DRAFT RESPONSES – Content not finalized at this point

NRC Staff comment 2

Please provide the methodology for calculating radionuclide-weighted alpha and beta counting efficiencies for the major radionuclide mixtures likely to be encountered at the Crow Butte Project. This should include, at a minimum, radionuclide mixtures for pregnant lixiviant and aged yellowcake.

As part of this description, please provide information on the radioactive source(s) used for determining the instrument efficiency of the alpha and beta detectors. This discussion should include information related to the physical size(s) of the source(s) in comparison to the active area of the probe(s) being calibrated and traceability (e.g., NIST) for the NRC staff to make a determination of consistency with applicable standards (e.g., ANSI, 2013).

Crow Butte Response

(preamble removed)…..

Tables 1 and 2 show an example of the calculation of the instrument efficiency for the Ludlum Model 43-93. The instrument efficiency, ε_i, was calculated according to the method outlined in ISO 7503-1 (ISO, 1988), namely that ε_i = (measured counts (cpm) – background counts (cpm)) / source surface emission rate (dpm). Note if the source area is greater than the probe area, source emissions (dpm) must be modified by ratio of (probe area/source area) to ensure the correct emissions are used. The instrument efficiency for the Model 43-93 is 35.9% for alpha and 52.2% for beta. The alpha instrument efficiency is already a radionuclide weighted efficiency, therefore the total weighted efficiency can be determined by multiplying by the source efficiency (0.25). The total alpha efficiency for aged yellowcake is 9.0%. It is important to note for clarity that the term 'source efficiency' as used by ISO 7503-1 refers to an actual alpha or beta contamination source (i.e. the object being measured for release), not to a reference source.

Table 1: Calibration Source Data

Source Isotope	Source ID	Source Activity (dpm)	Source Surface Emission (dpm)
U^{nat}	K1-076	23000	11390
Sr/Y-90	M2-098	189800	113800

Table 2: Instrument Efficiency Calculation

Source #	K1-076	M2-098
Total Activity (dpm)	11390	113800

Alpha 5 min bkg	31	
Beta 5 min bkg		1093
Source Size	150 cm^2	
Probe Size	100 cm^2	100 cm^2
	Alpha	Beta
Count 1	2657	59567
Count 2	2799	59632
Count 3	2772	59479
Count 4	2791	59319
Count 5	2747	60018
Count 6	2638	59449
Count 7	2781	59937
Count 8	2720	59637
Count 9	2671	59535
Count 10	2764	59924
Average cpm	2734	59649.7
Source Surface Emission (dpm)	11390	113800
Instrument Efficiency**	**35.9%**	**52.2%**
	(already radionuclide weighted)	

The radionuclide mixture weighted counting efficiency for beta was calculated using the methodology outlined in the draft (NRC, 2015) and is shown in Table 3. Because the lower energy beta emitters in aged yellowcake (i.e. Th-231 and Th-234) are not present in the Sr/Y 90 source, the instrument efficiency for these radionuclides will be assumed to be zero. The source for the uranium and activity fraction are NRC, 2015b. The source for the energy and branching ratio are from Table 2-2 of DOE, 2009 (low yield radiations are not included). The total weighted beta efficiency for the Model 43-93 for aged yellowcake is 12.5%. As stated earlier the total weighted alpha instrument efficiency for aged yellowcake is 9.0%.

Table 3: Mixture Weighted Beta Efficiency for Aged Yellowcake for Model 43-93

Isotope	Energy (keV)	Activity Fraction	Branching Ratio	Instrument Efficiency	Surface Efficiency	Weighted Efficiency
Th-234	103	0.489	0.21	0	0.25	0.0000
Th-234	193	0.489	0.79	0	0.25	0.0000
Pa-234m	2290	0.489	0.98	0.522	0.5	0.1251
Th-231	206	0.022	0.13	0	0.25	0.0000
Th-231	287	0.022	0.12	0	0.25	0.0000

Th-231	288	0.022	0.37	0	0.25	0.0000
Th-231	305	0.022	0.35	0	0.25	0.0000

Beta Counting Efficiency =	0.1251

The pregnant lixiviant is the process fluid which is returning from the wellfield to the plant, and will contain higher concentrations of radionuclides than the "barren lixiviant", or the process fluids which return to the wellfield after passing over the resin beds. In considering the mixtures, CBO has not taken into account radon gas (Rn-222) nor the short lived decay products of radon (radon daughters). Although the radon daughters are alpha and beta emitters, they were excluded from the calculations as the calculations are considering surface contamination levels, not airborne contamination levels.

Stata (NRC, 2015c; hereon referred to as "Strata") provided a very detailed explanation as to the assumptions used to determine the radionuclide composition for pregnant lixiviant. Currently, no assays of the Crow Butte lixiviant are available, therefore the same assumptions as those in the approved Strata application will be used. Crow Butte Operation uses an alkaline based mining method similar to Stata and the referenced data sources. As such, the same assumptions will be adopted for CBO. Specifically, Stata identified (DOE, 2009) as the source for aged yellowcake composition and two sources of data were identified regarding the radionuclide composition in lixiviant (Brown, 1982 and LCI, 2015). The LCI, 2015 document contained a radionuclide composition analysis on pregnant lixiviant from a Uranium Recovery facility in Wyoming, using alkaline based mining techniques similar to that proposed by CBO. The LCI, 2015 document showed that the concentrations of the long-lived decay products of natural uranium in the pregnant lixiviant are negligible. Two radionuclides had elevated concentrations, namely Ra-226 and Th-234, with concentrations of 2,700 and 2,290 pCi/L respectively. Converting to Bq/L yields Ra-226 and Th-234 concentrations of 99.9 and 84.7 Bq/L respectively. The paper (Brown, 1982) lists concentrations for Th-230 and Ra-226. The concentration ranges for Th-230 are 56 - 93 Bq/L, and for Ra-226 are 10 - 150 Bq/L. To be conservative, the upper end of the higher concentrations, specifically 150 Bq/L for Ra-226 and 93 Bq/L for Th230, will be used for this analysis.

As there was no data regarding the concentrations of Th-231 and Pa-234m for the pregnant lixiviant, in alignment with the Strata application, CBO made the following estimations: for Th-231 and Pa-234m, it is assumed that Th-231 was in secular equilibrium with U-235 and Pa-234m was in secular equilibrium with Th-234. This estimation is valid as the half-lives of the parent radionuclides are much longer than the half-lives of the daughter radionuclides.

The activity fractions for pregnant lixiviant were calculated using the data and estimations listed above. The specific activity of 6.77E-7 Ci/g for natural Uranium was found in footnote (3) to Appendix B of 10 CFR 20. An average concentration of uranium in pregnant lixiviant is 25-30 ppm, and a conservative estimate of the concentration of uranium in the pregnant lixiviant which will be used is 40 ppm. Converting to Bq/L yields:

Commented [KT1]: Needs confirmation

Concentration of U in pregnant lixiviant = 40 ppm = 40 mg/L = 0.04 g/L = 1E3 Bq/L

Therefore, the primary radionuclides of concern for contamination from pregnant lixiviant in regards to alpha and beta radiation are shown in Tables 4 and 5. Natural uranium, in Table 4, has been broken down by radionuclide according to natural abundance ratios.

Table 4: Primary Alpha Emitting Radionuclides in Lixiviant

	Bq/L	Fraction
U (total)	1,000	0.805
U-238	486	0.391
U-235	22	0.018
U-234	492	0.396
Th-230	93	0.075
Ra-226	150	0.121

Table 5: Primary Beta Emitting Radionuclides in Lixiviant

	Bq/L	Fraction
Th-234	84.7	0.443
Th-231	22	0.115
Pa-234m	84.7	0.443

Again following the process described in (NRC, 2015a) the radionuclide mixture weighted counting efficiency was determined for lixiviant for both alpha and beta, shown in Tables 6. The instrument efficiencies were again taken from Table 2 and the default source efficiencies, as recommended by ISO 7503-1 were be used. The source for the activity fractions are NRC, 2015b, LCI, 2015, and Brown, 1982. The sources for the energy and branching ratio are from Table 2-2 of DOE, 2009 and the Health Physics and Radiological Health Handbook (1992) (low yield radiations are not included).

Because CBO does not have a traceable beta calibration source which emits beta particles at energies similar to the lower energy betas emitters (i.e. Th-231 and Th-234), the instrument efficiency for those radionuclides is listed as zero. The Y90 emission at 2.245 MeV is comparable to the 2.29 MeV emission of Pa-234m. To better account for the low energy emissions, a C-14 source will be purchased and the beta mixture efficiency recalculated at time.

Table 6: Mixture Weighted Efficiencies for Pregnant Lixiviant.

Isotope	Energy (MeV)	Activity Fraction	Branching Ratio	Instrument Efficiency	Source Efficiency	Weighted Efficiency
U-238	4.15	0.391	0.21	0.359	0.25	0.0074
U-238	4.2	0.391	0.79	0.359	0.25	0.0277
U-234	4.72	0.396	0.28	0.359	0.25	0.0100

U-234	4.77	0.396	0.72	0.359	0.25	0.0256
U-235	4.21	0.018	0.06	0.359	0.25	0.0001
U-235	4.37	0.018	0.17	0.359	0.25	0.0003
U-235	4.4	0.018	0.55	0.359	0.25	0.0009
U-235	4.6	0.018	0.05	0.359	0.25	0.0001
Th-230	4.62	0.075	0.24	0.359	0.25	0.0016
Th-230	4.68	0.075	0.76	0.359	0.25	0.0051
Ra-226	4.6	0.121	0.06	0.359	0.25	0.0007
Ra-226	4.78	0.121	0.95	0.359	0.25	0.0103

Alpha Counting Efficiency =	0.0897

Isotope	Energy (keV)	Activity Fraction	Branching Ratio	Instrument Efficiency	Surface Efficiency	Weighted Efficiency
Th-234	103	0.443	0.21	0	0.25	0.0000
Th-234	193	0.443	0.79	0	0.25	0.0000
Pa-234m	2290	0.443	0.98	0.522	0.5	0.1133
Th-231	206	0.115	0.13	0	0.25	0.0000
Th-231	287	0.115	0.12	0	0.25	0.0000
Th-231	288	0.115	0.37	0	0.25	0.0000
Th-231	305	0.115	0.35	0	0.25	0.0000

Beta Counting Efficiency =	0.1133

In summary, the two mixture weighted efficiencies for alpha and beta are shown in Table 7, note this is based on the instrument efficiency calculation shown in Table 2.

Table 7: Summary of Instrument Weighted Efficiencies

Mixture	Radiation Type	Total Efficiency (NRC, 2015 method)
Aged Yellowcake	Alpha	9.0%
	Beta	12.5%
Pregnant Lixiviant	Alpha	9.0%
	Beta	11.3%

NRC staff comment 3

After calculating radionuclide-weighted beta counting efficiencies for the major radionuclide mixture likely to be encountered at the Crow Butte Project, please demonstrate that the stated MDC values for beta contamination on material and equipment can be met.

Crow Butte Response

As stated previously, the removable release limit in Regulatory Guide 8.30 is 1000 dpm/100cm^2, the average total activity limit is 5000 dpm/100cm^2 and the total maximum activity limit is 15,000 dpm/100 cm^2. In addition, the site procedural requirement to collect alpha smears if contamination levels exceed 750 dpm/100cm^2 remains in place.

For static measurements, the following formula will be applied:

$$MDC\left(\frac{DPM}{100cm^2}\right) = \frac{3 + 3.29\sqrt{R_b\, t_g(1 + \frac{t_g}{t_b})}}{\varepsilon_t t_g(\frac{SA}{100cm^2})}$$

where: R_b = the background count rate
t_g = the sample count time
t_b = the background count time
ε_t = the total efficiency
SA = probe surface area (cm^2)

There are numerous combinations of background and count times that can be used, however as an example, for beta emitting radionuclides, using a probe surface area of 100 cm^2, an efficiency of 11.3%, and a 1 minute sample count on materials and equipment, to meet the criteria of 750 dpm/100cm^2 the background rate is required to be 308 counts in 1 minute or 2575 counts in 5 minutes. If this background count rate is exceeded then smears may be required for loose contamination in order to release the equipment, as per existing site procedure, or the equipment will need to be moved to a lower background area for surveying.

Commented [KT2]: Does not seem possible near the plant, can meet this in the conference room and likely parking lot, but not the plant.

Bunker beta bkg measured around 260 dpm/100 cm2 (possible for people in bunker)

Near plant bkg > 6000 dpm/100 cm2 (not possible for equipment released at boundary)