Dr. Thomas Borch Comments of Sept. 5 2011 to August 25 Working Draft

Letterhead Stationary to be Added to Consensus Draft

- - - Date To Be Added - - -
Draft Template Dated August 25, 2011

EPA-SAB-11-xxx

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

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

Dear Administrator Jackson:

The Radiation Advisory Committee (RAC) of the Science Advisory Board, augmented for review of the draft technical document entitled *"Considerations Related to Post-Closure Monitoring of Uranium In-Situ Leach/In-Situ Recovery (ISL/ISR) Sites,"* (June 2011) has completed its review of the Agency's draft. This advisory provides direct answers to four charge questions posed by the Agency.

In reviewing the Agency's draft technical document during the meetings held by the SAB's RAC, the staff of the Agency's Office of Radiation and Indoor Air (ORIA) engaged in productive dialogue with the RAC and other participants. The Agency staff discussed the requirements for restoring the groundwater to predetermined conditions and the monitoring specified for determining that the in-situ leach solution remains within the minefield and that post-leaching groundwater has reached steady state. The draft technical report is concerned with pre-operational, operational, and post-operational aspects of groundwater monitoring, and the statistical means to demonstrate that pre- and post-operational groundwater quality is or is not the same. These topics inform the reader how to establish the baseline, demonstrate control of the leach solution, and show that the restored groundwater has reached steady state.

The basic advice by the RAC is to expand the draft technical report to provide - - in addition to its excellent general guidance - - sufficient specific information in the form of predictive models of spatial and temporal patterns of leach solution distribution and return by groundwater constituents to pre-operational levels. This approach should permit its reader to plan a technically and scientifically acceptable monitoring system for an *in-situ* leaching (ISL) uranium mine. The RAC realizes that, at this time, the EPA has not been able to develop a quantitative approach with only the limited data set of monitoring results that it has, but

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participants at the meetings stated that additional data sets are available from the operators of existing mines and fellow regulators, i.e., the US NRC and pertinent agreement states.

This basic advice has two broad components, for the near term and the long term. For the near term, the EPA should search out and accumulate data collected by mine operators in response to licensing conditions and guidance by the NRC or the state; compile the data systematically; and analyze the data to develop a set of guiding principles and assumptions. The point is to develop the best approach possible to a monitoring system within the limitations of insufficient information.

For the long term, e.g., a 5-year period, the EPA should reach a formal arrangement with the NRC and regulatory states to develop a carefully designed data base needed to create models that address the varied hydrogeological settings of ISL mines. These models should be built on the generally applicable physical and chemical principles that underlie currently used groundwater quality models. Gaining the participation of the scientific community would enlarge the labor force devoted to data mining and application.

Beyond this basic advice, the RAC made a number of specific recommendations to enhance and expand the current contents of the EPA draft technical report.

The SAB appreciates the opportunity to review this draft technical document and engage in thoughtful dialogue on this topic. It provides these recommendations as technical rationale and guidance to address the Agency's responsibilities for health and environmental protection aspects of 40 CFR Part 192 in compliance with section 206 of the Uranium Mill Tailings Radiation Control Act (UMTRCA, public law 95-604). We look forward to your response to the recommendations contained in this review.

Sincerely,

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

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# Augmented for Uranium In-Situ ISL/ISR Advisory

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**- - -  SAB Charter Board to be added for the Quality review Draft Cycle - - -**

Dr.  ……..(continue)……………

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# 1. EXECUTIVE SUMMARY

The Radiation Advisory Committee (RAC) of the Science Advisory Board (SAB) has completed its review of the Agency's draft technical document entitled *"Considerations Related to Post-Closure Monitoring of Uranium In-Situ leach/In-Situ Recovery (ISL/ISR) Sites "* dated June 2011 (U.S. EPA. ORIA. 2011). In the draft technical document, the EPA's Office of Radiation and Indoor Air (ORIA) describes the proposed technical approach to implementing changes in the Agency's methodology for revising 40 CFR Part 192 pertaining to EPA's Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings in accordance with the Uranium Mill Tailings Radiation and Control Act (UMTRCA) section 206, where 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. The EPA sought the SAB/RAC's advice on the technical and scientific underpinnings in the draft technical document.

In providing advice to the Agency, the RAC responded to four Charge Questions (CQs) pertaining to (1) groundwater monitoring network design, (2) baseline groundwater monitoring, (3) post-mining/restoration groundwater monitoring, and (4) suitable statistical techniques, notably for comparing pre- and post-monitoring results.

The basic advice by the RAC is to expand the draft technical report to provide - - in addition to its excellent general guidance - - sufficient specific information in the form of predictive models of spatial and temporal patterns of lixiviant distribution and return by groundwater constituents to pre-operational levels. This approach should permit its reader to plan a technically and scientifically acceptable monitoring system for an *in-situ* leaching (ISL) uranium mine.

This basic advice has two broad components, for the near term and the long term. For the near term, the EPA should search out and accumulate data collected by mine operators in response to licensing conditions and guidance by the NRC or the state; compile the data systematically; and analyze the data to develop a set of guiding principles and assumptions. The principle is to develop the best approach possible to a monitoring system, within the limitations of insufficient information. For the long term, e.g., a 5-year period, the EPA should arrange a formal arrangement with the NRC and regulatory states to develop a data base that contains the specific information needed to create models that address the varied hydrogeological settings of ISL mines. These models should be built on the generally applicable physical and chemical principles that underlie currently used groundwater quality models.

Beyond this basic advice, the RAC has the following recommendations to enhance and expand the current contents of the EPA draft technical report.

CQ 1:

1. Identify the indicators, both chemical and radioactive, for establishing conditions both pre- and post-operational;

2. Distinguish between primary and secondary indicators on basis of risk, return to pre-operating conditions, and information concerning other constituents;
3. Use monitoring information to develop insight into interactions and transformations during and after operation;
4. Develop systematic guidance for pattern of monitoring wells and sample collection, both for controlling the extent of contamination and comparing pre- and post-operational data;
5. Enhance post-operational trend monitoring by modeling groundwater indicator patterns; and
6. Include both water and soil monitoring for pre- and post-operation.

CQ 2:

1. Define monitoring objectives by the Data Quality Objectives approach;
2. Consider non-hazardous groundwater and soil constituents, e.g., iron (minerals), type of soil/geological material~~aluminum~~, and characteristics, e.g., pH, Eh~~eH~~, that can affect constituents of interest;
3. Establish occurrences and causes of temporal variations, e.g., seasonal, in groundwater chemistry, and adjust sample collection accordingly;
4. Identify critical and vulnerable pathways for planning the monitoring program;
5. Consider baseline water quality in adjoining (above, below, to side) aquifers, and nearby activities (mining, wells) that may affect minefield; and
6. Recognize importance of applying standard sample collection techniques, record keeping, and data compilation.

CQ 3:

1. Evaluate existing data sets for applicability to modeling across varied terrain;
2. Correlate physical and chemical parameters to provide a system description for predicting concentrations of limting constituents;
3. Establish criteria for collection and analysis of monitoring data;
4. Develop indicator list, and group constituent data; and
5. Determine and confirm oxidation states of limiting and indicator constituents.

CQ 4:

1. Apply statistical approach to designing well locations and sampling frequency; and
2. Select statistical evaluation approach in terms of strengths and weaknesses to suit questions to be answered.

Beyond charge questions:

Consider monitoring for other reasons, i.e., accidents, at other locations, i.e., surface contamination, and of other media, i.e., air and solids.

**Comment [b1]:** I suggest that we clearly state that its important to measure water quality with high temporal resolution before remediation begins and during the remediation period since that will be useful as a diagnostic tool for when a steady state concentration of water constituents has been achieved!

# 2. INTRODUCTION

## 2.1 Review Process

The ORIA/EPA requested technical advice in the format of an Advisory Review from the SAB to support revision of 40 CFR Part 192 and for this purpose has prepared the draft technical report "Considerations related to post-closure monitoring of uranium in-situ leach/in-situ recovery (ISL/ISR) sites, June 1, 2011." The Director, ORIA accompanied submission of this draft technical report with the letter (see Appendix B) to request this technical advice in the form of responses to four Charge Questions. The responses to these charge questions by the Radiation Advisory Committee of SAB are given in Sections 3 – 6 of this report.

The SAB RAC met in a public teleconference meeting on July 12, 2011 and conducted a face-to-face public meeting on July 18 and 19, 2011 for this review (see 76 Fed. Reg., 36918, June 23, 2011). Additional public conference calls took place on September 6, 2011 and October 5, 2011. These notices, the charge to the RAC and other supplemental information may be found at the SAB's Web site (http://www.sab.gov/sab). The quality review draft advisory dated October __, 2011was forwarded to the Chartered SAB for their November __, 2011 public teleconference meeting (see 76 Fed. Reg., _____, 0 __, 2011). This advisory reflects the suggested editorial changes from the Charter SAB.

## 2.2 The Mining Process

Uranium mining by ISL was gradually developed during the past 40 years ansd currently is preferred to surface and underground mining for a suitably contiguous ore body located in an aquifer between effective aquitards. Although uranium mining has been quiescent during the past decade, data on ISL has been accumulated by at least 3 mines, and renewed interest in uranium mining by ISL has been demonstrated by potential mine operators.

In the ISL mining process, an uranium-solubilizing lixiviant is delivered to the subsurface ore body by a set of injection wells, withdrawn at a central recovery well, processed to extract the dissolved uranium from the liquid at a surface facility, and returned through the injection wells for further uranium dissolution and extraction. When the process is terminated after a period determined by the operator (that may exceed 10 years), the lixiviant is replaced by water (possibly with suitable reagents) that is cycled through the injection and recovery wells with the intention of restoring the site groundwater to its pre-operational quality.

The uranium-solubilizing reagent in the lixiviant usually functions by oxidizing U(IV) to U(VI) and complexing the resulting uranium ion; reagents such as $O_2$ plus $CO_2$ gases or bicarbonate ions are used. Restoring groundwater quality by flushing 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 U(IV) form, and to make insoluble any other ions that were dissolved by the lixiviant.

The regulatory framework considered for revision is in accordance with the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA). The EPA establishes health and

**Comment [b2]: New important research shows that U(IV) formation in the environment does NOT always result in the formation of stable/insoluble uraninite (but sometimes results in the formation of monomeric U(IV) such as sorbed U(IV) species complexed by mineral surfaces, versus a U(IV) mineral) !!!: See the following examples:**

Veeramani, H.; Alessi, D. S.; Suvorova, E. I.; Lezama-Pacheco, J. S.; Stubbs, J. E.; Sharp, J. O.; Dippon, U.; Kappler, A.; Bargar, J. R.; Bernier-Latmani, R., Products of abiotic u(vi) reduction by biogenic magnetite and vivianite. *Geochim. Cosmochim. Acta* **2011,** *75*, 2512-2528.

Ray, A. E.; Bargar, J. R.; Sivaswamy, V.; Dohnalkova, A. C.; Fujita, Y.; Peyton, B. M.; Magnuson, T. S., Evidence for multiple modes of uranium immobilization by an anaerobic bacterium. *Geochim. Cosmochim. Acta* **2011,** *75*, 2684-2695.

Sivaswamy, V.; Boyanov, M. I.; Peyton, B. M.; Viamajala, S.; Gerlach, R.; Apel, W. A.; Sani, R. K.; Dohnalkova, A.; Kemner, K. M.; Borch, T., Multiple mechanisms of uranium immobilization by cellulomonas sp. Strain es6. *Biotechnology and Bioengineering* **2011,** *108*, 264-276.

Bernier-Latmani, R.; Veeramani, H.; Vecchia, E. D.; Junier, P.; Lezama-Pacheco, J. S.; Suvorova, E. I.; Sharp, J. O.; Wigginton, N. S.; Bargar, J. R., Non-uraninite products of microbial u(vi) reduction. *Environ. Sci. Technol.* **2010,** *44*, 9456-9462.

environmental protection standards in Part 192. The U.S. Nuclear Regulatory Agency (NRC) or the Agreement State controls future and currently active mine operation (Part 192 'Title 2 sites') by license conditions and guidance. The U.S. DOE is responsible for control of inactive ('Title 1 sites') mining and milling sites.

### 2.3 The Draft Technical Report

The technical report describes the mining process and the regulatory response, with focus on post-closure groundwater monitoring to demonstrate return to pre-operating groundwater conditions and meeting requirements of 40 CFR Part 264, Subpart F under the Resource Recovery and Conservation Act (RCRA) for groundwater impacted by this activity. It has chapters on RCRA groundwater monitoring requirements, groundwater monitoring at ISL facilities, technical considerations for ISL/ISR facilities, statistical analyses to compare pre- and post-ISL/ISR monitoring, monitoring issues at existing ISL facilities, and issues associated with establishing post-restoration steady state in groundwater constituents.

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-stability assurance (post-closure). For the critically important 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 appended as examples

### 2.4 The Charge and Charge Questions

The Director, ORIA, in Appendix B describes the current uranium mining situation and the EPA monitoring objectives. The presented Charge Questions focus on achieving reliable analyte results -- both radiological and non-radiological -- in post-closure groundwater monitoring. Important aspects that contribute to confidence in data reliability are identified in the four Charge Questions as (1) monitoring network design, (2) effective baseline monitoring, (3) restoration-phase monitoring that can define trends in groundwater constituents and the ultimate arrival at stability, and (4) use of appropriate statistical techniques and the data collection design needed for applying these techniques.

### 2.5 The RAC Response

The RAC found the draft technical report to be the work of authors highly competent in identifying the manifold requirements of the subject monitoring program and application of appropriate statistical tools. The ORIA and NRC staff members who participated in the meetings were helpful in expanding on the report contents and effective in responding to questions by RAC members.

The report discusses calculational approaches in some detail and gives selected data sets as examples. The report presents the appropriate general knowledge and guidance, but does not provide the quantifiable information, i.e., a model with design parameters, for designing an actual program for a specific site. Further, it does not evaluate the included data sets for their applicability to support such a progam, for example, by identifying the important indicator constituents and selecting detection limits recommended in the light of experience. The reasons stated at the meetings for the absence of a recommended systematic approach to monitoring design are that only a few data sets were available to ORIA staff, that hydrogeological settings differ greatly among ISL mining sites, and that no results of detailed studies are available. Discussion by participants suggested that a considerable batch of information beyond that alluded to by ORIA can be made available, but its systematic compilation and evaluation would require a cooperative effort by the regulators – the NRC, various states, and the EPA – and past and present ISL mine operators. Processes were also discussed for involving the research community to assist in mining the data and developing predictive models.

In subsequent sections, the RAC makes a number of recommendations for enhancing the draft technical report so that it can guide future users in designing their monitoring for reliable ISL mining operation. The recommendations focus on design of post-closure monitoring to demonstrate protection of the environment and human health, as well as a reasonable return to pre-operational groundwater quality, but also identify other aspects of site monitoring.

# 3. RESPONSE TO CHARGE QUESTION 1: 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 neywork. Identify any technical considerations that have been omitted or mischaracterized.*

## 3.1 Introduction

In addressing Charge Question #1, the RAC 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
- conceptual and/or kinetic models that provide assumptions and make use of the above data.

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

## 3.2 General Recommendations

The scientific/technical approach to addressing the topic in the technical report should be evidence-based, or at least evidence-informed. The discussion with EPA (and NRC) staff during the face-to-face meeting highlighted the limited amount of real data used to drive both regulation and guidance. Empirical site-specific approaches were emphasized during the presentations. While the RAC is sympathetic to the challenges in obtaining adequate data on which to base (or at least inform) regulatory approaches, the current seemingly *ad hoc* approach is not recommended.

Data need to be collected, reported, and analyzed in a comprehensive and standardized way (e.g., via standardized reporting protocols) to build the evidence base to inform, and ideally base upon, the regulatory approach. Accordingly, the RAC's general recommendation for the long term is that EPA initiate and maintain a formal process to build this evidence base, with the goal of developing a useful base in, say, 5 years.

The collected data should include information on (1) the constituents used for baseline characterization, (2) constituent concentrations observed immediately upon completion of mining (but prior to restoration), and (3) anticipated concentrations at restoration. All data from monitoring wells, including information on excursions during operation and subsequent recovery, should be actively gathered, because it will help provide a more complete picture of the groundwater situation. Geological monitoring information should also be collected from soil sampling 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 that contributes to understanding groundwater flow and predicting future concentrations of constituents both on- and off-site.

**Comment [b3]:** rewrite for clarity.... ---- do you mean to say "to characterize the mineralogy"?

Much data may actually already be available although not in one place or in one format. Mining companies have accumulated baseline data to support the mining process and possibly to justify the monitoring process to the regulator. Some kinetic modeling presumably has already been done for the same purposes; such models can be used to infer what missing data should be obtained. Even for geohydrological systems that differ widely, physical and chemical principles that apply everywhere will allow application of such modeling.

**Comment [b4]:** no evidence for that statement?

Ready accessibility of the available information to the public will facilitate analysis and modeling by the scientific/technical community. As seen for other datasets (e.g., RadNet following the recent nuclear power plant accidents), the scientific community is eager to perform some work that EPA would otherwise be expected to do, such that results would be available sooner because of the distributed, parallel effort.

As a short-term alternative until the needed large evidence base is accumulated, the RAC recommends that EPA articulate a set of guiding principles and assumptions on which to base regulations. By way of example, consider the issue of "seasonality" in the fluctuation of constituent concentrations in groundwater. A guiding principle or assumption is that every site is affected by seasonality to some extent. Two follow-on, partially mutually exclusive choices for assumptions could be:

1. Seasonality cannot be reliably characterized with less than 3 years of data; and
2. Seasonality varies from site to site so that the period for monitoring varies from site to site.

**Comment [b5]:** as discussed during the face to face meeting - Groundwater is rarely influenced by seasonality.

Assumption #1 would lead to guidance for 3 years of baseline data; and assumption #2 would require sufficient data to define a monitoring period.

## 3.3 Specific Recommendations

### 3.3.1 Indicators of Interest

The EPA should identify a set of indicators to establish baseline conditions and monitoring conditions post-closure, with direct linkage between the baseline and post-closure indicators. Indicators should include: (1) specific radionuclides, by mass or radioactivity concentration, as appropriate, (2) gross radioactivity, by alpha-particle, beta-partuicle, 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, Eh, flow). Where appropriate, the physico-chemical form (e.g., speciation/oxidation state, solubility) of the constituents should be determined.

Because this list of indicator sets will be long, primary and secondary indicators should be recognized. Such categorization might be helpful in risk-weighting the indicators for use in regulatory decision-making. For example, not all indicators will behave the same way post-closure compared with baseline conditions. The RAC is mindful that risk from a given groundwater constituent is itself dependent on both its intrinsic toxicity and its concentration, such that what constitutes a primary versus secondary indicator can be fluid.

### 3.3.2 Constituent Interactions and Environmental Transformations

Interactions among constituents, environmental transformations, and other processes acting on the constituents and aquifers will produce (potentially linked) changes in indicators over time, notably in mining and restoration processes. In anticipating and documenting these changes, EPA needs to be cognizant of the effects of:

- mass balance issues (especially lixiviant/extraction fluid),
- microbial action,
- environmental transformations associated with lixiviant flow and content, and
- impacts of external changes such as nearby activities or groundwater movement.

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.

### 3.3.3 Spatial and Temporal Extent of Sampling Requirements

A critical set of issues is the sampling needed to fully and accurately characterize the spatial and temporal patterns of changes in indicators, including changes produced by natural processes and lixiviant interactions (see also Section 6.1). A fundamental approach to adequate sampling is the Nyquist sampling theorem (REFERENCE), which states that sampling must occur at twice the highest frequency (spatial or temporal) present in the signal. Unfortunately, the spatial and temporal rate and time constants are largely unknown at present.

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Without such knowledge, it is common and prudent to sample finely in space and time, at least at several sites throughout the mining region, to obtain a sense of the kinetics/time constants involved. Initial data generated from this approach can then inform a subsequent standardized sampling scheme. Such a scheme will likely involve uniform sampling in space but non-uniform sampling in time to reflect the time-varying time constants of the anticipated non-linear (e.g., first order, not zero order) temporal kinetics. Note that much of the rapid change in post-closure conditions occurs immediately post-closure, at the beginning of the restoration process.

Critical issues for measurement and evaluation include:

- Spatial or temporal hotspots (distinguishing from outliers),
- Multi-resolution sampling (have coarse grid drive the need for finer sampling),
- Use of individual well data vs. average wellfield vs. hybrid approach,
- Seasonality or other periodicity,
- Trends related to factors such as groundwater flow, rainfall, and lixiviant flow,
- Measurement accuracy and precision, and
- Dealing with extreme weather events during baseline or post-closure monitoring.

Guidance for developing this information should be included in the technical report although formal determination of number and location of wells and frequency of sampling can be decided for the specific mine operation by licensing conditions and regulator guidance.

### 3.3.4 Role of Kinetic Modeling

Research is needed to obtain the measurements that provide empirical values of time-frames and (spatial and temporal) rate constants/reaction rates to validate kinetic models. Included are components (both causal and mediating), interconnections, and sensitivity (e.g., by perturbation analysis).

This effort must address consideration of:

- Geochemical modeling/chemical reaction kinetic equations/equilibrium thermodynamic equations,
- Choice of kinetic model (e.g., first order for both spatial and temporal kinetics),
- Natural attenuation processes (including adsorption and secondary minerals, microbial processes),
- Need for a conceptual (physical) model or not, and
- Interplay between sampling and modeling.

As in Section 3.4.3, the technical report should describethe specific effort needed, while the regulator can provide licensing conditions and guidance for the mine operation under consideration.

### 3.3.5 Establishing a Baseline

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), and
- Effects of changes in groundwater volume *per se* on baseline conditions.

This topic is discussed in detail in Section 4.

### 3.3.6 Post-Closure Monitoring

All of 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 aquifers to their pre-mining state, restoration is a dynamic process that itself introduces more spatial and temporal instabilities. Considerations include:

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

This topic is discussed in detail in Section 5.

### 3.3.7 Standardized Definitions, such as "Excursion" and "Contamination"

The RAC recommends standardized, cross-agency adoption of NRC's definitions, in which an *excursion* refers to an elevated reading within the mining field (that indicates the potential for contamination), and *contamination* refers to the detection of contaminants or elevated constituents at a well beyond the boundaries of the minefield (see also Section 5.2).

# 4. RESPONSE TO CHARGE QUESTION 2: 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 RAC

In responding to the EPA discussion of establishing baseline conditions in section 4.2 of the draft technical report, the RAC 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 on EPA technical documents, selected permit applications for proposed ISL operations, environmental impact studies, and license conditions established in ISL operating licenses issued by the NRC or the state.

## 4.2 Objectives of Background Characterization

The proposed approach for pre-mining chemical and radiological characterization must be defined in the context of the data-quality objectives (DQOs) for that data set. Examples of possible DQOs are listed below, the point being that each of these DQOs requires a different approach to the design and implementation of a baseline characterization program.

- Establish the upper range of background concentrations of hazardous constituents (e.g., regulated trace metals) in aquifers that bound the exempted aquifer (the simplest DQO);
- Demonstrate correlations among key geochemical constituents that may support optimization of the characterization approach (e.g, surrogates);
- Identify key geochemical constituents that control the mobility of hazardous constituents during the recovery phase (e.g., primary and secondary lists of indicator constituents);
- Understand the geologic controls that localized the mineralization of the uranium as well as other hazardous metals in the ore deposit;

  **Comment [b6]:** rewrite for clarity
- Identify optimal physic-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 upper ranges for background concentrations should be a function of location, e.g., upgradient, downgradient and offgradient of the mine deposit, or near-field and far-field of structural controls and potential pathways;

- Establish occurrence 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; and
- Identify the most critical or vulnerable pathways.  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. Failure of unlined (#S3) ponds at the Oak Ridge National Laboratory (ORNL) provides one example of the consequences of failing to recognize vulnerability. 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 (REFERENCE).

**Comment [b7]:** 1.  Kim, Y. J.; Moon, J. W.; Roh, Y.; Brooks, S. C., Mineralogical characterization of saprolite at the frc background site in oak ridge, tennessee. *Environ. Geol.* **2009,** *58*, 1301-1307.

Wu, W. M.; Carley, J.; Fienen, M.; Mehlhorn, T.; Lowe, K.; Nyman, J.; Luo, J.; Gentile, M. E.; Rajan, R.; Wagner, D.; Hickey, R. F.; Gu, B.; Watson, D.; Cirpka, O. A.; Kitanidis, P. K.; Jardine, P. M.; Criddle, C. S., Pilot-scale in situ bioremediation of uranium in a highly contaminated aquifer. 1. Conditioning of a treatment zone. *Environ. Sci. Technol.* **2006,** *40*, 3978-3985.

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### 4.3 Monitoring Analyte List

Chemical conditions should be defined broadly to encompass transport flow paths and conceptual model of mineralogic controls not only for hazardous constituents (e.g., trace metals) but also for associated parameters.  Iron is a good example because iron-bearing minerals are a key source, sink, and buffer for groundwater pH and redox chemistry.  Iron (oxy)hydroxides not only constitute one of the most important sorbents for trace metals but also are one the most important sources because they have the potential to release these sequestered constituents as reducing conditions are restored.  Important items in preparing the analyte list are:

- Characterize baseline conditions of chemical and secular equilibrium as one measure of mineralogic stability. This is an alternative approach to defining concentration ranges as the sole measure of background chemistry;
- Collect data needed to define the Eh-pH fields for the mine site as well as for the adjacent aquifers. Plot stability lines for site-specific redox couples of interest (e.g., Fe, Mn, S, Cr, Cu, Co, Mo, Ni, As, Hg, V, U) (Borsch et al 2010);

**Comment [b8]:** Borch, T.; Kretzschmar, R.; Kappler, A.; Cappellen, P. V.; Ginder-Vogel, M.; Voegelin, A.; Campbell, K., Biogeochemical redox processes and their impact on contaminant dynamics. *Environ. Sci. Technol.* **2010,** *44*, 15-23.

- Include aluminum as one of the constituents in the background characterization suite because of its utility for normalizing metal concentrations and fingerprinting 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; and
- Consider the radionuclide monitoring analyte list for characterization submitted by Porterfield (see public comment).

The technical report would provide better guidance to the reader by providing a table of groundwater constituents and their limits based on EPA RCRA regulations and a second list of groundwater constituents and limits applicable to uranium ISL, derived from evaluatiing monitoring results in response to licensing conditions at these sites.  Contents of the tables presented in the current draft are contradictory in some instances.  In the absence of commentary by the authors, they would be confusing if used as guidance for future monitoring.

### 4.4 Challenges for Background Characterization

The EPA draft document recognizes that the design and implementation of an appropriate baseline characterization program will be driven by site-specific factors. Some implications for establishing baseline conditions in the context of some real-world examples of some site-specific factors are:

- *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, there may be a potential for overlapping environmental impacts of operations, which may not be coincident in time and may lead to potential complications in defining background chemistries for a proposed mine as well as ambiguity about which mine is the source of any future excursions;

- *Contamination in adjacent abandoned mine shafts and tunnels* could complicate the definition of background chemistry. One mining application presented data on total dissolved solids (TDS) to support its opinion that water quality in mine workings intersected by the proposed ISL operations had been previously contaminated by conventional underground mining and, unlike native groundwater, does not meet primary drinking water standards for TDS. The company concluded that if groundwater in these mine workings were subsequently affected chemically by ISL mining, they should require less restoration effort than the native sandstone leached in other areas because, with a poor background water quality, restoration to background or a water-quality standard would be easier (REFERENCE);

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- *Dewatering effects of old mine workings* in or near a proposed ISL operation subject the formation to oxidizing conditions that may extend for some distance around the old mine working (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;

- *Variable shapes and orientations* of uranium deposits. For example, an outline of the East Roca Honda deposit showed the zone of strong uranium mineralization over a strike length of about 4000 ft and a width of approximately 400 to 700 ft (Ambrosia Lake Uranium Deposit, p 21 REFERENCE);

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- *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; and

- *Limited knowledge about site mineralogy*, particularly as 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 only performed rarely on cuttings from barren holes. Standard practice has been for samples of cuttings to be examined by a geologist who then prepares a lithologic log describing rock types, alteration, presence and nature of carbonaceous material, accessory minerals (including pyrite, hematite and/or limonite), oxidation state of the target sediments, and other geologic information.

The above items suggests that the technical document needs to (1) accumulate and overview the various types of mine characterizations are desirable for inclusion in the technical guidance document, (2) be flexible to accommodate other characterisitcs encountered at future mines, and (3) include models and coefficients for monitoring networks hwere available.

### 4.5 Duration of Monitoring to Determine Background

Consider adopting a phased approach to background characterization that takes into account the following:

- Need for additional background locations could be informed by the level of uncertainty in the range and spatial variability of constituents in the preceding phase,
- Need for additional data from a particular well (or the need to resample a well) could 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 could be based on testing for trends in the data indicating the extent to which the well has recovered from drilling and construction activities.

An important consideration is to establish the adequacy of development and re-equilibration time of baseline wells prior to sampling. Residual impacts from well drilling and completion can dominate the concentrations of some groundwater constituents (particularly trace metals) in the vicinity of the well screen for months (if not years). Documentation should be provided for the volume of water purged after well completion and before sample collection, and of the field parameters measured (i.e., pH, Eh, conductivity), to ensure that the groundwater sample is representative of predrilling conditions.

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.

### 4.6 Standardized Data Collection

A standardized data collection process is recommended for use in developing a national information sharing tool. Otherwise, the EPA will not have a full and accurate picture of regulatory activities in this field.

# 5. RESPONSE TO CHARGE QUESTION 3: 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 whren groundwater chemistry has reached a "stable" level.*

## 5.1 Introduction and Overview

The draft technical report points to two primary objectives within this charge question. The first is to provide comments on how the monitoring program during the post-mining/ restoration phase 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 the baseline, as addressed in charge question 2.

## 5.2 General Considerations and Recommendations

The EPA should prepare a glossary to the technical report to define terms in the report that have somewhat different definitions within the scientific community and hence are open to interpretation. These words include the following: colloid, steady state, irreversible (in the context of a chemical reaction), stability/stable, insoluble, baseline, and heterogeneity.

The EPA should develop a set of guiding principles that will be used to craft regulations. The currently proposed methods are relatively site specific. The regulations should provide generic guidance with provisions to be adapted to site specific conditions (i.e. geology, groundwater flow, groundwater chemistry).

For effective generic guidance, available data must be thoroughly 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 the available data, and public dissemination of the data. The latter will give the academic/research community the opportunity to evaluate the data and apply it 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 "integrate" knowledge of physical/chemical processes with what is known about a site. In this way, monitoring data can provide a means to test the model and suggest the remedial scheme.

## 5.3 Specific Considerations and Recommendations

### 5.3.1 Evaluation of Existing Datasets

Several data sets are available from existing and former sites during the baseline evaluation, operation, and restoration stages. The EPA should mine and evaluate these data for information relevant for setting the standards currently sought. Because geochemical, biological, and physical conditions are highly variable among in-situ mining sites, a corollary activity is to use the existing data to identify fundamental transferable ideas between each of the sites. Some examples to illustrate this point are:

- Correlations among various chemical and physical parameters can provide general descriptions of the systems may exist. For example,
  - The valence state of uranium and arsenic and the total measured aqueous concentration. For uranium, this is due to the increased solubility of the hexavalent state, U(VI), relative to the tetravalent state, U(IV). There should also be a relationship between the measured redox potential (when little or no dissolved oxygen is present) and the valence state of uranium and arsenic. However, rigorous analysis of the redox kinetics and speciation of the system may also be needed because many geochemical redox reactions do not achieve an equilibrium state and complexation with groundwater ions may provide thermochemical gradients which may favor an oxidized state of a metal-(loid) despite the presence of reducing conditions[1];
  - Due to the relative insolubility of radium sulfate, $RaSO_4(s)$, there should be a strong inverse relationship between the aqueous $^{226}Ra$ and $^{228}Ra$ concentrations and the sulfate concentration; and
  - Iron (oxy) hydroxides and clay minerals should be the strongest sorbents for uranium and radium in the subsurface. Therefore, there should be an inverse relationship between the aqueous uranium and radium concentrations and the amount of iron (oxy)hydroxide and clay minerals in the subsurface.
- 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. 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 (NRC, 2007). 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 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

**Comment [b9]:** Borch, T.; Kretzschmar, R.; Kappler, A.; Cappellen, P. V.; Ginder-Vogel, M.; Voegelin, A.; Campbell, K., Biogeochemical redox processes and their impact on contaminant dynamics. *Environ. Sci. Technol.* **2010,** *44*, 15-23.

**Comment [b10]:** is that the correct term? maybe just say "should be the most important sorbents"

**Comment [b11]:** Ref: Catalano, J. G.; Brown Jr, G. E., Uranyl adsorption onto montmorillonite: Evaluation of binding sites and carbonate complexation. *Geochim. Cosmochim. Acta* **2005,** *69*, 2995-3005.

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

[1] An example of this phenomenon has been clearly demonstrated by Wan et al., 2004 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 formation of thermodynamically favorable uranyl carbonate complexes such as $Ca_2UO_2(CO_3)_3$. Oxidation of U(IV) to U(VI) is highly undesirable because of the enhanced environmental mobility of U(VI) relative to U(IV).

stability after closure have been met. It was emphasized that development of justifiable conceptual model which captures the major chemical and physical phenomena at each site is required (NRC, 2007). This approach will allow for site-specific flexibility;

- 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 is to take a system far from an equilibrium state during normal operation. In order to predict aqueous concentrations of the analytes of concern, knowledge of the solubility, aqueous speciation, and sorption affinity is required. 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 Appendix B of the Draft Technical Report when discussing transitions from ferric oxyhydroxides to soluble ferrous iron to ferrous sulfide minerals.

- The draft report includes some discussion of the use of confidence levels for determining if restoration goals have been achieved. It is recommended that the EPA use the data from the sites which have completed restoration and post-closure monitoring as case studies to determine if the confidence level approach would reasonably bound the effects of the the actions taken.

- Consistent with the spirit that the existing monitoring data are valuable, efforts should be made to produce a uniform database of the collected site data that is used for characterization of baseline, operation, restoration, and post-closure activities. This database should be publically available to facilitate access by the academic/research community who 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.

#### 5.3.2 Criteria for Collection and Analysis of Monitoring Data

As discussed above, the RAC recommends that EPA issue a set of guiding principles to be used in forming this regulation. The current practices are primarily guided by site specific metrics which allow for a high degree of variability. A set of general principles that allows for consideration of variable site conditions but within a broadly consistent approach is required to ensure consistent standards are applied for all sites. Several relevant principles are noted below.

- Because in-situ mining drastically alters the subsurface physical and chemical environment, when mining ends and there are no further anthropogenic influences in the subsurface, the environment will begin to move towards an equilibrium state. One proposed method of returning the baseline hydrologic and chemical conditions during restoration activities implies that the system will return to a comparable steady state that existed before mining activities began. While groundwater chemical conditions can be generally restored, there do not appear to be any data indicating that the mineralogical and hydrological conditions can be fully restored. In addition to the water quality data, minerological data can be used to evaluate the long-term stability of the system. Since complete mineralogical characterization is likely not realistic or economically feasible, alternative approaches are needed. The EPA should require increased frequency of sampling for groundwater monitoring immediately after mining operations stop. Data that monitors these changes can be used to validate and verify the hydro-geochemical models to provide confidence that the system is indeed returning to a baseline condition;

- 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;

- All data should be incorporated into the consistent, publically available database discussed above to encourage interrogation of the data in an effort to further refine monitoring during in-situ mining activities; and

- 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 looking 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.

### 5.3.3 Grouping Constituents for Monitoring Activities

Although an exhaustive set of data would be desirable to allow evaluation of all parameters, a more practical approach is to collect data for a set of high priority primary parameters as determined for each site. Then, if necessary, a second set of lower priority parameters can be specified. -The recommended list of primary analytes and water quality parameters is:[2]

**Comment [b12]:** Maybe we should recommend that these analytes should also be used to establish the baseline (pre-mining) for easy comparison!!?

- Radionuclides: **U(IV/VI), $^{226}$Ra, gross alpha, gross beta**
- Trace metals: **As(III/V),** Se(-II,O, IV,VI), Mo, V, **Fe(II)/Fe(III)**,
- Major Ions: Na, Ca, Mg, Cl, $CO_3^{2-}/HCO_3^-$, **$S^{-2}/SO_4^{2-}$**, $NH_3(aq)/NO_3^-$,
- Water quality parameters: **pH, $E_H$, dissolved $O_2(g)$**, TDS

The items in bold are recommended for the primary list. Oxidation states of the primary analytes of interest are noted and knowledge of redox speciation would be useful for determining the stability of a site. Practical limitations in preserving the redox state of a field sample must be considered. To the extent that data can be obtained, the information will be invaluable. For example, the sulfide/sulfate ratio will help to understand and explain the Ra aqueous concentrations and the distribution of uranium between U(IV) and U(VI) states has a direct relationship to the measured aqueous concentrations of uranium due to the insolubility of U(IV)

[2] Selenium speciation 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.

relative to U(VI). There are practical limitations for measuring analyte redox speciation but, in most subsurface conditions, simple pH and redox potential measurements are possible. Coupling these field measurements with the hydrogeochemical modeling discussed above could be useful for predicting analyte redox speciation.

### 5.3.4 Risk Weighting Scheme

Restoration activities from existing sites shown in the appendix of the Draft Technical Report had tables that listed all measured analytes and water quality parameters but had no discussion of the implications if a value is above the baseline. For example, would it matter if the Ca concentration is above the baseline concentration but the U and Ra concentrations are all at or below baseline levels? The EPA should develop a risk-weighting scheme to apply to the analytes being monitored during baseline and restoration activities. This can be used to determine if there is a risk to a given analyte being out of compliance. This will prevent a scenario where a site must continue restoration activities even though it has met the goals for the highest risk analytes. This scheme could be combined with the recommendation of a primary and secondary list discussed above where only the analytes on the primary list must meet the restoration goals where the secondary list contains analytes of concern but little risk.

# 6. RESPONSE TO CHARGE QUESTION 4: 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 Chargew Questions 2 and 3), as well as the subsequent data requirements for their use.*

## 6.1 Design of Well Placement and Sampling Program

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 mining on hydrodynamics and water chemistry complex. The technical report lays out 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 technical report, although other EPA reports may cover this issue in other contexts.

It seems appropriate to give a general outline in this report of methods to determine well numbers and well density. A basic approach could specify monitoring an initial number of wells that would be adequate under a presumed standard physical model for groundwater pollutant concentrations (based on prior standard practice). Then after an initial (suggest 1 year) interval, heterogeneity (and seasonality, see below) would be evaluated and if the coefficient of variation (comparing different wells) of key potential pollutants is unexpectedly high, then additional wells would be added to the system prior to the start of the ISL operations (in time to get a few months of baseline data for those wells before operations begin).

## 6.2 Statistical Analysis Discussions

The statistical analyses discussed in the technical report assume that there are monitoring wells that provide measurements in both the pre- and the post-mining/restoration, and describes a set of statistical analyses to determine

1. 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 pre or post-period),
2. 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 $\Delta$,
3. Whether a group of wells are heterogeneous in either their temporal trends or in their post – pre period differences in concentration levels, and

4. Whether, in longer follow-up, trends are evident in individual wells or overall in a group of wells.

The technical report mainly discusses non-parametric statistical methods to test for trends, pre-post differences and heterogeneity prescribing the use of the Mann-Kendall test for trends, the Wilcoxon test for pre-post differences, and a test for heterogeneity based on the Wilcoxon test for trend. Also given is an approximation to the sample size needed to test for pre-post differences so that power and type I error of the statistical analysis are controlled.

In practice, many complications arise in applying this relatively simple and straight-forward approach to data for real ISL operations. A few of these are discussed below.

A) The general non-parametric approach taken has weaknesses as well as strengths. While robustness to outliers, non-detects, and actual data blunders (mis-recordings of values, etc.) 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.

   The proposed test for heterogeneity (across wells) based on using the z-scores 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 be reflective of more observations available (and hence more power) to detect the post-pre level changes, and not any underlying heterogeneity. 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.

**Comment [b13]:** Do we need to define z-scores?

B) Interpreting heterogeneity. What should follow when 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?

C) Little is stated in the technical report about how wells should be grouped together in order 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 would make 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 to both attenuate the overall estimate of post-pre mining/restoration differences and reduce the ability to detect heterogeneity. If heterogeneity is detected it would be quite 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.

D) Seasonality, or whatever underlying factor it represents, complicates the proposed analyses. Sufficient data must have been collected to estimate seasonal trends adequately for providing reliably deseasonalized data for statistical analysis. This would require 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 in order to determine the response of the post-ISL/restoration water system to these events. The potential for such events to dominate aquifer conditions must be evaluated at each proposed site.

It is worth noting that 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 to do formal seasonal adjustment since the seasonality terms are essentially “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/restoration) in response to these events.

E) Multiple Comparisons. The hypothesis testing framework described in the 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 technical report the null hypothesis is that the post – pre mining/ restoration differences for a given potential pollutant are at or above a given criterion $\Delta$. 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, $\delta$, are different than the null value $\Delta$, 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 $\Delta$ 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, $\delta$, are at or above $\Delta$, in which case we could allow a very relaxed p-value), but rather the composite null hypothesis that at least one of the $\delta$ are equal or above $\Delta$. In particular for the null hypothesis that exactly one of the $\delta$ is equal to $\Delta$ and all other $\delta$ are so far from $\Delta$ that the power to reject $\delta=\Delta$ 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 $\delta$ equal to $\Delta$), the nominal level provides a conservative test. In this setting, control of the experiment wise 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. Since the site is only released if all null hypotheses are rejected, then the sample size needs to be set so that there is a reasonable probability that all null hypotheses can be rejected, assuming that they are all false. It is in the site operators' interest to perform careful power analysis to provide enough measurements to considerably decrease the nominal type II error for each test, while keeping the type I error rate at a traditional (e.g. 5 or 10 percent) value in each analysis.

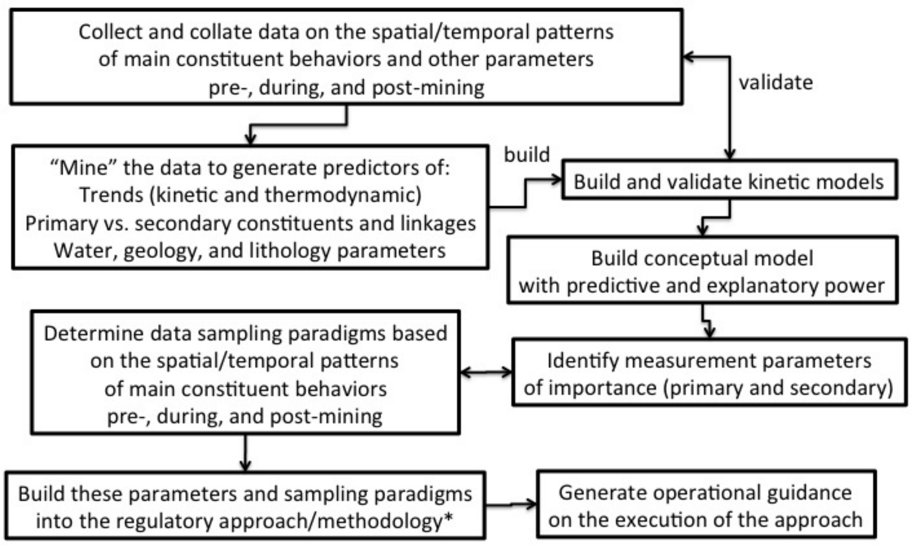
# 7. RESPONSE TO OTHER ISSUES BEYOND THE CHARGE

The following situations may only indirectly affect post-closure groundwater monitoring, but will have an important impact on protection of persons and the environment. For this reason, the technical report should discuss these potential events, the monitoring responsive to them, and the range of actions that is considered by the EPA to control expected adverse environmental consequences.

- Contamination of groundwater beyond the minefield during operation,
- Liquid, solid, and airborne contaminants released during routine operation from surface structures, pipelines, evaporation ponds, well drilling, and sample collection,
- The effect of hypothesized 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.
- 

**Comment [b14]:** what about the potential impact of 1) natural disasters such as earth quakes or 2) climate change? Should that be considered as well before mining?

**TABLE** 1 **–** Representation of data and coupled analyses to generate an evidence-informed regulatory approach and methodology, as depicted in the following flowchart




*"parameters and sampling paradigms" = a standardized approach/methodology for determining the monitoring requirements at a given site (but the requirements themselves are site-specific

# REFERENCES CITED

Comment [b15]: update with new references (still several missing in-text references)


Ablequist, Eric 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

Ambrosia Lake Uranium Deposit, p 21 (See Section 4.5 - - -Need reference here - -- KJK)

Bor~~s~~ch, et al. 2010. Biogeochemical Redox Processes and their Impact on Contaminant Dynamics. *Environ. Sci. Technol.* 2010, *44*, 15-23.

Comment [b16]: Borch, T.; Kretzschmar, R.; Kappler, A.; Cappellen, P. V.; Ginder-Vogel, M.; Voegelin, A.; Campbell, K., Biogeochemical redox processes and their impact on contaminant dynamics. *Environ. Sci. Technol.* **2010,** *44*, 15-23.

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

Nyquist Sampling Theorem (See Section 3.4.3 - - - Need full citation here - - - KJK)

ORNL (Need Reference in Section 4.3 pertaining to fractured clay allowing releases of constituents into the subsurface. - - - KJK)

Savannah River references (Do we need the public comment submittal to be referenced in the text and cited? - - KJK)

Susan Hall, 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

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## Web-based Citations and Hotlinks
## (To be added as Appropriate - - - KJK)

(IF NEEDED)

# APPENDIX A – EDITORIAL COMMENTS

**(IF NEEDED)**

# APPENDIX B – THE CHARGE FROM THE AGENCY TO THE SAB

June 2, 2011

**MEMORANDUM**

Field Code Changed

**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 C – ACRONYMS, SYMBOLS AND ABBREVIATIONS

(To contain acronyms relevant to the Uranium In-Situ ISL/ISR Advisory that are actually used in this text. Needs to be checked. - - - KJK)

| | |
|---|---|
| As | Arsenic |
| CFR | U.S. Code of Federal Regulations |
| Ca | Calcium |
| Cl | Chlorine |
| $CO_3$ | Carbonate ion |
| CQ | Charge Question |
| Cr | Chromium |
| Cu | Copper |
| Δ | Delta (differences) (?) |
| DQOs | Data Quality Objectives |
| Eh (Also $E_H$) | Oxidation / Reduction Potential (ORP) or ~~(?)~~Redox Potential (measured in volts) |
| EPA | Environnemental Protection Agency (U.S. EPA) |
| Fe | Iron |
| $HCO_3$ | Bicarbonate ion |
| Hg | Mercury |
| ISL | In-Situ Leach |
| ISR | In-Situ Recovery |
| Mg | Magnesium |
| $NH_3$ | Ammonia |
| Mn | Manganese |

| | |
|---|---|
| Mo | Molybdinum |
| Ni | Nickel |
| $NO_3$ | Nitrate ion |
| $\delta$ | Post & pre-differences (?) |
| $O_2$ | Dissolved Oxygen |
| ORIA | Office of Radiation and Indoor Air (U.S. EPA/ORIA) |
| ORNL | Oak Ridge National Laboratory |
| pH | Negative Log Concentration of Hydrogen Ions |
| Ra | Radium (Also $^{226}Ra$ and $^{228}Ra$ isotopes) |
| RAC | Radiation Advisory Committee (U.S. EPA/SAB/RAC) |
| RCRA | Resource Conservation and Recovery Act |
| S | Sulfide |
| SAB | Science Advisory Board (U.S. EPA/SAB) |
| $SO_4$ | Sulfate |
| TDS | Total Dissolved Solids |
| U | Uranium |
| UMTRCA | Uranium Mill Tailings Radiation and Control Act |
| V | Vanadium |

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