

**NATURAL RESOURCES DEFENSE COUNCIL'S & POWDER RIVER BASIN  
RESOURCE COUNCIL'S PETITION FOR REVIEW**

**EXHIBIT 11**

UNITED STATES OF AMERICA  
NUCLEAR REGULATORY COMMISSION  
BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of )  
)  
STRATA ENERGY, INC., ) Docket No. 40-9091-MLA  
)  
(Ross *In Situ* Recovery Uranium Project) )

**Pre-Filed Rebuttal Testimony of Dr. Lance Larson on  
Contentions 2 and 3**

**Q. 1. Dr. Larson, you’ve testified in this proceeding before today?**

A. 1. Yes, my name is Dr. Lance Larson and I provided pre-filed direct testimony in this proceeding on August 25, 2014. *See* JTI003. My credentials were provided at that time. *See* JTI004.

**Q.2. How is your rebuttal testimony filed this day organized?**

A. 2. My testimony is organized as follows:

- 1) Response to Staff and SEI Testimony regarding Contention 2 and the matter of whether the FSEIS analyzes the environmental impacts that will occur if the applicant cannot restore groundwater to primary or secondary limits; and
- 2) Response to Staff and SEI Testimony regarding Contention 3 and the matter of whether the FSEIS fails to include adequate hydrological information to demonstrate SEI’s ability to contain groundwater fluid migration.

**I. Response to Staff and SEI Testimony regarding Contention 2**

**Q. 3. Staff asserts (at 31) “Consistent with the Commission’s generic determination in the GEIS (Ex. NRC007 at 4.2-27), the Staff determined in the FSEIS (Ex. SEI009A at 4-40 and 4-48) that the potential impacts to water quality of the exempted aquifer as a result of Ross Project operations would be expected to be SMALL and temporary because Strata is required by Condition 10.6 of its license (Ex. SEI015) to comply with 10 C.F.R. Part 40, Appendix A, Criterion 5B. In other words, the Staff concluded in the FSEIS that the potential impacts to water quality of the exempted aquifer as a result of ISR operations would be SMALL and temporary regardless of which of the three options defined in 10 C.F.R. Part 40, Appendix A, Criterion 5B, is used.” How do you respond?**

A. 3. I do not agree that the environmental impact of an ACL is “small and temporary” regardless of the extent of contamination, which is what Staff seems to imply with its reliance on the yet to be determined ACL. Rather, the FSEIS, and now the Staff in its testimony, fail to present a clear picture of the extent of groundwater impacts at previous ISL sites, as what they purport to call a “bounding analysis” fails to accurately present the data and further, fails to accurately and precisely display the irreversible degradation of the natural resource. As documented in my August 25, 2014, prefiled direct testimony, the likelihood of meeting either the original baseline or the EPA Maximum Contamination Limit for uranium, is vanishingly small. Relying on the examples NRC cites in the FSEIS or in their August testimony (JTI003; p.22), and the underlying data from NRC sources on which the Storymaps are based, it is my professional opinion that the Ross Project will not have “SMALL and Temporary” impacts on groundwater quality, but rather that those impacts will be large and long-term. As I will discuss

below, Staff's "bounding analysis" fails to accurately provide a meaningful discussion of the irretrievable and irreversible impacts of ISL operations.

**Q.4. Staff asserts (at 33) *"the Commission approved restoration of uranium to values ranging from 4 to 71 times post-licensing, pre-operational background values. Specifically, the average concentration of uranium in the wellfield(s) for which the Commission issued restoration approval were as follows: (1) Crow Butte Wellfield 1: 1.73 mg/L, or 18 times background levels; (2) Smith Ranch- Highland A-Wellfield: 3.53 mg/L, or 71 times background levels; and (3) Irigaray Mine Units 1-9: 1.83 mg/L, or 4 times background levels (Crow Butte Resources, 2001; PRI, 2004; Cogema, 2006b). In other words, based upon the available historical record of uranium concentrations at the close of active restoration, if an ACL is requested by Strata for the Ross Project, it is likely to range between 1.7 mg/L and 3.5 mg/L, or 4 to 71 times the post-licensing, preoperational background values for uranium that ranged from 0.05 to 0.52 mg/L."* How do you respond to this?**

A.4. The figures above are what Staff purports, post hoc, to call its "bounding analysis." This data was not presented as a bounding analysis in the FSEIS and for the reasons I explain below, it should not be understood or presented as a meaningful or accurate bounding analysis. I will discuss the reasons for this in turn.

### **Crow Butte**

First, as noted in my August testimony, in neither the FSEIS or in Staff's August testimony is there a risk or dose calculation to support the contention that the elevated radium-226 and uranium concentrations pose no threat to human health and the environment.

Second, Staff further asserts (at 37) *“the FSEIS documented the systematic approach taken by the Commission in 2003, in which it: (1) assessed concentrations in groundwater after aquifer restoration; (2) ensured the stability of concentrations over time; (3) compared the groundwater concentrations to primary and secondary standards; and (4) applied those standards to arrive at a determination that the groundwater concentrations presented by Crow Butte for Wellfield 1 were protective of human health and the environment.”*

The FSEIS did no such thing. The FSEIS (SEI009A at 4-46) briefly describes the Crow Butte history, states that restoration levels were approved, citing a 2001 Crowe Butte restoration report. Such a treatment leaves out important details. On March 29, 2002, obliquely referenced in the FSEIS as “stability monitoring,” the NRC Staff denied the Crow Butte restoration report referenced and discussed in the FSEIS as being not protective of human health and the environment. (JTI053; p. 99). In that document, Staff concluded *“the data in your Restoration Report, submitted by letter dated January 14, 2000, and the additional information submitted by letter dated August 24, 2001, do not demonstrate that the restoration activities in Unit 1, have resulted in constituent levels that will remain below levels protective of human health and the environment, in accordance with 10 CFR 40.31(h) and Criterion 5F, 10 CFR Part 40, Appendix A.”*

Further, upon collection of additional groundwater samples between June and September 2002, the groundwater samples observed uranium concentrations of similar magnitudes (1.6 – 1.8 mg/L) (JTI053: p. 125 – 126), thus, precisely the same as what was described above as below levels deemed to be protective of human health and the environment. However, while there was no decrease in the uranium, but seemingly not approaching an arbitrarily set secondary standard of 5 mg/L, after this second round of stability sampling, NRC approved the restoration. To

reiterate, despite roughly equivalent uranium concentrations observed previously which were deemed not protective, the NRC approved restoration as adequately protective. The basis for finding similar concentrations protective in one instance and not in another is not discussed at all in the FSEIS. Indeed, approval of the Crow Butte mine unit 1 concentration levels -- 1.73 mg/L, or 18 times background levels -- as “protective of human health and the environment” was determined by an arbitrary standard chosen out of expedience for that site and has little meaning for assessing a future ACL at the Ross project. It also demonstrates the subjective statement “protective of human health and the environment” is only condition dependent, and lacks scientific or empirical basis for assessing restoration performance.

### **Smith Ranch**

For Smith Ranch wellfield A, Staff acknowledges the averaging of uranium concentrations at 71 times the background as a purported high end of what could happen at Ross. However, Staff has not performed analysis on the entire distribution of data available from the Staff’s own data at Smith Ranch, which could justify why that concentration is applicable and not something potentially much higher. As evidenced by the underlying NRC spreadsheet groundwater data,<sup>1</sup> groundwater contamination at ISL sites widely varies spatially and temporally, and these need to be factored into the data analysis. In neither its FSEIS or subsequent testimony has the Staff done such analysis.

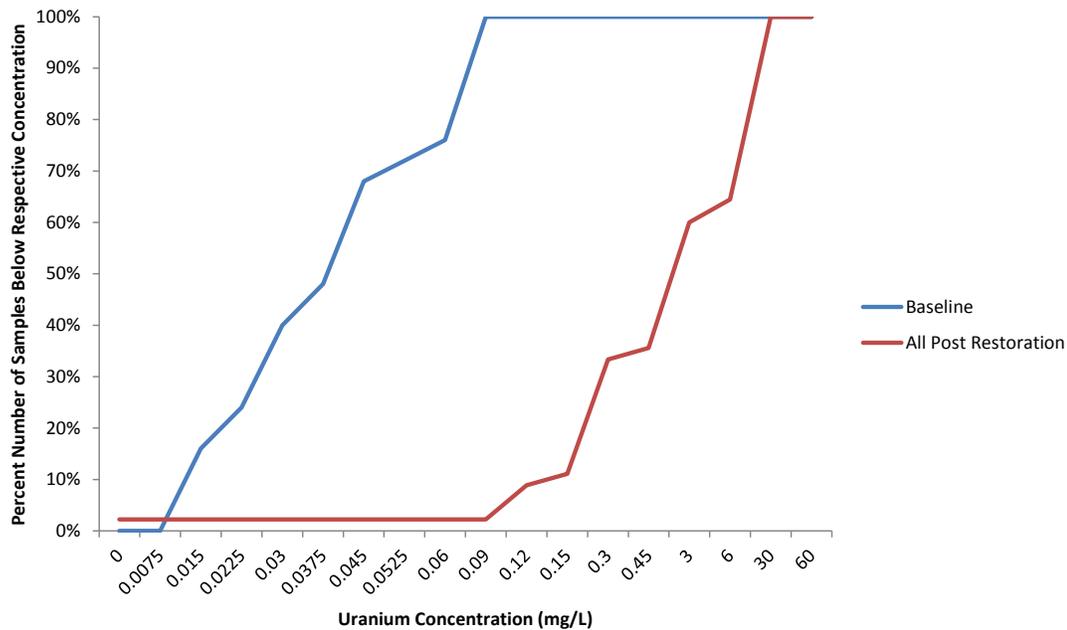
As a measure of contrast, compare Staff’s anecdotal and conclusory statements regarding restoration at Smith Ranch with the substantially more complete picture presented in my August testimony for Smith Ranch. There, I provide examples of various wells and a comparison of

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<sup>1</sup> Per the Board’s September 10, 2014 Order, Joint Intervenors will file the spreadsheets in .pdf form on September 16, 2014.

post-restoration and baseline uranium concentrations in the groundwater. For example, samples at well MP-4 observed extremely elevated uranium concentrations (5.5 – 11.5 mg/L) compared to average baseline (0.03 mg/L), exceeding the average baseline uranium concentration by ~183x - 383x, with no evidence that natural attenuation was decreasing elevated uranium concentrations. Well MP-5 observed a similar trend, where uranium concentrations range from 5.9 – 11.00 mg/L, where 11.00 mg/L was the last sample available suggesting an progressively increasing trend. The average baseline was 0.04 mg/L, indicating concentrations had increased between 148x – 275x baseline concentrations, well above the 71x proposed by Staff. Further, according to the NRC Staff's spreadsheets, these samples were all collected between February 1999 and November 1999, implying they should be relevant to the bounding analysis. None of these complexities and none of this granular data or analysis are presented by Staff in the FSEIS or in their testimony.

For this rebuttal, I've prepared a cumulative histogram from the NRC's own data used in the August Testimony at Smith Ranch wellfield A (MP1 – MP5) that demonstrates that extreme contamination levels (defined as >3 mg/L or 100x safe drinking water standards) were approximately 40% of the post restoration samples. All baseline samples were used (n=25) and all post-restoration samples were used (n = 45) in creation of the cumulative histogram.



**Q.5. Staff (at 39, 40) asserts that in your March declaration you and Dr. Abitz failed to fully present the analysis of Borch *et al.* as it related to declining uranium concentrations. Specifically, Staff asserts “[Drs. Abitz and Larson note, the 2005–2012 data from well MP-4 demonstrate that the production zone continues to contain elevated levels of uranium. The authors of the study cited by Drs. Abitz and Larson determined that the uranium level in that well increased 4.4 percent over the monitoring period (see Ex. NRC037 at PDF 6, Table 3). However, Drs. Abitz and Larson do not discuss the full analysis and conclusion reached in the study. In their independent review of the post-restoration data at A-Wellfield, the study identifies the 30 percent decline in uranium concentrations in well I-21 between 2005 and 2012 (Ex. NRC037 at PDF 6, Table 3), and the low levels of uranium reported in the surrounding monitoring wells and concludes that the natural attenuation process is occurring as predicted by Power Resources Inc.’s analysis (see Exs. NRC037; NRC028 at 64, 94). Based**

*on our review of the post-restoration groundwater presented in the study by Borch et al (2012), we believe that it is consistent with the conclusion reached by the Commission when it approved restoration of A-Wellfield, which is that the level of uranium at the time of restoration approval was protective of human health and the environment. (Ex. NRC027).”*

**How do you respond?**

A.5. It is Staff that inaccurately presents the Borch *et al.* conclusions and improperly concludes without qualification that natural attenuation is responsible for the decrease in uranium.

Specifically, in the analysis of the Borch *et al.* 2012 paper from Smith Highland, the NRC Staff conclude that natural attenuation was responsible for the decrease in uranium concentrations at well I-21. However, NRC Staff’s conclusion is taken out of context, as Borch *et al.* fully state: (NRC037 at p.7):

“The trend at I-21 could be due to more uranium being attenuated by natural processes or leaving with groundwater than the influx of uranium. It is very difficult to speculate or model the most likely natural attenuation processes controlling the fate and transport of U at this site due to the general lack of hydrological and biogeochemical data.” (emphasis added).

In others words, the authors attempted to explain that decreased uranium concentrations observed at well I-21 could be due to *either* natural attenuation *or* because the net uranium flux was migrating from well. The difference between the two is stark, and important for assessing the potential for uranium transport. The authors further conclude that there is insufficient data to attempt to model these complex hydro-biogeochemical reactions that influence the transport of uranium in an aquifer. The incomplete hydrological and biogeochemical dataset issue has been raised previously (JTI003; p. 50-52) and will also be discussed in depth in contention 3.

Further, not discussed by Staff in either the FSEIS or their testimony, a crucial matter for any meaningful attempt at bounding analysis of potential restoration results, is the trend toward

increasing uranium concentrations within the ore zone. An example of this that should have been analyzed in the FSEIS is the results and data from Smith Highland mine unit A. The uranium concentration trends within the mine unit, suggest that concentrations are *either* increasing or staying stable, and elevated. Samples taken at this site after the Borch *et al.* 2012 demonstrate this trend. The 2012 sample from I-21 actually increased to 2.13 mg/L from 2011, which observed 0.663 mg/L (NRC029; p. 52). The 2012 sample from MP-4 observed a uranium concentration of 17.3 mg/L, the highest concentration measured at this well. Note, that the uranium concentration observed at MP-4 at the beginning of 1999 was 5.50 mg/L (See JTI005B-R; p. 28-29), suggesting that between 1999 and 2012 uranium concentrations at well MP-4 more than tripled ( from 5.5 mg/L to 17.3 mg/L). These results indicate that the effects on groundwater in the ore zone are not SMALL nor temporary as continually asserted throughout the FSEIS.

Increasing uranium trends are also confirmed in wells from ‘restored groundwater’ at Christensen mine unit 5-2. This is clearly a trend across sites that has received no attention from the Staff, either in the FSEIS or the in their testimony. For example, Monitor Wells 5AH57-1, 5AG-70, and 5AV46-1 were former injection wells used in the ‘first’ operation of Christensen Ranch mine unit 5, which all had been converted to monitoring wells upon the operation of mine unit 5-2 (NRC041; p.2 and 4-6). Within a year of sampling, these wells observed alarmingly increasing trends of uranium concentrations. For example well 5AV46-1 observed a significant increase in uranium concentrations in less than a year (from 11/28/2011 to 7/2/2012), from ~5.4 mg/L to 31.2 mg/L (180x to 1,040x safe drinking water standards). The last sample observed at 5AV46-1 observed the maximum concentration measured (31.2 mg/L), indicating an upward trend in groundwater that had been “restored” (JTI054; p. 8). It’s important to note that the ‘first’ post-restoration stability measurements in mine unit 5 ended in 8/1/2004, suggesting

concentrations were increasing, and are still rising, within the well field to extremely high concentrations roughly a decade after stability monitoring ended. Again, these data suggest there's very little empirical evidence that the environmental impacts will be either "small" or temporary. In fact, the publically available groundwater data suggest the impacts to groundwater are and will be large and permanent.

**Q.6. Staff (at 40-41) criticizes your analysis of the Irigaray baseline and restoration results. Specifically, Staff asserts, "*Furthermore, to attempt to recalculate the uranium concentrations using the initial average "baseline" concentrations as proposed by Drs. Abitz and Larson is neither practicable nor useful for the purposes of the discussion of historic restoration approvals in the FSEIS. First, a recalculation of these values using the alternate approach proposed by Drs. Abitz and Larson would require the Staff to essentially re-do the technical evaluation previously performed by the Commission for this wellfield using a different assumption regarding averaging baseline of wellfields. Such an exercise would be predicated on the availability of all the necessary raw data and an outlay of time and resources disproportionate to the value of the exercise, in that it would not serve the purpose of the discussion in the FSEIS – to record what actually occurred when the Commission approved alternate restoration values at Irigaray in the past. Second, the result of such an effort would likely not impact the range of concentration values for uranium recorded in the FSEIS as approved secondary restoration standards at the Irigaray wellfields. For the hypothetical situation in which the uranium baseline concentrations for Irigaray Mine Units 1-9 excluded data from Mine Unit 1, following the approach suggested by Drs. Abitz and Larson, it is almost certain that the restoration uranium concentrations in Mine Units 1 and Mine Units 2-***

*9 would fall below the high end of the range for uranium established by the three facilities presented in the FSEIS – that is, 3.5 mg/L, or approximately 71 times the background value for uranium, as approved by the Commission for Smith Ranch-Highland A Wellfield.*

*Therefore, we do not believe that the Intervenors’ concerns regarding the Commission’s approach for approving alternate restoration values at Irigaray Mine Units 1-9 meaningfully affect the Staff’s evaluations or conclusions in the Ross Project FSEIS.”* **How do you respond?**

A.6. Staff’s assertion that the “post-licensing, pre-operational background values for uranium that ranged from 0.05 to 0.52 mg/L”, is flawed and unjustified. First, by examining the actual cumulative distribution for baseline data from a representative site, such as Willow Creek - Christensen Ranch, the value of 0.05 mg/L would be higher than roughly 85% of the baseline samples measured (JTI003; p. 41, figure). For the Smith Highland Samples, 0.05 mg/L baseline would have exceeded approximately 70% of the observed baseline samples (See histogram figure above). There is no justification to assume a concentration at such a high baseline concentration (0.05 mg/L), when that value is unrepresentative of the actual concentrations observed in the groundwater representative of baseline groundwater at ISL sites.

Next, I’ve explained, in my initial testimony (JTI003; p.16), that pre-mining leach activities which were not restored in Irigaray mine unit 1 had a profound impact on the ‘average baseline’ concentrations (See table in JTI003; p.15). This extremely high value, which was an artifact of injection of lixiviant prior to collection of ‘baseline’ samples, was used in order to skew the baseline dataset for mine units 2-9 to the substantially higher value ~0.52 mg/L. Therefore, the upper bound baseline concentration is also unjustified.

By determining that the range of uranium concentration increases at Irigaray mine units 1-9 showed only an increase of 4x displays the pitfalls of how not to perform a meaningful data analysis. While the Staff acknowledges that Irigaray mine unit 1 data was skewed from research and development activities (NRC001, p.22), they assert that the results of mine units 2-9, data which I presented in my initial testimony (JTI003; p.15), would “*fall below the high end of the range for uranium established by the three facilities presented in the FSEIS – that is 3.5 mg/L, or approximately 71 times the background value for uranium*”.

However, the approach to claim that these values are within the “bounding analysis” does not compare how those values changed from respective baseline values for each individual mine unit. To only consider the ‘final’ concentrations and not compare them to an actual and representative sample of initial average baseline concentrations shows the fallacy of the proverbial ‘one-armed fisherman’ (imagine a one-armed fisherman gesturing to describe the size of a fish he had caught: “It was this big”). To put it plainly, while the average stability concentrations of Irigaray mine units 2-9 ranged from approximately 1.46 – 3.8 mg/L; the actual range of increase from average baseline increased between 16x – 125x (See table in JTI003; p.15), exceeding both the upper and lower bounding limits proposed by Staff (4x – 71x). Again, this example presents how the “bounding analysis” suggested by Staff, using the available data of approved restoration ISL sites, does not provide a meaningful range of baseline values nor potential ACLs.

**Q.7. But didn’t Staff (at 41) assert that Intervenors’ approach for approving alternate restoration values at Irigaray Mine Units 1-9 would not meaningfully affect the Staff’s evaluations or conclusions in the Ross Project FSEIS?**

A.7. Staff asserts that what transpired at the Irigaray site has no relevance on the Ross operation (NRC001, p.22), but Staff is incorrect. This situation directly parallels the two failed groundwater restorations from Nubeth's research and development activities within the Ross project boundaries. In other words, localized previous mining activities at Nubeth would result in high 'background' or 'baseline' values, and mask the actual impacts to the groundwater, which would be used to absolve groundwater restoration responsibilities. This is true, regardless of the type of lixiviant used (NRC001, p.22), whereas ISL sites using sodium carbonate lixiviants have also failed to restoration baseline values at all ISL operations in the US after ending ammonia based lixiviants in the early 1980s.

Of note, Staff cites Cogema's Christensen Ranch mine units 2-6 has requested approval for restoration in 2008. Uranium One acquired the license from Cogema in 2009 (~5 years prior to the FSEIS) and has restarted ISL operations in parts of mine unit 5, and began operations in several new mine units without prior approval of the restoration report for mine units 2-6.

JTI055. I discussed and presented data for specific groundwater contamination from the 'first baseline' and 'first post-restoration' at Christensen Ranch (JTI005B-R; p.1-20). It's unclear from the FSEIS, how the agency would proceed to handle a pending groundwater restoration approval of several mine units (MU2-MU6), while concurrent ISL operations are occurring at adjacent (MU7, MU8, MU9, MU10-A, MU10-B: JTI055) and within former mine units (MU 5-2: JTI056; p.2), and the potential environmental impacts to groundwater which would ensue in such a process.

## **II. Response to Staff and SEI Testimony regarding Contention 3**

**Q.8. Staff (at 71, 72) mounts a defense of its presentation of subsurface geochemistry and geochemical mechanisms of uranium transport in the FSEIS. Specifically, Staff challenges your claim that the FSEIS (SEI009A at 4-41) is “inaccurate and an oversimplification of the dominant geochemical mechanisms which dictate subsurface transport of soluble uranium.” Staff asserts its position in the FSEIS is fact, and Staff’s approval of chloride, conductivity, and total alkalinity as described in the SER (SEI014 at 280) and in License Condition 11.4 is consistent with analysis of excursion and recommendations for excursion monitoring parameters in Staub et al. (1986) (NRC020 at 37-39). They go on to note that geochemical reactions involving uranium that are described by Drs. Abitz and Larson in their paragraphs 48–50 are the very reasons why uranium is not monitored as an indicator parameter for excursions. Further, Staff asserts the point is not whether uranium may increase in the groundwater from an excursion. The point is which parameter should be monitored as a leading indicator to identify the excursion most quickly. Staff concludes, “[i]n response to the geochemical reactions involving uranium described by Abitz and Larson (paragraphs 48-50), the rate of uranium transport in the aquifer could be slowed by adsorption and precipitation; and therefore, uranium is not a leading indicator of an excursion into the groundwater outside the production zone. There is nothing vague or contradictory about the information and impact analysis in the FSEIS.” How do you respond to Staff’s defense of its treatment of the potential for fluid migration in the aquifer?**

A.8. Respectfully, the NRC Staff’s understanding and associated presentation of uranium subsurface geochemistry contaminant fate and transport is dated and thus, the FSEIS is lacking

in its treatment of the matter. This is an area of significant concern and in my August testimony I expressed fundamental disagreements with the NRC over how they interpret geochemical interactions that will take place in the subsurface when efforts to establish baseline are commenced and, more important, when mining commences. This is especially important as the FSEIS fails to account for the potential for contaminant excursions in light of an inadequate assessment of aquifer confinement. Specifically, by failing to accurately understand and assess uranium fate and transport in the subsurface combined with a failure to sufficiently analyze the potential for and impacts associated with vertical fluid migration, through unidentified or unsealed drillholes between aquifer units, Staff essentially dilutes the significant and irreversible environmental impact. A clear understanding of these pathways is directly relevant to the FSEIS's failure to analyze sufficiently the potential for and impacts associated with fluid migration associated with unplugged exploratory boreholes, including the adequacy of applicant's plans to mitigate possible borehole-related migration impacts by monitoring wellfields surrounding the boreholes and/or plugging the boreholes.

**Q.9. Dr. Larson, let's unpack this one piece at a time, so let's start with the geochemistry and whether the FSEIS presented adequate hydrological information to demonstrate SEI's ability to contain groundwater fluid migration?**

A.9. In defending its presentation of subsurface geochemistry and why it doesn't use uranium as an excursion indicator, the NRC Staff claims that the assertion in the FSEIS (SEI009A at 4-41) and in its direct testimony (p. 71, 72, note 5) that "*These constituents move through the aquifer faster than other water-quality parameters, and therefore levels above these would indicate excursions before radionuclides and other elements move outside the production (i.e., uranium-*

*recovery) zone*” is a statement of fact. This purported statement of fact is made without any citation or supporting evidence, only a professional opinion.

However, the scientific literature over the last decade contradicts NRC’s assertion and its simplistic assumptions regarding conventional uranium transport mechanisms, especially concerning geochemical conditions which arise due to ISL operations. A factual statement regarding uranium transport is that uranium mobility in groundwater is dependent on a host of site specific hydro-biogeochemical conditions, which can be mutually agreed upon by SEI, Staff, and Intervenors’. This is articulated by a current quote from the homepage of Gary Curtis, an environmental engineer with the USGS:

“Groundwater contamination from hexavalent uranium U(VI) is a problem at many federal sites because of its importance in the nuclear fuel cycle. The adsorption and therefore mobility of U(VI) in groundwater is controlled by the local geochemical conditions such as pH and especially the alkalinity which is usually composed primarily of bicarbonate and carbonate ions. Understanding the mobility of U(VI) in groundwater is a key prerequisite to estimating the discharge to receiving water bodies, quantifying risks from the use of contaminated groundwater and evaluating site management alternatives.” JTI057.

Now that we’ve established uranium mobility in groundwater is dependent on a host of site specific hydro-biogeochemical conditions, and not qualitative conjectures of speed, I will present a review of the updated science on the issue of fluid migration and potential uranium transport that is entirely missing from the FSEIS and staff’s post hoc defense in its August testimony. In short, I conclude NRC Staff’s model of uranium transport is poor and does not adequately support the control of unwarranted fluid migration off-site.

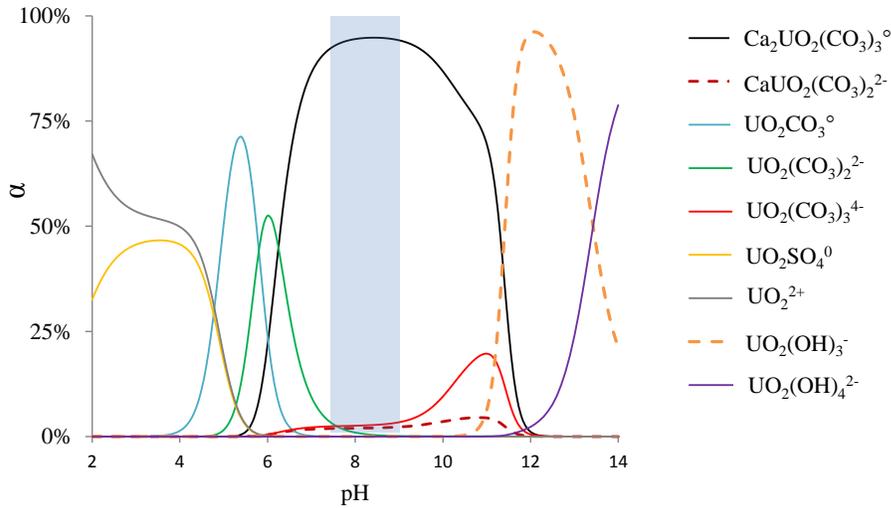
**Q.10. Why do you say this?**

A.10. I will start with some basic technical data that informs the development of the science of uranium’s potential for fluid migration in the last decade.

In natural environments, uranium forms complexes with various anions, termed ligands, in solution. Complexes are species which form when the central atom interacts with a ligand. Uranium can conceivably exist as several species given the specific conditions of the solution (See figure below).

Fox et al. (JTI058 at p. 8, paragraph 2, (2006)) demonstrated that the presence of calcium and carbonates have significant impact on uranium adsorption to reactive mineral surfaces. This is due to the formation of calcium-uranyl-carbonate complexes (Ca-UO<sub>2</sub>-CO<sub>3</sub>) which are thermodynamically stable under those conditions. Kelly et al. (JTI059 (2007)) observed evidence of the existence of these species with spectroscopy and thermodynamic speciation calculations predicted geochemical stability ranges. These measurements provide direct evidence for the existence of these complexes and consistency was established with thermodynamic speciation calculation predictions, which were used in my geochemical model below.

I've created the figure below using a geochemical modeling software (PHREEQC v.3.1.2) using an updated thermodynamic database which includes the formation of the Ca-UO<sub>2</sub>-CO<sub>3</sub> complexes and representative average stability data from Christensen Ranch ISL mine unit 5. The pH was the master independent variable and average post-restoration constituent concentrations were held constant. The shaded grey region shows the range of measured pH values from the stability samples at Christensen Ranch. The table below the figure shows the input data into the thermodynamic database and model. This figure shows, unequivocally, that the representative geochemical conditions in the aquifer post-restoration are largely dominated by Ca-UO<sub>2</sub>-CO<sub>3</sub> complexes predicted by the updated thermodynamic database. This geochemical evidence has significant implications towards uranium adsorption and reductive precipitation which will be discussed below.



Relevant aqueous species and PHREEQC input data

Aqueous Species	Reaction	log K
$\text{Ca}_2\text{UO}_2(\text{CO}_3)_3^0$	$2\text{Ca}^{2+} + \text{UO}_2^{2+} + 3\text{CO}_3^{2-} = \text{Ca}_2\text{UO}_2(\text{CO}_3)_3^0$	30.6
$\text{CaUO}_2(\text{CO}_3)_2^{2-}$	$\text{Ca}^{2+} + \text{UO}_2^{2+} + 3\text{CO}_3^{2-} = \text{CaUO}_2(\text{CO}_3)_2^{2-}$	25.4
$\text{UO}_2\text{CO}_3^0$	$\text{UO}_2^{2+} + \text{CO}_3^{2-} = \text{UO}_2\text{CO}_3^0$	9.63
$\text{UO}_2(\text{CO}_3)_2^{2-}$	$\text{UO}_2^{2+} + 2\text{CO}_3^{2-} = \text{UO}_2(\text{CO}_3)_2^{2-}$	17.0
$\text{UO}_2(\text{CO}_3)_3^{4-}$	$\text{UO}_2^{2+} + 3\text{CO}_3^{2-} = \text{UO}_2(\text{CO}_3)_3^{4-}$	21.63
$\text{UO}_2\text{SO}_4^0$	$\text{UO}_2^{2+} + \text{SO}_4^{2-} = \text{UO}_2\text{SO}_4^0$	3.15
$\text{UO}_2(\text{OH})_3^-$	$\text{UO}_2^{2+} + 3\text{H}_2\text{O} = \text{UO}_2(\text{OH})_3^- + 3\text{H}^+$	-19.2
$\text{UO}_2(\text{OH})_4^{2-}$	$\text{UO}_2^{2+} + 3\text{H}_2\text{O} = \text{UO}_2(\text{OH})_4^{2-} + 4\text{H}^+$	-33.0

	Baseline Ore					Stability Ore				
	mean	n	std	min	max	mean	n	std	min	max
Ca	10.4	100	4.1	2.5	32.6	33.4	100	29.9	4	138
Mg	1.4	100	0.6	0.2	3.2	6.7	100	6.1	1	30.8
Na	146.4	100	11.5	115	180	154.1	100	86.8	51	420
$\text{SO}_4^{2-}$	215.5	100	33.5	185	330	150.0	100	107.2	21	408
Cl	7.4	200	0.9	5.6	13.1	11.0	100	10.0	2	37.9
$\text{CO}_3\text{T}$	113.3	200	20.6	79.4	217.4	275.9	100	182.6	86	864
pH	8.8	200	0.4	8.03	10.86	8.1	100	0.3	7.4	8.9
U(VI)	0.026	100	0.0	0.0060	0.22	2.26	100	3.7	0.0069	21.7

Concentrations in mg/L

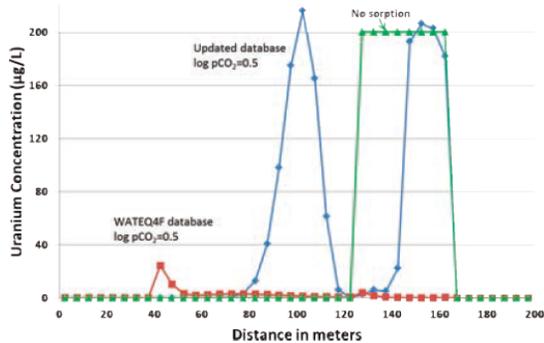
**Q.11. So you've explained that geochemical conditions in the aquifer post-restoration are largely dominated by Ca-UO<sub>2</sub>-CO<sub>3</sub> complexes, and that calcium and carbonates have significant impact on uranium adsorption to reactive mineral surfaces. Please explain adsorption and why this matters to Staff's defense (at 71, 72) of its presentation of subsurface geochemistry and geochemical mechanisms of uranium transport in the FSEIS?**

A.11. Adsorption describes the phenomenon where certain ions attract to a reactive surface. When the predominant uranium species are Ca-UO<sub>2</sub>-CO<sub>3</sub> complexes, uranium adsorption observed decreases with respect to various reactive surfaces (JTI058; p. 8, paragraph 2). When this finding was input into geochemical transport models, the authors found that under certain ISL relevant conditions there was substantial uncertainty with respect to uranium mobility (See figure below).

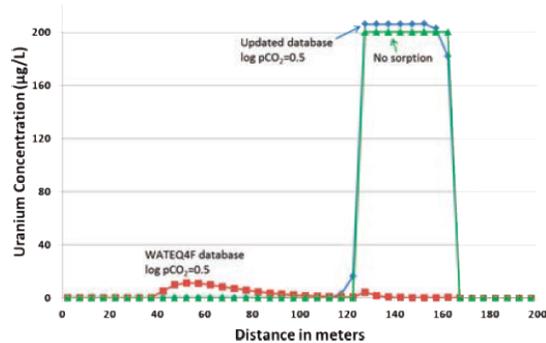
For example, the USGS used an updated geochemical model to simulate uranium transport from conditions similar to the proposed Dewey-Burdock ISL operation, SD (figure from JTI042, p. 5). The authors demonstrated the recently updated thermodynamic database, based on the addition of Ca-UO<sub>2</sub>-CO<sub>3</sub> and U(VI)-CO<sub>3</sub> complexes, display the nonreactive transport of uranium in confined aquifers. The red line indicates the modeled uranium concentration using outdated thermodynamic database (WATEQ4F) without considering CA-UO<sub>2</sub>-CO<sub>3</sub> complexes. The uranium concentrations predicted by the red line are substantially lower due to the assumption that Ca-UO<sub>2</sub>-CO<sub>3</sub> complexes are not present in solution and adsorptive processes are removing uranium from solution.

The blue line shows the modeled uranium concentration using (WATEQ4F) which includes the updated thermodynamic database. The uranium concentrations predicted by the blue line are substantially higher, because of the stability of updated uranium complexes and

their inability to react with iron oxides. Thus, under these geochemical conditions, uranium is highly mobile and does not adhere to conventional adsorptive mechanisms and remains elevated in the groundwater downgradient. The green line displays the concentration of uranium when adsorption was removed from the model (nonreactive transport).



*Fig. 9* Uranium concentrations in groundwater at 25 years with 500 ppm Fe and CO<sub>2</sub> in recovery zone of log pCO<sub>2</sub> equal to 0.5 and downgradient calcite equal to 0.15 weight percent. Green line is with no sorption, blue line is with updated database and red line is with WATEQ4F database.



*Fig. 10* Uranium concentrations in groundwater at 25 years with 500 ppm Fe and CO<sub>2</sub> in recovery zone of log pCO<sub>2</sub> equal to 0.5 and infinite calcite. Green line is with no sorption, blue line is with updated database and red line is with WATEQ4F database.

**Q.12 So older models presumed problematic concentrations of uranium wouldn't migrate, but newer models demonstrate fluid migration occurs at an increased rate over what was previously expected?**

A.12. Essentially, yes. Under the geochemical conditions modeled, within 25 years the front edge of the uranium plume was predicted to migrate roughly 165 m (See figure above). More importantly is the vast difference between model results for the updated thermodynamic database (Blue) and the outdated thermodynamic database (Red) suggesting that uranium transport from ISL sites is grossly underestimated and transport of high levels of uranium concentrations

beyond the well field could reasonably occur within the span of a human life time or a matter of decades once hydraulic control is lost or absent.

Further, there is empirical evidence that the presence of reducing conditions is a poor assumption that will impede uranium transport through spontaneous precipitation. This is supported by groundwater samples taken from Kingsville Dome in Texas which observed very elevated uranium concentrations under reducing conditions. In brief, all groundwater samples observed indicators that reducing conditions were present: low dissolved oxygen (<1 – 0.24 mg/L), occurrence of ferrous iron ( $\text{Fe}^{2+}$ ) in solution, and the detection of sulfide (JTI060; p.60). All of these factors indicate evidence for reducing conditions present in the groundwater affected by ISL.

Indeed, the measured geochemical evidence from Kingsville Dome ISL groundwater samples strongly suggests ISL influenced uranium concentrations remain extremely elevated under reducing conditions. While all geochemical parameters mentioned previously indicate reducing conditions were present in the aquifer samples, uranium concentrations ranged between 4.7 – 12.5 mg/L (JTI060; p.59), which range 157x – 417x above safe drinking water standards and consistent with many of the elevated samples observed at Willow Creek and Smith Highland. This observation (very high dissolved uranium concentrations under reducing conditions) is consistent with scientific literature which has found decreased abiotic reduction of uranium due to the presence of bicarbonate (JTI060; p.46 ) and the kinetics of sulfide promoted uranyl-carbonate complexes are substantially lower than uranyl-hydroxide complexes (JTI061). Moreover, biotic reduction of uranium in the presence of calcium has observed decreased uranium reduction rates compared to conditions where no Ca was present (JTI043; p.2, paragraph 2). This suggests that biotic reduction of uranium in the form of  $\text{Ca-UO}_2\text{-CO}_3$

complexes is less bioavailable than other forms. In plain terms, certain microorganisms have difficulty 'eating' (reducing U(VI) to U(IV)) uranium when it's mixed with Calcium and carbonate, then they would without those ions present.

Therefore, Staff's qualitative statement that "*These constituents move through the aquifer faster than other water-quality parameters, and therefore levels above these would indicate excursions before radionuclides and other elements move outside the production (i.e., uranium-recovery) zone*" is neither a statement of fact nor consistent with the current scientific knowledge concerning geochemical process which dictate the migration of uranium in ISL aquifers. The subsurface geochemistry at these sites are highly complex and none of the biogeochemical data required to adequately predict uranium fluid migration is collected, analyzed, nor acknowledged by the NRC Staff. Without a thorough understanding of subsurface hydro-biogeochemical mechanisms, it is impossible to adequately address the risks to adjacent aquifers and private well locations by uranium migration.

**Q.13. The NRC Staff assert that they have adequately described how mining activities will disturb reducing geochemical conditions (NRC001; p.70-71) and proceed to explain the ISL mining process. Does this adequately explain how the reducing conditions will be affected?**

A.13. No. A recent explanation from scientific research provides a more thorough and appropriate discussion of ISL recovery's disruption to the naturally established geochemical conditions. None of this was provided in the FSEIS:

*"This reversal of the ISR process does not naturally occur under regulatory time frames for the bulk of the leached ore zone. In fact, the persistence of uranium and other contaminants elevated*

*during ISR operations, in spite of years of restoration effort, is a strong motivation for investigating more efficient and effective restoration approaches.” (JTI060; p.44)*

In other words, the authors explain that ISR process will have, for all practical purposes, permanent impacts to the geochemical conditions within the ore zone. Further, the authors provide incentive to study obstinately elevated uranium concentrations in groundwater due to ISL activities and following ISL groundwater restorations. This is consistent with much of the groundwater data and trends presented throughout my initial testimony (JTI003), and reported in this document. In other words, the geochemical conditions, and thus groundwater quality, within the ore zone will be permanently altered, and subsequently degraded upon ISL operations. Yet, with this overwhelming evidence, Staff continues to assert to the environmental impacts to groundwater will be “small and temporary”.

**Q.15. Let’s turn to the matter of understanding these issues as they relate to excursions.**

**Could you explain further?**

A.15. There’s little dispute that horizontal excursions can be recovered during mining operations by iteratively adjusting the net hydraulic head gradient. Yet, the unforeseen circumstances when horizontal excursions cannot be recovered, or a loss of hydraulic control, are troublesome. NRC Staff’s discussion (NRC001; p. 73) of well 5MW66 as a successful example horizontal excursion recovery is questionable. This well has been on excursion status on-and-off for almost a decade and there is little explanation for the source plume in NRC’s own data (JTI062). Further, uranium concentrations were observed at 1.1 and 0.5 mg/L (4/23/2012 and 5/1/2012) while all

three excursion parameters were below respective detection limits (NRC041; p.9), which supports the notion uranium can be very elevated even while excursion parameters are below detection. It is unclear why 0.4 mg/L is used (13.3x safe drinking water standard) as the detection limit for uranium. Modern techniques to measure uranium, such as ICP-MS, can detect uranium as low as 0.0003 mg/L. The inclusion of hydro-geochemical data would provide the necessary information to assess and correct potential horizontal excursions; however none of this data is collected, assessed, or acknowledged by the NRC Staff.

**Q.16.NRC dismisses (NRC001 at 59 and SEI009A; p.4-42) the possibility of fluid migration and associated excursions via the boreholes at the Ross site as follows: “[b]reaches to the integrity of the confining unit from historical exploration and delineation drillholes will be minimized by the applicant’s locating and abandoning the drillholes within the wellfields (citing License Condition 10.12 .)” Id. How do you respond?**

A.16. As discussed in my August Testimony, there are a sizable number of unfilled and unlocated boreholes and with the difficulty of locating and properly plugging them, the potential for problematic vertical migration is significant, notwithstanding a license condition that assures us the holes will be filled. The Texas example cited by Dr. Abitz in his direct testimony (JTI001 at ¶ 41) illustrates this point precisely. There, the Texas regulator issued a “Notice of Violation” that detailed losing track of the boreholes and failing to properly manage them (JTI026; p. 3-8) – all in direct violation of express license conditions. None of this actual evidence is analyzed or discussed in the FSEIS or staff’s or SEI’s testimony.

**Q.17. Does this conclude your testimony.**

A. 17. Yes.

I, Dr. Lance N. Larson, do hereby declare under penalty of perjury that my statements in the foregoing testimony and my statement of professional qualifications are true and correct to the best of my knowledge and belief.

Executed in Accord with 10 C.F.R. § 2.304(d).

/(electronic signature approved)/

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