

Preliminary Comments from Members of the Chartered SAB and SAB Liaisons on the SAB draft *Advisory on EPA’s Draft Technical Document entitled Considerations Related to Post-14 Closure Monitoring of Uranium In-Situ Leach/In-Situ Recovery (ISL/ISR) Sites.*

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Comments from lead reviewers

Comments from Dr. Taylor Eighmy

The draft technical ORIA technical report is intended to frame issues associated with establishing the groundwater baseline for new ISL facilities, demonstrating that the restored groundwater has reached steady state, and post-restoration stability monitoring to ensure that the groundwater quality will not deteriorate over time after restoration.

The SAB RAC advisory was given four charge questions by the agency to consider as it examined the technical report. The advisory appropriately addresses the charge questions and adds additional thoughts for consideration beyond the charge questions about the greater purpose of the technical report.

Overall Comments:

1. General Thoughts:

The augmented RAC has assembled a very thorough advisory of the EPA ORIA's draft technical report *Considerations Related to Post-Closure Monitoring of Uranium In-Situ Leach/In-Situ Recovery (ISL/ISR) Sites*. The advisory reflects a number of public meetings and a great deal of synthesis.

Three additional general comments:

First, as noted by the RAC advisory, ISL represents a massive redox/geochemical transient perturbation of a spatially complex reduced porous ore body that imposes dramatic changes on a mostly equilibrium-governed geochemical condition. How the initial condition is described is essential to understanding the eventual rebound. The agency's draft technical report should probably include some significant discussions on best practices for establishing a baseline mineralogical and hydrogeologic model of an intended ISL site. The better the baseline model, the better all subsequent leaching/recovery/monitoring efforts. It also lends itself to better computational modeling. Such a baseline model would include a 3D understanding of the geologic formation, aquifer/aquitard mapping, hydraulic gradients, pump test response at various scales, geotechnical fracture mapping at various scales, transmissivity, etc. Obviously many reactive transport scales are present in the formation, but much of the focus needs to be on the understanding of the primary and secondary fracture surfaces and their existing weathered mineralogies in the unperturbed formation. Most uranium deposit sandstones can have complex porosities; they can be loosely cemented with significant inter-granular (primary) porosity or tightly cemented with secondary fracture (or microfracture) porosity with relatively high surface area to volume ratios. The draft ORIA technical report might benefit from a section that more fully emphasizes/discusses these issues in detail.

Second, there are many analogous systems where massive transient redox/geochemical perturbations occur that have also wrestled with sampling, monitoring, analyte selection, and modeling: landfill leachate plumes, acid mine drainage plumes, and subsurface reactive barriers.

All of these analogues have made progress in identifying issues around spatially complex and porous geology, time/scale/rebound, equilibrium versus kinetic reactions, redox couples that best indicate the dominant redox system, issues around groundwater sampling under reduced conditions, and model application. The draft ORIA technical report might benefit from a section that more fully emphasizes/discusses these analogues.

Third, the best hope to inform decision making about ISL design, operations, restoration, closure and monitoring will come from the application of reactive transport models that are rich in thermodynamic databases for redox couples, reactive surfaces, sulfur/iron/carbonate minerals, surface sorption/precipitation reactions, and kinetic modules. This is somewhat discussed in the technical report and greatly expanded upon by the RAC advisory. There are new developments in this field and how these are incorporated by the agency would be of immense benefit to the effort. MIN3P is one such example, with common heritages to other models, but will particular applicability to pyrite-dominated heterogeneous and porous systems. I am sure there are others. The technical report discusses this and the RAC audit goes into sufficient detail, and this aspect is very important.

Fourth, given the above, the sampling programs that are used should also develop data that best populate these models. Further, some surface spectroscopies (e.g., XPS, EXAFS) and mineralogical analyses (e.g., XRD) will be needed to characterize the preexisting minerals and their surfaces within the secondary pore system. Drilling techniques and core recovery/processing for these rock samples is also important to discuss.

2. Emphasis of Some Important Points in the Committee's Review of the Draft Study Plan:

The focus on geochemical transport models is excellent.

The descriptions of statistical methods applicability and additional statistical approaches are also excellent.

3. Mapping the Report to the Summary and to the Letter to the Administrator:

I found that mapping was very evident between the advisory and the letter. The letter is concise and clear. Though it does not lay out summary answers to numbered charge questions, I found it clear in its response and in its messaging to the administrator.

4. Report Organization:

The report is well organized and clear to follow and aligns well with the four charge questions. I did detect some different writing voices, mainly about the level of detail and terminology in different sections of the report about geochemistry and modeling.

Response to the Four Specific Questions:

1. Were the original charge questions to the Panel adequately addressed?

I believe that all four charge questions were adequately addressed.

2. Are there any technical errors or omissions in the report or issues that are inadequately dealt with?

See comments above.

3. Is the report clear and logical?

Yes, very much so.

4. Are the conclusions drawn or recommendations provided supported by the body of the report?

Yes, very much so.

Comments from Dr. James Mihelcic

1. Were the original charge questions adequately addressed?

The report is strong in addressing the first three charge questions. I did not think the fourth charge question was directly answered. The charge question is: “Comment on statistical techniques that would be applicable for use with ISL/ISR mining applications (particularly for the areas in Change Questions 2 and 3) as well as the subsequent data requirements for their use.” I do not think the report provides EPA guidance on which statistical techniques are applicable for direct use. For example, on page 28 (lines 15-23) it is stated which non-parametric statistical methods are “mainly” discussed in the draft technical report. Several specific statistical tests are mentioned in this paragraph. However, the SAB review never provides EPA any guidance on which techniques they should employ. There is also no mention of the appropriateness of the Mann-Kendall test in the review (though this was one of the techniques mentioned in the paragraph mentioned on page 28). Most of Section 6.2 that addresses Charge Question 4 is mostly a very academic discussion on the strengths and weaknesses of non-parametric approaches. While this discussion will be important to the agency’s decision making, it does not provide any guidance on what specific techniques to specifically utilize. As a reviewer, it appeared to me that the intention of this charge question was to obtain some specific guidance from the SAB (note that I recognize I was not in discussions with EPA like the panel was). Along this same train of thought, on page four (Executive summary) I did not see specific recommendations made to the Administrator on which specific techniques are application.

2. Are there any technical errors or omissions in the report or issues that are inadequately dealt with in the Panel’s report?

I am supportive to see the report recommend that EPA consider potential effects of construction and development activities on capability of monitoring well to provide water quality samples that are representative of baseline conditions. Given EPA’s movement towards green chemistry and green engineering, it would be appropriate to incorporate the appropriate terminology regarding this topic (i.e., wording of “life cycle”). Thus, I recommend that on page 18 (lines 4-6) the wording “life cycle” be added to the sentence so it reads “Little discussion is provided in the draft technical report about potential effects over the life cycle of the mining process (i.e., drilling, well construction and development activities).....”

The seasonality in groundwater quality was brought up on page 8 (lines 8-10). There it was suggested that the potential of seasonality in groundwater quality will require seasonal measurements of at least one year. I thought the remainder of the document was contradictory and weak in regards to this topic. For example, on page 12 (lines 11-12) it is stated that the current common practice is to set the default at one year monitoring period. Later the report states that a longer term period is needed to assess analysis of water samples collected from freshwater aquifers that overlies or underlies the production zone (page 15, lines 25-26). I did not think the report adequately provided the agency guidance on what was an appropriate level of time. So this section lacked detail on what I think is an important topic in developing a

monitoring program. Is it the one year default or something else? If it is something else, this should be discussed in greater detail and the report should be more consistent on this issue.

Regarding this topic, the draft report recommends on page 10 (line 15) that EPA provide additional discussion on extreme weather events influence monitoring during extreme weather events. I am curious if the panel discussed longer term events that could impact subsurface hydrology and the associated water quality measurements. For example, did they discuss short and long terms changes to groundwater hydrology from changes in land use (perhaps logging in this environment), changes in land use from disease or infestation of invasive species (such as with the pinebark beetle) and also changes in climate? It appears the monitoring program is solely focused on short duration changes in water quality though I believe the mines can be running for decades. Also, it is quickly stated on page 30 (line 1-2) that comments provided by E Striz to the RAC stated extreme weather events rarely markedly affect the deep aquifers of interest. I am not clear from this comment if the SAB supports this statement or simply accommodating a public comment. I say this because there is no other reference provided, and as worded, it appears to just be a random thought placed in the document. I am not disagreeing with the statement of E Striz, just want to let the authors know that the statement is just left hanging as the document currently reads and this point could be developed more clearly for the agency if the panel believes it is important.

I thought there was an omission in Section 5.7 (page 26). The focus in this section was ensuring protection of public health by maintaining water quality so that the hazard quotient remains below 1. This is however only applicable to changes in groundwater chemistry that change water quality, and accordingly impact human health. However, changes in groundwater chemistry may have a large impact on the use (and treatment) of the water through changes in water quality. This is because water users not only look to secure sufficient quantities of water, but also are now interested in better matching use with quality. This is because we are now better at determining the economic and associated environmental consequences associated with water quality that relate to chemical or physical constituents that do not directly impact public health, but will still require adding materials and energy (directed and indirect) to remove the constituents prior to use. Regarding indirect and direct energy (and the associated carbon emissions), there is a body of scientific literature (that though is in its infancy) that has pointed out the large embodied energy associated with the life stage of water supply and treatment. This is because we are now better understanding the indirect energy required to construct reactors and pipelines, manufacture chemicals and transport them to the treatment plant, etc., that can be added to the direct energy associated with day to day operation of a supply/treatment systems (i.e., electricity bill).

3. Is the Panel's draft report clear and logical?

I found the report well organized, the appropriate size, and easy to read. The contributors should be acknowledged for an excellent job. One item, when I was reading Section 4.5 (page 20), I thought this section could be better linked with information provided in Section 4.3. These two sections did not seem well integrated. For example, Section 4.3 (page 17) addressed several sampling issues in detail, for example, those related to collection of filtered/nonfiltered sample.

However, the Section 4.5 discussion does not refer to this specific items or others covered in Section 4.3.

4. Are the conclusions drawn or recommendations provided supported by the body of the Committee's report.

The conclusions and recommendations are supported by the body of the report. In the letter to Administrator (first page, lines 32-26) no mention is made that agency requested comments on "suitable and applicable statistical techniques ..." I noticed this item was addressed in the following paragraph that states what the SAB commented on; however, as I stated earlier, I think more specifics should be provided to EPA regarding this charge question.

Other Comments.

Page 7, line 42 (again on page 24, line 22). It is stated two times in the draft report that providing ready accessibility of available information to the public will facilitate analysis and modeling by the scientific/technical community which I agree. However, making data available to the public also facilitates public trust in the decision making process. As written this statement makes it seem that the only reason to provide data to the public is to provide the scientific community data to use. It ignores an important constituent of EPA which is the general public. We should think beyond our professional interests in why EPA should make data publically available.

Page 11, line 24. The use of the wording "(or not)" was not clear to this reader.

Related to seasonal events, modeling can also help inform changes due to seasonality (could be mentioned on page 11, lines 32-33)

The words "sorbent" and "adsorbent" are used in document. I suggest the word "sorbent" be used throughout.

Page 32, lines 15-17. Have footnotes on page 16 that provides example where a confining layer (in terms of surface impoundment) was a major problem. So the statement on page 32 (lines 15-17) contradicts the page 16 footnote.

Comments from Dr. Horace Keith Moo-Young

Considerations Related to Post-Closure Monitoring of 29 Uranium In-Situ Leach/In-Situ Recovery
This report details the considerations related to post-closure monitoring of Uranium In Situ Leaching and Recovery. The ISL process utilizes an extraction fluid being pumped underground through a set of injection wells to solubilize uranium. 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. The agency requested comments on the technical aspects of designing and implementing the groundwater monitoring networks at ISL uranium mines. In this report, the SAB provided recommendations 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.

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. The SAB specifically made recommendations on the following items:

- Identifying data sets to be used in designing monitoring networks,
- Analyze data sets to develop groundwater and fate and transport models,
- apply environmental models with realistic boundary conditions for site specific considerations,
- Systematically develop sampling and analysis plans for sites,
- Specify criteria for specific analytes to link monitoring and modeling.

1. Were the original charge questions to SAB Standing or Ad Hoc Committees adequately addressed?

Yes, the original charge questions were addressed. Four questions were asked of the SAB and these questions were appropriately analyzed.

The four questions were as follows:

- 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.

2. Are there any technical errors or omissions in the report or issues that are not adequately dealt with in the Committee’s report?

The committee appropriately answered the questions of concern from EPA. However, in the opinion of this SAB member, the scope of the questions as it relates to post ISL monitoring does not adequately address the major concerns as it relates to monitoring of the site during the operations. In Situ Leaching techniques are *not* always controllable, safe, nor environmentally benign, and the hidden costs are usually borne by the underground environment. The

process of ISL has the potential of creating permanent contamination of groundwater, which is often used by local people and industries for drinking water supplies, and can also contaminate land which was otherwise good agriculturally productive land. As pointed out in the documents, ISL can lead to potential contamination through the following perspectives:

- the risk of spreading of leaching liquid outside of the uranium deposit, involving subsequent groundwater contamination,
- the unpredictable impact of the leaching liquid on the rock of the deposit,
- the impossibility of restoring natural groundwater conditions after completion of the leaching operations.

Moreover, in-situ leaching releases considerable amounts of radon, and produces certain amounts of waste slurries and waste water during recovery of the uranium from the liquid. Areas of potential concern for ISL where in the groundwater pumping system (below ground), surface distribution pipes (above ground), leakage of the retention (evaporation) pond, and a failure in the processing plant. Each of these leads to different environmental releases and consequences which traditional groundwater monitoring networks will not deal. These surface level processes, should require monitoring to strive to mitigate unwanted environmental releases. Thus, it is strongly recommended that vadose zone monitoring be included in the monitoring network plan.

The importance of geochemical fate and transport modeling with reaction kinetics and thermodynamic capabilities is key to providing and verifying the modeling of the site specific conditions. A key aspect of the modeling will be to appropriately monitor and conduct mass balances prior to, during and post ISL. Understanding the fate and transport and mass balance are key to providing appropriate modeling verification and validation with the monitoring network.

Is the Committee's report clear and logical?

The report is clear and logical. There are some typos as well a formatting and grammatical concerns. Moreover, the use of bulleted items should be provided a paragraph which describes the bullet points.

4. Are the conclusions drawn or recommendations provided supported by the body of the Committee's report?

Yes, the conclusions support the body of the committee's report.

Additional Comments

There are many ways in which complex chemical problems can lead to failure and releases from In Situ Leach mining. The most important ways are through precipitation of minerals from a saturated solution and ion exchange with clays. Problems might also arise in the restoration phase of an ISL due to the presence of organic matter within the

aquifer materials. Many trace elements, including radionuclides, attach themselves preferentially (or form soluble chemical complexes) to organic compounds in solution such as humic and fulvic acids formed by the degradation of vegetation (Fetter, 1993). Thus the presence of organic matter within groundwater can lead to conditions where many trace metals and radionuclides, which would not otherwise would be soluble and affect groundwater quality, are soluble and therefore have the potential for migration in the direction of groundwater flow. As a result of these natural organic matter, there is a high potential for facilitated transport in the subsurface.

Natural attenuation was discussed in the report. In particular, the statement “Restoring groundwater quality after mining by flushing the aquifer with water is considered to be natural attenuation”. However, thermodynamic, reaction kinetics, fate and transport, attenuation stability, and subsurface condition in both the groundwater and vadose zone will dictate the potential for natural attenuation. The key aspects of analyzing for natural attenuation is the data collection and analysis process:

- development of a detailed knowledge of the system hydrogeology to establish transport pathway(s),
- determination of the *mechanism(s) and rate(s)* of contaminant attenuation,
- determination of the *capacity* of the aquifer to sustain attenuation of the mass of contaminant within the ground-water plume needed to achieve cleanup goals, and
- evaluation of the long-term *stability* of immobilized contaminants.

Spectroscopic techniques need to be a part of the monitoring for natural attenuation such as XPS, XFS, and XANES.

Although mining is often presented with idealized diagrams and figures outlining the geologic strata and essential processes involved, the basic concepts are always based on simplified theory and the reality of geological and hydrogeological systems are that they are inherently complex and often difficult to interpret and predict. Another fundamental problem in the design of a groundwater monitoring regime for ISL mines is the inherent variability and complexity of the geologic structures that form the ore deposit. Geologic formations may potentially have complex subsurface conditions. One major concern for ISL sites is the potential contamination to the subsurface as a result of leakage to bedrock. This is a special concern in karst and limestone terrain. Other examples issues that can be caused by complex geologic conditions at sites may lead to undetected excursions or problems in leaching, the behaviour of faults in regional groundwater flow, and the presence of fractures (limestone or karstic terrain) causing unpredictable contaminant migration away from the site.

The retention pond (or evaporation pond, depending on the management option chosen for waste solutions) is used to temporarily store waste solutions arising from the ISL process. Thus, the design of the pond needs to ensure that there is no escape of these solutions, and that if an escape occurs, it can be quickly detected and remedial action undertaken. Such designs might incorporate two distinct layers of a chemically unreactive plastic liner material, such as high density polyethylene (HDPE), with sand or porous material in between these two plastic layers. Monitoring devices would be placed in this sand layer, and also below the lower layer, to detect any escape of the stored waste solutions. A layer of suitable clay might then be placed beneath the entire facility to provide a further barrier of low permeability to inhibit the escape of leaching

solutions. SAB reviewed the Surface Impoundment study over 10 years ago. This study is applicable to the retention ponds at the ISL sites.

Comments from Dr. Jerry Schnoor

I have reviewed the SAB Draft Report listed above. I believe the committee has done a good job of responding to the four charge questions. The report is well written and makes valid points related to ensuring adequate approaches for designing a monitoring network, establishing baseline groundwater chemical conditions, monitoring the post-mining/restoration phase, and establishing suitable statistical techniques applicable for monitoring ISL/ISR mining applications.

The Quality Review Questions and my responses are shown below:

Question 1: Were the original charge questions to SAB adequately addressed.

Yes, the original charge questions were adequately addressed by the SAB. However, I found it rather odd that the four charge questions did not appear verbatim anywhere in the document except in Appendix A, page A2. Perhaps that is because the charge questions were not really written by EPA ORIA as normal charges, rather as requests for comments on several areas in the report, *Considerations Related to Post-Closure Monitoring of Uranium In-Situ Leach/In-Situ Recovery (ISL/ISR) Sites*. I duly note that the SAB report paraphrases the charge “questions” in the Executive Summary, and that the Chapters in the SAB report are meant to correspond to the charges (Chapter 3 = Charge 1; Chapter 4 = Charge 2; Chapter 4 = Charge 3; and Chapter 6 = Charge 4).

Question 2: Are there any technical errors or omissions in the report or issues that are not adequately dealt with in the Committee’s report?

I find no technical errors or omissions. However, I would like to see more emphasis on the importance of understanding the geologic setting at the sites than is provided in the SAB report. I did not read the original EPA ORIA report that was reviewed, so I am not sure if it covers the following areas in any detail, but here are a few issues that may require a little additional discussion and possible recommendations.

- **Know the geology first.** In order to design and implement a monitoring network, the geology of the site must be known in detail, especially the vertical stratigraphy throughout the area to be “mined” by ISL/ISR. ISL/ISR mining is supposed to require a unit with high hydraulic conductivity surrounded above and below by “tight” aquitard units to contain the mining operation. There should be firm evidence of this as the extant hydrogeologic setting. Without knowledge of the vertical stratigraphy, it is impossible to design a proper monitoring network. Certainly, units above and below the active mining area should be sampled routinely to ensure that aquitard units are not “leaky”. In addition to the geology, it is obvious that one should know the potential groundwater “receptors”, if any, in the vicinity of the operation. This includes units above and below the ISL/ISR mining operation. Page 16, lines 8-11, make an excellent point in this regard (vulnerable pathways).
- **Water Balance.** A monitoring network should require a detailed water balance to be monitored and maintained during the operational period. In other words, if the

mining operation is putting more lixiviant solution into the unit than it is pumping out in its extraction well, that is compelling evidence that water/lixiviant/contaminants are migrating to other locations. These other locations should (hopefully) be samples as a part of the monitoring network.

- **Chemical lixiviant.** The chemical formula for the lixiviant should be known in order to construct mass balances on constituents. Page 8, lines 39-40 are excellent and very important points made in the report.

These could be included in the discussion of the sixth bulleted recommendation under Charge 1 (page 3).

Question 3: Is the Committee's report clear and logical?

Yes, the report is clear and logical. I have a just a couple of questions/comments.

On page 7, line 30, it seems somewhat arbitrary to specify 3-5 years for the time required to build an evidence base.

On page 8, section 3.4 on indicators... one key indicator for post-mining/restoration is the ratio of carbonates to sulfides in the mined unit. If there is insufficient neutralization potential remaining in the unit, it is likely to continue to oxidize from remnant lixiviant and cause mobilization of U(VI) and other contaminants.

Page 16, lines 32-33, makes a good point regarding Eh-pH fields and the over-riding importance of understanding the effect of redox on chemical speciation.

Question 4: Are the conclusions drawn or recommendations provided supported by the body of the Committee's report?

Yes, the conclusions and recommendations contained in the response to charge questions are supported in the body of the SAB's report.

Comments from other SAB Members

Comments from Dr. George Alexeeff

1. Were the original charge questions adequately addressed?

The draft report thoroughly responds to the charge questions.

2. Are there any technical errors or omissions in the report or issues that are inadequately dealt with in the Panel's report?

I did not identify any technical errors or omissions in the report or issues that are inadequately dealt with in the Panel's report.

3. Is the Panel's draft report clear and logical?

The Panel's report is clear and logical. A few clarifications would improve the report.

Executive Summary, page 1, lines 40-42. This should be revised for clarity. Possibly: The application of statistics and the Resource Conservation and Recovery Act (RCRA) regulations to groundwater monitoring is discussed in sufficient detail. A similar level of detail should be provided for other important topics as well.

Executive Summary, page 2, lines 5-18. Line 17 refers to the fifth topic. This reviewer could only identify three other topics. Clearly laying out each topic would improve clarity.

Page 8, lines 14-22. The report could also indicate the need for criteria for establishing detection levels for the indicators.

4. Are the conclusions drawn or recommendations provided supported by the body of the Committee's report?

In general, the conclusions and recommendations are supported by the body of the committees report.

Page 2, line 44-45. The following bullet does not seem to be supported by the text:

“Distinguish between primary and secondary indicators on basis of risk, return to pre-operating conditions, and information concerning other constituents (3.4).”

The text in section 3.4 states

“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.”

The SAB report did not establish risk to be a useful criterion, the report simply stated criteria are needed. Based on the report I suggest the bullet be revised to:

“Specify criteria by which to distinguish between primary and secondary indicators.”

Comments from Dr. Joseph Arvai

1. Were the original charge questions to SAB Standing or Ad Hoc Committees adequately addressed?

By and large, yes.

However, with respect to CQ1 (regarding the technical elements of a monitoring network), one might consider decision making needs as a “technical element”. Specifically, the report makes a recommendation regarding “Evidence-Based Decision Making”, though it’s not clear to me from the report what the nature of the decisions to be made are. In a post-closure context, one could imagine tracking a wide range of environmental parameters (“indicators of interest”) *that are related to objectives that guide impending decisions.*

However, these decision points/problems/opportunities/alternatives are not clearly elucidated within the report. As a result, it’s difficult adequately characterize (or, in some cases, even imagine) the management objectives that ought to guide these decisions and, importantly, the measurement/monitoring criteria (i.e., indicators of interest) that will define or characterize these objectives. I think the flow diagram presented in Figure 1 attempts to add some clarity. However, it’s still not clear to me what the decisions are; without a clear handle on the decisions, it’s difficult to evaluate the measurement/monitoring criteria.

Perhaps some further discussion with respect to the nature of the decisions that need to be informed by post-closure monitoring (e.g., on pp. 7 and/or 8) might help to alleviate these concerns. Later in the report (pg. 32), monitoring beyond groundwater *is* discussed, which suggests that decisions will need to be informed by more than just technical objectives and related indicators of interest. It might be helpful to provide some examples of these.

2. Are there are any technical errors or omissions in the report or issues that are not adequately dealt with in the Committee’s report?

Yes, with the exception of the need for greater clarity around the decisions that monitoring will need to inform; see above.

3. Is the Committee’s report clear and logical?

Yes.

4. Are the conclusions drawn or recommendations provided supported by the body of the Committee’s report?

Yes.

Comments from Dr. Terry Daniel

This was in general a clear and well-written review that seemed to address all of the charge questions in depth, as well as extending the review to some important areas not specifically called out in the charge questions. The recommendations of the panel (for the SAB) were clearly stated in most cases, but the frequent use of “the EPA is encouraged ...” made the strength of some panel conclusions difficult to determine. The strength of these lesser recommendations should be clearly described, either collectively or individually, as needed to communicate the panel’s conclusions.

The second and third paragraphs in the executive summary seem to be rather redundant, effectively repeating the charge question issues twice. The tactic of using a terse summary listing of numerous recommendations/issues/suggestions under each charge question seemed too granular for the executive summary and did not work very well. What is lost is any indication of the relative strength and importance of each recommendation listed. Some more narrative approach that provides an overview and highlights the most important points under each charge question would be more effective and more appropriate to an executive summary.

QR questions

1. Were the original charge questions to SAB Standing or Ad Hoc Committees adequately addressed? YES
2. Are there any technical errors or omissions in the report or issues that are not adequately dealt with in the Committee’s report? Not that this non-expert reviewer detected.
3. Is the Committee’s report clear and logical? Yes, but it might be improved as suggested in the overall comments above.
4. Are the conclusions drawn or recommendations provided supported by the body of the Committee’s report? Yes.

Some minor specifics

P 5

A meeting participant provided a list ...
What meeting? Public participation?

P 12

The RAC recommends ...
Should be SAB recommends?

Comments from Dr. George Daston

I found this report to be succinct and clear.

We were asked to address four specific questions as part of the quality review.

1. whether the original charge questions to SAB Standing or Ad Hoc Committees were adequately addressed;
2. whether there are any technical errors or omissions in the report or issues that are inadequately dealt with in the Committee's report;
3. whether the Committee's report is clear and logical; and
4. whether the conclusions drawn or recommendations provided are supported by the body of the Committee's report.

Question 1: The charge questions posed to the review panel were all adequately addressed.

Question 2: I found no technical errors or omissions in the report.

Question 3: I found the report to be clearly and logically presented. There seems to me to be a disparity in the tone of the letter to the Administrator and the report itself. My reading of the report was that it was highly critical of most aspects of EPA's draft document, with the finding that only one aspect of the document being adequately documented. The letter to the Administrator does not seem to adequately convey the level of concern that the Radiation Advisory Committee expressed in its report.

Question 4: I found the conclusions of the report to be well documented and supported.

Comments from Dr. Costel Denson

General Comments

This report is well written. It is clear, sensibly organized and concise in its comments. This reviewer was particularly pleased to read the added section entitled, "Additional issues beyond the charge." Well done.

1. Were the original charge questions to the Panel adequately addressed?

Four (4) charge questions were posed. All were adequately addressed.

2. Are there any technical errors or omissions in the report or issues that are inadequately dealt with in the Panel's report?

There were no technical errors or omissions that this reviewer could find or identify. All issues were adequately dealt with.

3. Is the Panel's draft report clear and logical?

This draft report is well written. It is clear and logical.

4. Are the conclusions drawn or recommendations provided supported by the body of the Panel's report?

All the conclusions drawn and recommendations provided are well supported in the body of the report

Comments from Dr. Michael Dourson

Charge Questions:

- Were the original charge questions to adequately addressed? They appear to be.
- Are there any technical errors or omissions in the report or issues that are inadequately dealt with in the Panel's report? I am unable to answer this question, since it lies well outside my area of expertise.
- Is the Panel's draft report clear and logical? Yes, but see also comments below.
- Are the conclusions drawn or recommendations provided supported by the body of the Committee's report ? Yes, but see also comments below.

General Comments:

I very much like the panels recommendations to gather available monitoring data to identify data sets that could inform EPA's regulatory decisions, compile and systematically analyze these data to support modeling, apply models to provide realistic predictions of the rates at which chemicals of concern approach stable conditions following mining operations, describing approaches for determining the optimal number and location of monitoring wells, and specify criteria for selecting such chemicals and for monitoring objectives. These recommendations seemed well supported by the panel's report.

As with the prior SAB report I reviewed, these and other recommendations seem well wrought, but I feel their collective burden on agency staff. I do not have any expertise in this area, so I am unable to recommend how the panel might wish to reduce this perceived burden, or if is even a burden. Perhaps the panel might give EPA staff a sense of choice or priority among its recommendations, if appropriate.

Specific comments:

On page 38, line 23. A hazard index of 1 or less is protective and thus acceptable.

On page 42, line 16. What does the panel mean by "margin of safety"? Please define the use of this term in this context.

Comments from Dr. Barbara Harper

- Were the original charge questions to adequately addressed? Yes
- Are there any technical errors or omissions in the report or issues that are inadequately dealt with in the Panel's report? No major omissions or errors, just some suggestions (see below) for a few things that could be strengthened.
- Is the Panel's draft report clear and logical? Yes; very good
- Are the conclusions drawn or recommendations provided supported by the body of the Committee's report? Yes; very good

Page 5, lines 11-15. Based on the review, I gather that the basic ISL process occurs in the ore body with the intent of leaching uranium into existing groundwater and capturing the leachate before it has a chance to migrate outside the capture zone. In other words, ISL is essentially a process that intentionally contaminates groundwater and then recovers the contaminant (i.e., remediates the groundwater).

Lines 42-43:

“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.”

Comment: Could this be restated so that the objective is to determine *when* post-operating gw quality has returned to “near” pre-mining conditions and to determine whether mine operations have not adversely impacted gw *quality* [for some time frame]? The phrase ‘groundwater supplies’ sounds like a reference to drinking water concentrations rather than to non-degradation or baseline.

The term ‘stabilization’ of groundwater sounds like monitored natural attenuation (p. 5, line 27; Section 5.2), but my impression of MNA was that it is totally passive, not active flushing. In some cases MNA takes tens or hundreds of years – what temporal evaluation (or lifespan of monitoring networks) is recommended?

I work at a site that has uranium groundwater issues-- uranium geochemistry is hugely complex and not well understood despite millions of dollars of research. A lot of models are run with the assumption (or hope) that the geochemistry behaves itself (i.e., what happens in the test tube also happens in the field), but the monitoring data often do not support this. We also see multiple fronts or long smears of uranium moving from the soil to the groundwater, and groundwater concentrations fluctuate in inexplicable ways, so the expectation that uranium will slowly and predictably decline in groundwater and never rebound once the lixiviant is removed seems pretty remote. The SAB report might add a section on the success, or lack thereof, of remediating existing uranium groundwater contamination at Superfund sites.

Should an equal weight be given to vadose zone models (page 4 and Additional comments)? Or is the discussion considering an integrated vadose-groundwater system as a given?

It is good that the review devotes so much space to defining baseline, but the lixiviant does not have a ‘baseline.’ Are the lixiviant mix and other additives covered by trade secrets? Are they covered by the requirement to return to baseline (i.e., return to non-detect)? I’m not sure the

review explicitly stated that the composition of the lixiviant and extraction fluid must be identified and monitored (like fracking chemicals that are no longer able to be kept secret), or how detection limits for them would be set.

Comments from Dr. Agnes Kane

The authors of the SAB draft report are to be congratulated for producing a very thorough review and important recommendations for consideration by EPA. Their emphasis on uniformity in definitions, application of both modeling and monitoring, and consistent methods for data collection and analysis is highly appropriate. Mining and groundwater quality are controversial issues and the RAC was very careful to present its analyses and recommendations clearly and directly. The additional issues identified by the RAC are also important, especially the need for closer interactions between EPA and NRC.

1. **Were the original charge questions adequately addressed?** Yes – very thoroughly with detailed explanations and specific references.
2. **Are there any technical errors or omissions?** None identified.
3. **Is the Committee's report clear and logical?** This report is very clear and presented logically. The flowchart developed in Figure 1 is very useful in describing the recommended evidence-informed regulatory approach and methods to be used in implementing this approach. This report is accessible to a wide audience, including the public.
4. **Are the conclusions drawn or recommendations provided supported by the Committee's report?** Yes – the Executive Summary clearly emphasizes the most important points which are expanded in detail in the body of the report.

Comments from Dr. Cecil Lue-Hing

General comments

The review is well done, and offers a wide range of meaningful recommendations. The review also discusses additional issues beyond the Charge which emphasizes the importance of modeling as an important tool in the management of the monitoring aspects of before, during, and post-mining operations.

Comments on Quality Review Questions

1 – Were the original charge questions to adequately addressed?

Yes.

2 – Are there any technical errors or omissions in the report or issues that are inadequately dealt with in the Panel’s report?

None that were obvious.

3 – Is the Panel’s draft report clear and logical? and

Yes.

4 – Are the conclusions drawn or recommendations provided supported by the body of the Committee’s report

Yes.

Comments from Dr. James Johnson

1. Were the original charge questions to SAB Standing or Ad Hoc Committees adequately addressed? YES
2. Are there are any technical errors or omissions in the report or issues that are not adequately dealt with in the Committee's report? None that I could detect.
3. Is the Committee's report clear and logical? Yes, but it might be improved as suggested in the overall comments below.
4. Are the conclusions drawn or recommendations provided supported by the body of the Committee's report? Yes.

Comments:

- i. The information in the letter to the administrator does not exactly reflect the information in the Executive Summary, i.e.,
 - a. Page 2 of the letter, line 1: ...an excellent preliminary framework vs. page 1 of the Executive Summary, line 37 ...an excellent framework.
 - b. Page 2 of the letter, line 37: ...only a few topics contain vs. page 1 of the Executive Summary, lines 8-9: missing is sufficient data on most important topics.
- ii. Throughout the report there is much discussion on the end points for post operational restoration, stable state vs. post operation ground water quality vs. steady state conditions,. It appears this is a significant enough issue to mention in the letter to the administrator.
- iii. Page X, line 19: NACEPT = National Advisory Council for Environmental Policy and Technology
- iv. Page 5, lines 8-9 There is mention of a meeting with no definition of where, when and what the meeting was about.
- v. Risk is mentioned several times throughout the report. If sustainability is the true north for the Agency, perhaps it should be mentioned that the discussions about risk should be reframed in the context of sustainability, i.e., maximizing good vs. minimizing harm.

Comments from Dr. Judy Meyer

This topic is outside my immediate expertise, and I greatly appreciated the clarity of presentation in the report.

Page, line number

1. Were the original charge questions to the SAB Committee adequately addressed?

YES – I found the answers very clear and well organized, giving EPA useful and specific guidance. I also appreciated section 7, addressing very important topics not covered by the charge questions.

2. Are there any technical errors or omissions in the report or issues that are not adequately dealt with in the Committee's report?

The following are what I consider to be omissions in the report in need of correction or at least the committee needs to provide arguments that they don't need to be considered.

When standing committees are augmented, I think it is important to say something about their areas of expertise in general terms in the brief description of the committee process (6, 29-35).

Because I am not familiar with ISL/ISR procedures, I don't know what is in the fluid that is used for extraction. Nothing is said about this in the ES and little is said in the background section 2.1. That seems to be a critical omission. It seems relevant to considerations of what might be contaminating groundwater other than radiation. The nature of the fluids used is a big issue in fracking, and it would also seem to be a potential problem here. This also comes up in section 3.4. The recommendation for measuring TDS for assessing water quality strikes me as inadequate. I would think the fluid has constituents with potential human or environmental health effects that would occur at concentrations so low that they would not impact TDS. It seems that the determination of what to measure with respect to water quality should reflect what are the major constituents of concern in the extraction fluids and the likely compounds extracted by those fluids. This is addressed somewhat more fully in section 4.3 and 5.7 (although I still don't know what is in the lixiviant), but those considerations are not reflected in the earlier sections.

In section 2.1 nothing is said about disposal of the water used for flushing during the pump and treat phase (i.e. as the aquifer is being restored). Is there not significant potential for surface water contamination depending on how that liquid is handled? Should that not also be a consideration here? Something could be said about this in section 7.

Something should be said about the range of depths of these mines because that is relevant to the nature of the groundwater encountered. If it is really deep, ancient groundwater, then seasonality seems irrelevant. If the injection/extraction occurs at shallower depths, then seasonality becomes more relevant. There is nothing in the report that would help a reader understand this. Similarly, in all the discussion of wells, nothing is said about appropriate well depth; all the discussion is about number and density.

22, 22: It would seem to me that one consideration in the restoration scenario and potential adoption of ACLs would be potential exposure of humans and wildlife to the contaminants, yet this is not mentioned anywhere. Are there some regulations about how close these sites

can be to drinking water or irrigation wells? Shouldn't this be of some concern when deciding whether ACLs are appropriate? This is mentioned in section 7 (I was pleased to see it there), but I think it is also relevant in this earlier section.

3. Is the Committee's report clear and logical?

Overall, YES, but ...

Letter 1,43: Rather than "demonstrate that" I would prefer "determine whether" and "whether" rather than "that" on the next line. "Determine that" gives the false impression that stability is a foregone conclusion, when in fact one should be determining whether or not it has been achieved.

7, 27 and 11, 25: Is Figure 1 in the report not this review (I couldn't find it). I just found it on p. 14. It needs to appear sooner!

13, 8: How does the committee define these terms as they are used in this document? For example, I note that excursion is used several times in subsequent pages.

4. Are the conclusions drawn or recommendations provided supported by the body of the Committee's report?

YES

I'm not quite sure where to put this comment, so will just put it here at the end as something for the committee to consider. I know that USGS has considerable expertise in modeling and monitoring groundwater. To what extent has there been any collaboration between EPA and USGS in developing this document? I would think their expertise would be very relevant to the science behind many of the issues discussed here. Might that be suggested as a useful collaboration as EPA expands the document as the committee is requesting. Section 7.5 is one place where this could be done.

Editorial

4,17: recommended misspelled

22, 40: effectiveness "of" not "or"

34, 11: "accessibility of"

34, 28: Indy has sensitized me to the use of "believes" in these documents. After this very technical and well-informed document, the SAB can make a much stronger statement than "believes."

Comments from Dr. Eileen Murphy

1. Were the original charge questions to SAB Standing or Ad Hoc Committees adequately addressed?

Yes. The report is clear and extremely well-written. The responses to EPA's charge questions are technically valid and will serve to inform the development of sound procedures for monitoring impacts of uranium in-situ mining.

However, I think one minor recommendation may be too specific. The committee recommends "...identifying criteria for selecting analytes of primary and secondary importance for monitoring and listing their required detection limits and data precision." As analytical methods change over time, including this very specific information in a guidance manual may become outdated quickly. There are standard analytical method documents that delineate required detection limits for analytes that are updated periodically. Those method documents can be referred to here rather than listing the same information statically.

2. Are there any technical errors or omissions in the report or issues that are not adequately dealt with in the Committee's report?

None that this reviewer could find.

3. Is the Committee's report clear and logical?

Yes. The report is clearly laid-out and well designed. The writing is excellent and the recommendations clearly stated and validated.

4. Are the conclusions drawn or recommendations provided supported by the body of the Committee's report?

Yes.

Comments from Dr. James Opaluch

1. Were the charge questions to the Panel adequately addressed?

The Panel did an excellent job addressing the charge questions. I particularly appreciated that the Recommendations in the Executive Summary and the sections of the report were organized around the charge questions.

2. Are there any technical errors or omissions in the report or issues that are inadequately dealt with in the Panel's report?

This report definitely lies outside of my area of expertise, but I don't see any technical errors, omissions or issues that are inadequately dealt with in the report.

3. Is the Panel's report clear and logical?

In general, the report appears to me to be clear and logical.

4. Are the conclusions drawn or recommendations provided supported by the body of the Panel's report?

To the extent I am able to judge, the recommendations are well supported by the body of the report. The report makes several particularly important points with respect to statistical methods. In particular, as important as the specific statistical methods are, it is far more important that the data be adequate to support the analysis. The most rigorous statistical techniques are of little use if the number and selection of monitoring sites is inadequate. In particular, it is essential that monitoring wells are sufficient in number, density and especially location so the sample is properly representative of the contamination risk. This is well stated on lines 10-12 of page 27, where the report indicates:

“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.*” (emphasis added)

This point is also clearly expressed on lines 18-21. But one minor point, in order to further emphasize this essential element, I recommend that report add “location” to the sentence on lines 23-24 in the following paragraph, so the sentence reads:

“The SAB recommends that the technical report give a summary of methods to determine the number, density **and location** of monitoring wells.”

Section 6.2.1 Strengths and Weaknesses of Nonparametric Methods

Perhaps this discussion could be re-written as a more concrete recommendation to indicate where parametric vs. non-parametric methods would be more useful. For example, non-parametric methods might be recommended where outliers or data errors are more a concern, while a linear

model might be recommended where these are less of a concern, and where numbers of measurements are not balanced across wells.

Comments from Dr. Duncan Patten

Advisory on EPA's Draft Technical Document entitled *Considerations Related to Post-14 Closure Monitoring of Uranium In-Situ Leach/In-Situ Recovery (ISL/ISR) Sites*

Comments by Patten

~Were the original charge questions to adequately addressed?
Adequately addressed but with some questions (see below)

2. Are there any technical errors or omissions in the report or issues that are inadequately dealt with in the Panel's report?

The report should be clear about where and when to monitor and, in order for monitoring to develop a clear time sequence of groundwater quality changes the monitoring should be on and off site pre, post and during operations (see comments below).

3. Is the Panel's draft report clear and logical?

Well organized

4. Are the conclusions drawn or recommendations provided supported by the body of the Committee's report

Recommendations are supported by body of report but some gaps in monitoring sequencing and locations seem to raise questions about thorough consideration of ISL/ISR data collection.

Comments:

Letter to Admin. First two sentences need to be more clearly presented and tied together in some way.

Ex Summary: pg 2, line 17. Mentioned 5th topic but nowhere are there four previous topics cited.

Throughout the text (mentioned several times below) the monitoring test during operations should be carried out not only outside to test for migration of chemicals but also on site.

Page 5, line 21. waste is "pumped to disposal wells"... do the monitoring procedures test the consequence of using these disposal wells and if not, should this review mention that need?

Page 7. Lines 29-34. In this list of when monitoring on site should be done shouldn't one step be "looking at constituent concentrations during operations" (see next comment).

Page 8, lines 37-38. Modification of groundwater in the production zone. How does one know what is going on? Monitoring during production in the production zone is necessary to create the "time sequence" the review finds necessary and this will help understand post production monitoring data.

It seems as though where recommendations deal with on site contamination well tests are limited to pre and post operations. Is this because people who monitor on site pre and post are not allowed on site during operations to monitor? If so, this needs to be addressed and corrected in the procedures. The review makes a good point of emphasizing the need for baseline conditions but should emphasize the need to get baseline data at all monitoring locations (on and off site).

Figure 1. Should have some feedback arrows. Using this figure as a guide, how does it show how one tests the effectiveness of the final and/or many of the stages in the sequence presented?

Page 16, line 3. How are "gradients" determined? Perhaps this is answered in lines 30-33 pg 18, but if so not clearly.

Page 19, line 1. Is a "systematic grid" with no randomness to its establishment or layout "statistically valid"?

Page 20, line 21. Isn't there extensive literature on groundwater sampling (monitoring) that this report might suggest?

Comments from Dr. Amanda Rodewald

1. Were the original charge questions to adequately addressed?

The Panel's responses were thorough and included many explicit recommendations to EPA. They did an excellent job in clearly articulating the recommendations both in terms of instructions and rationale. That said, the last part of Charge Question 4 regarding subsequent data requirement for the use of certain statistical approaches did not seem to be specifically covered in detail. It might be that the information was distributed throughout that section. The Panel might consider including a subsection with the heading "data requirements".

2. Are there any technical errors or omissions in the report or issues that are inadequately dealt with in the Panel's report?

Not that I detected, though this is not in my area of expertise.

3. Is the Panel's draft report clear and logical? and

Yes, their use of bulleted lists for recommendations was especially helpful.

4. Are the conclusions drawn or recommendations provided supported by the body of the Committee's report?

The Panel provided explanations of the rationale underlying suggestions and concerns.

Other comments:

I applaud the Panel for providing so much useful input beyond the original charge questions.

They raised a number of important issues.

I would recommend substituting a different phrase in Figure 1 for "'mine' the data". Perhaps "explore existing data sets"?

Comments from Dr. James Sanders

1. Were the original charge questions to SAB Standing or Ad Hoc Committees adequately addressed?

To the extent of my knowledge, yes.

2. Are there any technical errors or omissions in the report or issues that are not adequately dealt with in the Committee's report?

To the extent of my knowledge, no.

3. Is the Committee's report clear and logical?

Yes, however I do have a few minor comments appended below, and one general comment about the executive summary. This summary, after a brief introduction and some general statements, is largely a series of bulleted comments pertaining to each charge question. I have never seen this format used in SAB reports. It allows the executive summary to be brief in length, but I am not sure that it conveys much information to the reader. If a reader were to examine this section alone, they will not obtain much understanding about the issues addressed more fully in the body of the report. Of course, all summaries are constrained—but is this version too much so?

4. Are the conclusions drawn or recommendations provided supported by the body of the Committee's report?

Yes. Some minor comments and typos below.

p. x, line 31. PPA should be PAA?

p. 7, line 27. Figure 1 is noted here, but is not found until p. 14. It should follow this reference.

p. 12, line 34. RAC should be SAB

p. 29, line 39. RAC should be SAB

p. 34, line 10. RAC should be SAB

Comments from Dr. Peter Thorne

1. Were the charge questions adequately addressed?

The charge questions were very thoroughly addressed.

2. Are there any technical errors or omissions in the report or issues that are not adequately dealt with in the draft report?

The review document did not provide any information on the general or specific ingredients or characteristics of lixivants. The term pregnant lixiviant (in Table B1) was not defined.

3. Is the draft report clear and logical?

There is a strong recommendation that sophisticated modeling be conducted and that sufficient monitoring is needed to provide the data for the modeling efforts. Modeling was suggested to account for spatial, temporal and chemical phenomena; seasonal, short-term, long-term and extreme event fluctuations; and to provide within-well and between-well variance components; all for up to three dozen analytes. It was further suggested that this modeling utilize parametric methods and include repeated measure analysis and consideration of multiple comparisons issues depending upon the null hypothesis being tested. This modeling seems to be a high-level task and it is unclear to me if this would be required of the Mining Companies. If so, do they have the requisite expertise to perform this modeling? It would certainly be a useful scientific endeavor but will require significant personnel and data resources to carry out in a rigorous manner.

4. Are the conclusions drawn or recommendations provided supported by the body of the draft report?

Yes. The draft report suggests an extensive enhancement and expansion of the Draft Technical Document.

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