-Burdock site (U.S. EPA. 2011, Table A-1). Mentioned in NRC 2003 but discounted
Polonium-210	Data reported for Dewey-Burdock site (U.S. EPA. 2011, Table A-1).
Radon-222	Data reported for Dewey-Burdock site (U.S. EPA. 2011, Table A-1).
Thorium-230	Data reported for Dewey-Burdock site (U.S. EPA. 2011, Table A-1).
Radium-226	–
Radium-228	–
Uranium-234/Uranium-238	Acivity ratio is an indicator of uranium release and transport processes, attenuation
Other Characterization Parameters	
Microbial community composition	Redox control
Colloid concentration and composition	Transport mechanism