Cameco Resources
Crow Butte Operation

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August 1, 2017

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Attn: Document Control Desk, Director
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

2016 Annual ALARA Report
Source Materials License SUA-1534
Docket Number 40-8943

Dear Director:

Enclosed please find a copy of the Crow Butte Mine 2016 Annual ALARA Report and 2016 Land Use Survey. These reports are required under License Condition 11.2 of Source Materials License SUA-1534 (November 2014).

If you have any questions, please feel free to contact me at (308) 665-2215 ext 114.

Sincerely,

Larry Teahon

Larry Teahon
SHEQ Manager

Attachments: As Stated

cc: Deputy Director
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ALARA Audit Report for 2016

Crow Butte Operations

Prepared for:

Cameco Crow Butte Operations
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Prepared by:

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SHEQ Systems
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July 31, 2017

EXECUTIVE SUMMARY

An ALARA audit of the Crow Butte Operations (CBO) in situ uranium recovery facility was conducted by Cameco's SHEQ Systems Department on May 16-18, 2017. The audit commenced with an opening meeting on Tuesday, May 16th led by the auditors, Kari Toews and Morgan Bradford. A close out meeting at which preliminary audit results were presented was held on Thursday afternoon, May 18th.

For purposes of the ALARA audit, numerous records were examined prior to and during the audit visit including those shown in the table below.

Radiation Program Documents
Nuclear Regulatory Commission inspection reports
Previous audit reports
RSO and HPT training Records
Annual radiation worker training records
Visitor orientation records
Bioassay laboratory reports
Worker dosimetry reports
Radon decay product measurements
Air particulate measurement data
Routine inspection logs (daily walk through and weekly RSO inspection)
Monthly RSO reports
SERP records
Monthly Safety Meeting records
Quarterly RSO staff performance review
Survey instrument calibration records
On-site survey records
RWPs
Semi-annual environmental monitoring reports
Environmental gamma measurement data
Environment air particulate concentrations
Respirator program

No findings or violations were noted during the inspections and recommendations are included in Section 3.2 of the document. The site personnel were very helpful and records both electronic and paper were readily available during the audit.

The maximum occupational dose for 2016 was 0.323 rem. The average TEDE was 0.133 rem. The average and maximum doses are continuing a general downward trend. In part, this is reflective of the drop in production and activities at the site. The radiation safety data, including the dose records, are entered into Cameco's CamRad database or paper records. The trends in average and maximum annual doses prepared by Cameco are shown in Appendix A.

The total equivalent dose equivalent (TEDE) to the maximally exposed member of the public, the nearest resident, for 2016 was 32.4 mrem. This TEDE value includes estimated doses from inhalation of uranium, radium-226 and radon as well as gamma dose for the year. The 2016 dose is less than the dose from 2015 of 66 mrem. It is possible this result can, in part, be related to a decrease in production, however it is more likely the result of variability of background radon concentrations and uncertainty with such low measurements.

The ALARA report is divided into fourteen sections having to do with various aspects of the facility's operation as shown in the following table.

Report Section	Audit Records Discussed
2.1	Routine operations (Bioassay data, internal doses, external doses)
2.2	Safety meeting minutes, attendance records, training program
2.3	Inspection reports
2.4	Radiological survey and monitoring data
2.5	Radiation work permits
2.6	Safety and Environmental Review Panel (SERP)
2.7	Environmental radiological effluent and surveillance data
2.8	Instrument calibration records
2.9	Source leak tests
2.10	Review of radiation protection records
2.11	Unusual events
3.0	Summary of 2015 audit findings and recommendations
4.0	References

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LIST OF ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
μCi	Microcurie
μg/L	Microgram per liter
ALARA	As Low As Reasonably Achievable
ALI	Annual Limit of Intake
APR	Air Purifying Respirator
Bq/m^3	Becquerel per cubic meter
CBO	Crow Butte Operations
CEDE	Committed Effective Dose Equivalent
Ci	Curie
CPP	Central Processing Plant
DAC	Derived Air Concentration
HPT	Health Physics Technician
ICRP	International Commission on Radiological Protection
keV	Thousand electron volts
ND	Non detect
NRC	Nuclear Regulatory Commission
NVLAP	National Voluntary Laboratory Accreditation Program
OSHA	Occupational Safety and Health Administration
OSL	Optically Stimulated Luminescent (Dosimeter)
pCi/L	Picocuries per liter
RML	Radioactive Materials License
RPF	Respirator Protection Factor
RSO	Radiation Safety Officer
RWP	Radiation Work Permit
SERP	Safety and Environment Review Panel
TEDE	Total Effective Dose Equivalent
WL	Working Level – measure of the concentration of radon decay products

1.0 INTRODUCTION

The ALARA Audit for 2016 operations at the Crow Butte Operations (CBO) in situ uranium recovery facility was conducted by Cameco's SHEQ Systems Department on May 16-18, 2017. The audit commenced with an opening meeting on Tuesday, May 16th led by the auditors, Kari Toews and Morgan Bradford, both Health Physicists from Cameco's corporate Safety, Health, Environment and Quality (SHEQ) department. A close out meeting at which preliminary audit results were presented was held on Thursday afternoon, May 18th. Attendees of the kick off and close out meetings were:

Auditors:

- Kari Toews, Lead Auditor
- Morgan Bradford, Auditor

Crow Butte Operations:

- Larry Teahon, Manager, SHEQ, Safety, Health, Environment and Quality
- Tami Dyer, Radiation Safety Officer
- Casey Yada, Health Physics Technician

Cameco personnel were very helpful in conducting this audit. Documents and records were clear, accessible and produced efficiently by the site upon request.

1.1 Site History

Commercial operations at the Crow Butte commenced in April 1991. The in situ recovery process extracts uranium from the Basal Chadron sandstone aquifers at a depth of approximately 400 to 800 feet below the ground surface. The uranium in the formations is leached by a solution pumped through injection wells. The uranium-rich solution is pumped through recovery wells to the CPP where the uranium is extracted by ion exchange, precipitated, and dried in a "zero emissions" vacuum dryer. The purified uranium product (yellowcake) is packaged in 55 gallon drums and transported to the Blind River refinery in Port Hope, Ontario for chemical processing. Based on the process used for drying the precipitate and laboratory data, the uranium product is classified as "soluble" for the purpose of radiation protection.

In addition, Amendment #1 to the Source Materials License (SUA-1534) was issued in December of 2016. The site was granted an exemption to the requirement to use the total beta activity of radionuclide mixtures in air when demonstrating compliance to 10 CFR 20.1201 due to the very low dose potential. As part of that condition, at the same frequency that plant isotopic samples are collected, the site must assess the mixture of radionuclides in air to ensure it remains below 1% of their respective DACs in Appendix B of 10 CFR 20. In addition, LC 11.11 was removed and the commitments related to that condition were added to License Condition (LC) 9.2.

1.2 ALARA Audit Requirements

License Condition (LC) 9.7 of the License SUA-1534[1] requires an annual ALARA audit of the CBO mill radiation safety program consistent with the recommendations in Nuclear Regulation Commission Regulatory Guide 8.31 (NRC, 2002). In accordance with LC 9.7 and the guidance in Regulatory Guide 8.31, the records reviewed in the ALARA audit were as follows:

- Bioassay results
- Records of internal and external exposures
- Safety meeting minutes, attendance records, and training program records
- Routine inspection reports and Monthly RSO reports
- Radiological survey and monitoring data
- Environmental radiological effluent and monitoring data
- Radiation Work Permits (RWPs)
- Surveys required by RWPs
- Reports of overexposures submitted to the NRC
- Reviews of operating and monitoring procedures completed during the period
- Results of required leak tests on radioactive sources
- Instrument calibration records

In addition, the following topics were addressed:

- Trends in occupational radiation doses
- Operation and maintenance of effluent control devices

1.3 Summary of General Site Activities in 2016

As noted in Section 1.1, five units are in restoration and five mine units are in production. The plant was fully operational for 2016 with a total yellowcake production of approximately 232,233 pounds. Tami Dyer is the current RSO. Casey Yada is the Health Physics Technician (HPT).

1.4 Occupational Dose Summary

Occupational radiation doses are discussed in detail in Section 2.1. The committed effective dose equivalent (CEDE) for each monitored worker is calculated monthly based on average uranium concentration in airborne particulate material and the radon daughter concentration in

[1] The license, issued on November 5, 2014, retains the same license number but is not a numbered amendment as it is considered a new license.

each area in which the individual works and the time spent in the area. The total effective dose equivalent (TEDE) is calculated quarterly based on the deep dose equivalent measured by the worker's badge and the total CEDE for the three months of the quarter. The maximum occupational dose for 2016 was 0.323 rem for a plant operator. The maximum dose in 2015, also for a plant operator, was 0.389 rem. The average TEDE for 2016 was 0.133 rem; the average TEDE for 2015 was 0.168 rem. The distribution of TEDEs for all workers is shown in Figure 1 and Table 2.

Table 1: Distribution of annual TEDE for 2014, 2015 and 2016.

Dose Range (rem/y)	2014 (rem/y)	2015 (rem/y)	2016 (rem/y)
	Number of workers	Number of workers	Number of workers
0.000 – 0.050	14	16	10
0.051 - 0.100	1	3	3
0.101 – 0.150	1	2	10
0.151 – 0.200	7	11	9
0.201 – 0.250	5	6	5
0.251 – 0.300	8	4	1
0.301 – 0.350	3	4	2
0.351 – 0.400	3	3	0
0.401 – 0.450	0	2	0
0.451 – 0.500	0	0	0
Total number of monitored workers	42	51	40

The distribution of workers by dose is similar for all years, with a peak below 0.05 rem and a second peak at somewhat higher doses. All annual doses were less than the 0.5 rem per year criterion that requires dose tracking under 10 CFR 20. In 2016, that second peak occurred at a somewhat lower dose (between 0.1 and 0.15 rem/y) than previous years and there were fewer workers at the high end of the distribution. This is most likely related to the decrease in production rate and reduction in overall activities at the facility.

The radiation safety data used for dosimetry are entered into Cameco's CamRad data base. The trends in average and maximum annual doses are shown in Appendix A.

The recommendation from the previous ALARA audit to clarify worker categories was completed. During 2016, workers were reclassified into 7 categories based on the type of work typically performed and area of the facility in which they normally perform their work. The CamRad databased utilizes these categories for reporting and trending of information.

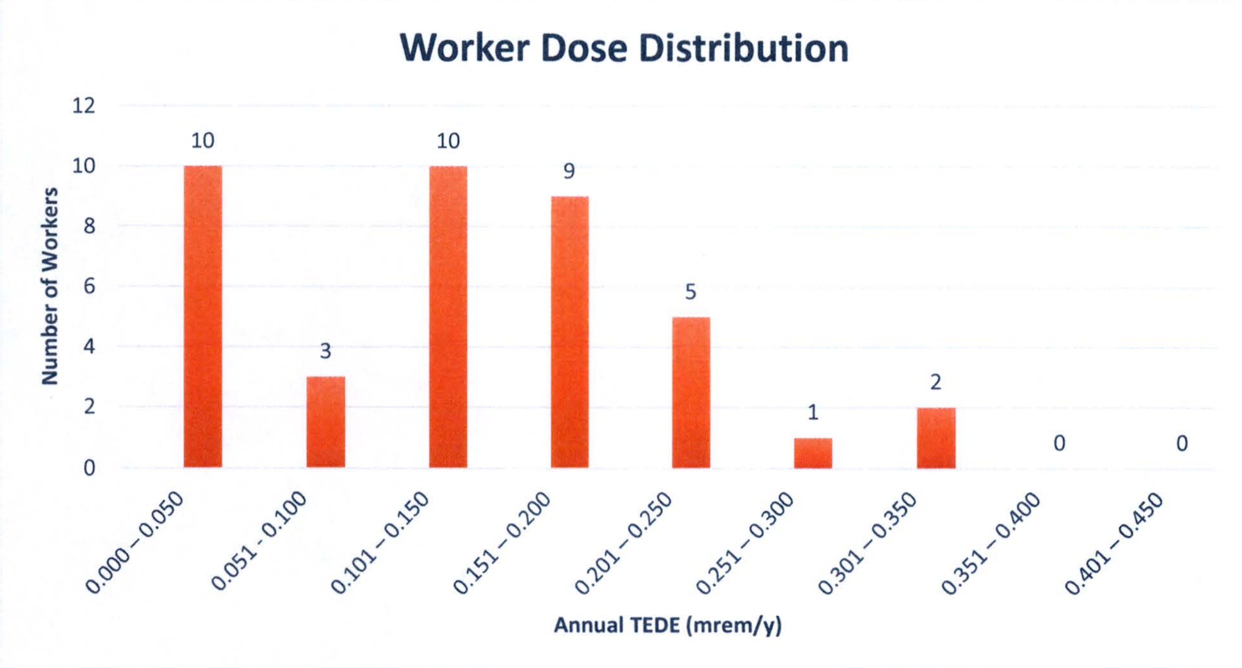


Figure 1. 2016 Annual worker TEDE distribution.

1.5 Public Dose Summary

The potential dose to members of the public is calculated based on the net average measured concentrations of radionuclides in airborne particulate matter, radon concentration, and measured total gamma dose for the calendar year. The potential doses at all monitoring stations are calculated and reported in the Semi-Annual Radiological Effluent and Environmental Monitoring Report for the second half of the calendar year.

Monitoring Station AM-9 is located at the nearest residence, where the maximally exposed member of the public resides. Monitoring station AM-6 is the background monitoring station. Table 3 contains the data from AM6 and AM9 and the calculated dose to that maximum receptor. The complete table from the Semi-Annual Radiological Effluent and Environmental Monitoring Report is included in Appendix B. The table currently shows the results to one significant figure, however, when calculating the net concentration it would be helpful to show the data to two significant figures (i.e. one decimal place in scientific notation).

Table 3: Summary of Data from AM6 and AM9

Location	Analyte	Average Annual Concentration	Average Net Concentration (Above Bkg)	10 CFR 20 App. B, Table 2	Occupancy Factor	Indoor Equilibrium Factor	Dose to Public mrem/y
AM6 (background)	Uranium (μCi/ml)	1.0E-16		9.E-14			
	Radium-226 (μCi/ml)	9.0E-17		9.E-13			
	Lead-210 (μCi/ml)	1.5E-14		6.E-13			
	Radon-222 (μCi/ml)	2.3E-10		1.E-10			

	Gamma (mrem/yr)	21.1		--			
AM9 (nearest resident)	Uranium (µCi/ml)	1.3E-16	2.5E-17	9.E-14			0.01
	Radium-226 (µCi/ml)	1.3E-16	3.5E-17	9.E-13			0.00
	Lead-210 (µCi/ml)	1.5E-14	0	6.E-13			0.00
	Radon-222 (µCi/ml)	3.5E-10	1.2.E-10	1.E-10	0.75	0.50	22.5
	Gamma (mrem/yr)	31	9.9	--			9.9
	TEDE (mrem/y)						**32.4**

The average net uranium, radium-226 and lead-210 concentrations at AM-9 were 2.5E-17 µCi/ml, 3.5E-17 µCi/ml and 0 µCi/ml, respectively. Dose from inhalation of these radionuclides calculated by dividing the net average measured concentration for each radionuclide by its respective 10 CFR 20 Appendix B, Table 2 effluent standard (included in Table 3 for each radionuclide) and then multiplying that ratio by 50 mrem/y. The total dose from these radionuclides for 2016 is 0.01 mrem.

The net annual average radon concentration was 1.2 E-10 µCi/mL which is slightly higher than the 10 CFR 20, Appendix B effluent standard for Rn-222 in equilibrium with its decay products. However, because the measurement location is not at the boundary to the restricted zone this is not an acceptable criteria for comparison. The radon dose to the maximum receptor, as per commitments references in LC 9.2 of the Materials License (SUA-1534), is calculated as per equation (1).

$$Dose\ Rn222\ (mrem) = \frac{Average\ Concentration\ above\ Background * 50\ mrem * Occupancy\ Factor * Equilibrium\ Factor}{10\ CFR\ 20\ AppB\ Table\ 2\ value\ in\ \mu Ci/ml} \quad (1)$$

The occupancy factor is based an estimate of the time spend in the residence. This estimate was made as follows:

> Total hours per year (8760) – time spend at work (40 hrs * 49 weeks worked) – time away due to hobbies/vacations/errands/etc. (48 hr * 10 weekends + 2hrs * 180 days) = 5960 hours.

This value represents and occupancy factor of 68%. However, because these are estimates, the site used an occupancy factor of 75% to be conservative and consistent with previous years. The nearest resident was determined based on a land use survey, which is attached to this ALARA report as Appendix C. The equilibrium factor is assumed to be 0.50 for an indoor receptor as per the recommendations of the NRC draft radon guidance (FSME-ISG-01, NRC 2014) and LC 9.2 of the Materials License. The estimated dose from radon decay products was 22.5 mrem for 2016.

The net gamma dose for the year 2016 was 9.9 mrem/y. The total effective dose equivalent (TEDE) for the member of the public was 32 mrem, which is less than the 10 CFR 20.1301 dose limit for members of the public.

This methodology for calculation of public dose has been in place since 2015. The public dose in 2015 was 66 mrem, approximately twice that of 2016. The difference in public dose between 2015 and 2016 may in part be related to a decrease in production, but is also likely a result of the variability of background radon concentrations and uncertainty associated with making measurements at these very low levels.

Recommendation 1: Include two significant figures in the airborne contaminant and radon concentrations in the Public Dose report.

2.0 ALARA AUDIT RESULTS

The 2016 ALARA Audit was conducted on May 16 – 18, 2017 at the Crow Butte In-Situ Recovery facility in Crawford, Nebraska (CBO). The auditors were assisted in obtaining information by Larry Teahon, SHEQ Manager, Tami Dyer, Radiation Safety Officer and Casey Yada, Health Physics Technician.

Records reviewed by the auditors prior to or during the site visit are listed in Table 4.

Table 4. Records reviewed for this audit.

Radiation program documents
Nuclear Regulatory Commission inspection reports
Previous audit reports
RSO and HPT training Records
Annual radiation worker training records
Bioassay laboratory reports
Worker dosimetry reports
Radon decay product measurements
Air particulate measurement data
Routine inspection logs (daily walk through and weekly RSO inspection)
Monthly RSO reports
SERP records
Monthly Safety Meeting records
Quarterly planned task observation
Survey instrument calibration records
SHEQ Monthly Reports
Radiation Work Permits
Semi-annual environmental monitoring reports
Environmental gamma measurement data
Environment air particulate concentrations
Respirator program

Results of the ALARA Audit records review are discussed by sections as shown in Table 5.

Table 5. Audit results by report section.

Report Section	Audit Records Discussed
2.1	Routine operations (Bioassay data, internal doses, external doses)
2.2	Safety meeting minutes, attendance records, training program
2.3	Inspection reports
2.4	Radiological survey and monitoring data
2.5	Radiation work permits
2.6	Safety and Environmental Review Panel (SERP)
2.7	Environmental radiological effluent and surveillance data
2.8	Instrument calibration records
2.9	Source leak tests
2.10	Review of radiation protection records
2.11	Unusual events
3.0	Summary of 2015 audit findings and recommendations
4.0	References

2.1 Routine Operations

2.1.1 Bioassay Data

Routine bioassays are conducted quarterly for all CBO personnel with the potential for exposure to uranium and monthly for individuals working in the dryer facility and packaging yellowcake. The samples are submitted to Intermountain Laboratories (IML) in Sheridan, Wyoming for analysis. IML operates under Radioactive Materials License No. 49-29405-01 which expires on 10/30/2020.

As summarized in Table 6, 159 samples were submitted to IML in 2016. They included routine monthly and quarterly samples, pre-employment and termination samples. Each batch of samples was accompanied by two spiked samples and one blank. The spiked samples and blanks were prepared from synthetic urine in the CBO laboratory and submitted as blind samples under the names of workers. The results of all spiked samples were within the quality control limits. The largest deviation between the actual spike concentration and laboratory result was 16%, with the majority were below 5%. All measured blank sample concentrations were below the reporting limit of 5 micrograms per liter (µg/L). All urine bioassay concentrations were less than the laboratory reporting limit, 5 µg/L.

Table 6. Results of urine bioassay samples submitted during 2016.

Date collected	No. samples	% Difference in spike and result		Uranium concentrations (µg/L)
		Spike 1	Spike 2	
1/11/2016 - 1/13/2016	3	6.6	5.6	<5
02/08/2016	1	3	1.7	<5
3/18/2016 - 3/22/2016	31	4.7	4.5	<5

3/24/2016 - 3/30/2016	6	1.5	4	<5
4/28/2016	1	5	0.2	<5
5/11/2016 - 5/12/2016	6	7.7	5.9	<5
5/14/2016	1	6.5	4.5	<5
6/2/2016 - 6/8/2016	35	16	12	<5
7/18/2016	1	5.4	1.6	<5
8/19/2016	1	0.6	1.3	<5
9/10/2016 - 9/14/2016	29	6	4	<5
9/18/2016 - 9/23/2016	3	4	2	<5
10/3/2016 - 10/6/2016	4	0.9	1.7	<5
10/14/2016	2	5	4	<5
11/05/2016	1	5.8	5.8	<5
12/2/2016 - 12/11/2016	34	1.1	0.4	<5
Total	159			

The process for assigning a worker dose based on a bioassay sample was discussed with the site. The site procedure, CBR-RPP-008, Section 1.6.7, indicates that Regulatory Guides 8.22, 8.11, and 8.9 will be used to assign dose. These references are the applicable references for use in this situation, however, it would be of benefit to have a more detailed plan in place to ensure that the necessary follow-up samples and calculation are performed if this situation were to occur.

Recommendation 2: It is recommended that additional detail be added to Section 1.6.7 of CBR-RPP-008 to provide more guidance on the process for calculating and assigning a dose from bioassay samples.

2.1.2 Internal Doses

The Committed Effective Dose Equivalent (CEDE) for workers is calculated based on the estimated intake of uranium (μCi) and exposure to radon decay products (WLM). The ratio of the calculated annual uranium intake to the Annual Limit of Intake (ALI) for soluble uranium is multiplied by 5 rem to obtain the dose. The maximum and average doses to workers are reported in the Monthly Radiation Safety Report.

2.1.2.1 Radionuclide Concentrations in Airborne Particulate Matter

Uranium concentrations in air are measured in plant areas using area samplers with flow rates in the range of 40 to 50 L/m and breathing zone samplers with flow rates of approximately 5 L/m. The gross alpha concentrations are calculated and assumed to all be attributable to uranium. The estimated uranium concentrations are used in conjunction with the worker's time in the area to calculate the potential uranium inhalation intake.

The concentration calculations and formulas used in CamRad were checked and found to be accurate. Users can classify samples as dosimetry or engineering in the database. Dosimetry samples are used in the calculation of worker doses. Engineering samples are generally related to samples taken to investigate issues and not indicative of routine worker exposures. Sample classifications and results are reviewed monthly by the RSO to ensure they are entered and categorized correctly.

The dosimetry samples in CamRad are averaged monthly by exposure area. Worker doses (in μCi) are calculated by multiplying the monthly average airborne uranium concentration (in μCi/ml) by the number of hours each worker was exposed and the standard breathing rate (1.2×10^6 ml/hr). Currently there is one exposure area at the site, the main plant, and all exposure hours are assigned to that location; this includes time spent in the wellfields, deep disposal well and laboratory. Dosimetry reports are generated on a monthly basis and reviewed by the RSO.

The monthly maximum and average uranium intakes, as reported in the Monthly Radiation Safety Summary reports, are shown in Table 7. All calculated monthly intakes were less than 2% of the 10 CFR 20 ALI, pro-rated over a 12 month period (8.33E-2 μCi).

The previous ALARA audit recommended that Cameco consider use of the effective dose ALI (2 μCi) rather than the 1 μCi ALI currently in use. The expected difference in dose was estimated to be about 10% of the TEDE on average. Due to the low difference, the site has decided to continue, at this time, with use of the 1 μCi ALI.

Table 7. Monthly and average uranium intake by workers for 2016.

Month	Maximum U Intake (μCi)	Average U Intake (μCi)
January	1.43E-3	9.24E-4
February	1.23E-3	6.90E-4
March	9.99E-4	6.61E-4
April	9.71E-4	6.06E-4
May	7.49E-4	4.50E-4
June	7.03E-4	4.77E-4
July	6.55E-4	4.02E-4
August	1.04E-3	6.59E-4
September	7.06E-4	4.82E-4
October	8.19E-4	4.44E-4
November	8.28E-4	4.99E-4
December	1.11E-3	7.25E-4

The reports available from CamRad also include an estimate of the soluble uranium intake by individuals for the time frames specified by the report to allow the site to demonstrate compliance to the weekly intake limit of 10 mg. Soluble intake values were reviewed on a monthly basis for 2016. The maximum intake over an entire month was 2.117 mg, therefore, the weekly intake limit was also met.

The site also performed semi-annual isotopic monitoring of airborne particulates in the plant. Since the last ALARA audit, the site has requested and been granted an exemption for the reporting of Th-234, Pb-210 and Bi-210 doses. A requirement of that exemption is that these radionuclides be present at concentrations below 1% of their respective DACs. The results from 2016 sampling are shown below for these radionuclides; each is below the required 1% of its DAC.

Table 8. Average Airborne Beta Particulate Concentrations Compared to DAC - 2016.

Radionuclide	Average Concentration (μCi/ml)	DAC (μCi/ml)	Percent of DAC
Th234	5.14E-14	8E-8	0.00006%
Pb-210	2.06E-14	2E-10	0.01%
Bi-210	2.06E-14	1E-8	0.0003%

2.1.2.2 Radon Decay Product Concentrations

Radon decay product concentrations are measured monthly in 12 locations in the plant using the Modified Kusnetz method to calculate worker doses. Samples for use in worker dose calculations are entered into CamRad. The concentration calculations and formulas used in CamRad were checked and found to be accurate. Similar to airborne uranium samples, users can classify samples as dosimetry or engineering in the database and dosimetry samples are used in the calculation of worker doses. Sample classifications and results are reviewed monthly by the RSO to ensure they are entered and categorized correctly.

Monthly samples in CamRad are averaged by exposure area to calculate the average concentration. Worker doses are calculated by multiplying the average monthly radon daughter concentration (in Working Levels (WL)) by the number of hours each worker was exposed in the month, then dividing by 170 working level hours per month to obtain a worker exposure in Working Level Months (WLM). Currently there is one exposure area at the site, the main plant, and all exposure hours are assigned to that location; this includes time spent in the wellfields, deep disposal well and lab. Dosimetry reports are generated on a monthly basis and reviewed by the RSO.

The practice of assigning all time that workers are potentially exposed to radiation sources to the plant will conservatively estimate doses to workers in these other areas, because the site has demonstrated in their license application that the plant radon daughter average is higher than these other areas.

The monthly maximum and average radon decay product exposures are reported in the Monthly Radiation Safety Report and are given in Table 9. All radon decay product exposures were less than 5% of the prorated monthly exposure limit 0.33 WLM based on 4 WLM per year.

Table 9. Worker radon decay products exposures during 2016.

Month	Maximum WLM	Average WLM
January	0.0087	0.0055
February	0.0113	0.0064
March	0.0115	0.0076
April	0.0050	0.0031
May	0.0098	0.0059
June	0.0074	0.0052
July	0.0102	0.0063
August	0.0059	0.0038
September	0.0068	0.0046
October	0.0082	0.0046
November	0.0100	0.0060
December	0.0066	0.0043

Only samples used for dosimetry are typically entered into the database, non-dosimetry samples are typically only entered into Excel spreadsheets and printed for recordkeeping purposes. It was also noted that dosimetry samples are double entered into spreadsheets so they can be printed for records. The calculations in the spreadsheets were checked and a minor issue was found in the calculation of the time factor for determining the Kuznetz factor. In the spreadsheet, the time factor is calculated as (start time of counting – end time of sampling + 1 minute). The final term in the equation (1 minute) accounts for a portion of the time the pump is run while taking a sample. Generally this should be ½ of the pump run time. For the modified Kuznetz sample performed at site, the run time of the pump is 5 minutes, therefore this last term should be 2.5 (or rounded to an integer) rather than 1 minute. This difference is minor and results in only a few percent difference in the final result. In addition, the spreadsheets are not used for dosimetry purposes. It is the opinion of the auditors that double entry and the use of spreadsheets introduces potential for entry or calculation error as well as being inefficient.

Recommendation 3: It is recommended the site consider use of the database for all sample entries and develop suitable reports for printing and record keeping purposes to improve efficiency and reduce potential for error.

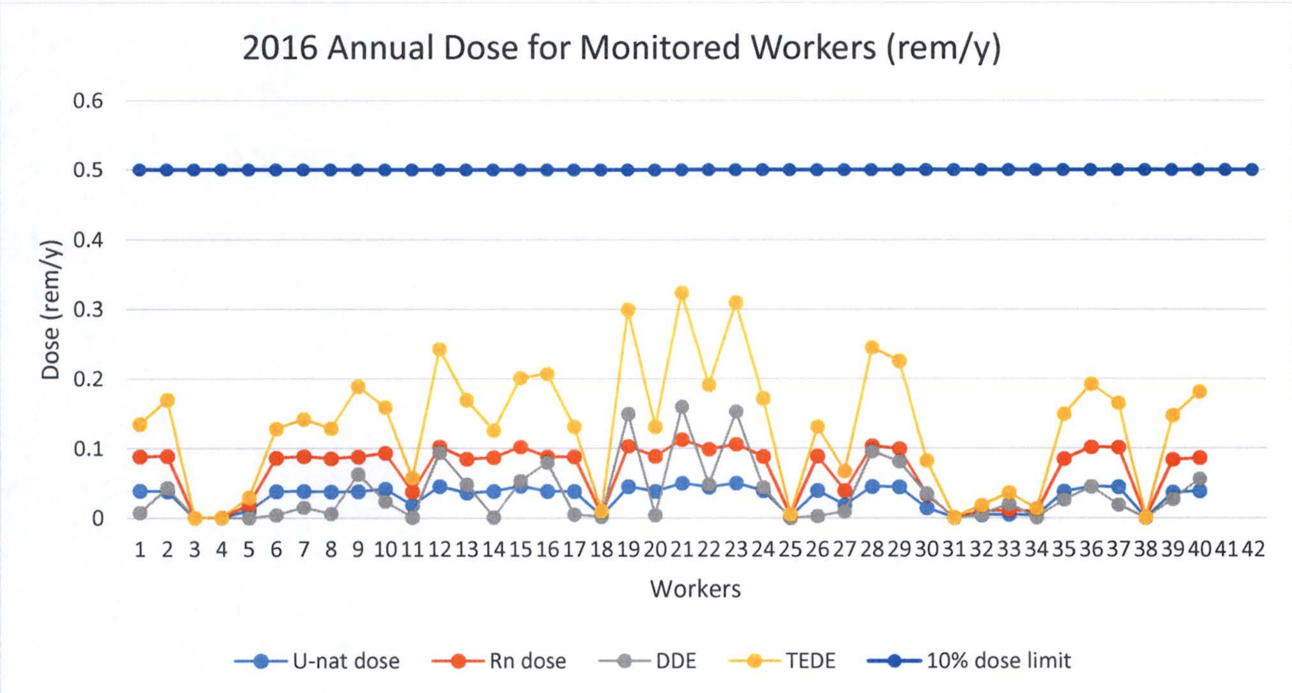
2.1.3 External Doses

Occupational direct gamma and beta radiation doses are measured using Optically Stimulated Luminescent (OSL) dosimeters supplied by Landauer, Inc. All Crow Butte workers are issued dosimeters except for three individuals in administration who do not routinely access the restricted areas of the facility. The OSL dosimeters measure deep dose equivalent, shallow (skin) dose and dose to the lens of the eye. Currently only the deep dose is imported into the CamRad database. During a review of a quarterly report from Landauer it was confirmed that the shallow and eye dose were comparable to the deep dose and no elevated readings were observed. The dosimeters are exchanged quarterly. When not in use, dosimeters are stored on a badge board near the building entry. Workers pick up their dosimeters at the start of the shift and return them to the badge board at the end of the shift. The control badge is stored on the badge board. The vendor subtracts the control badge dose from the worker badge dose to obtain the reported dose to the worker. The maximum gamma dose to an individual worker in 2016 was 0.16 rem. The average external dose was 0.039 rem.

2.1.4 Total Effective Dose Equivalent (TEDE)

The TEDE for each worker is calculated by adding the dose from inhalation of radon decay products and uranium in airborne dust to the deep dose equivalent (DDE) measured using the worker's OSL badge. The Annual TEDE, including the breakdown by dose component, for individual workers is shown in Figure 2. The annual average 2016 CEDE from inhalation of Rn decay products was 0.068 rem; the CEDE from inhalation of uranium was 0.03 rem; the average DDE from direct radiation was 0.039 for an average TEDE of 0.133 rem or 2.7 percent of the annual occupational dose limit. The maximum annual TEDE was 0.323 rem or 6.5 percent of the annual dose limit. All of the worker doses were less than 10 percent of the annual dose limit, the level that requires dose monitoring under 10 CFR 20.1502.

Figure 2. Worker doses by pathway in 2016.



Workers are grouped into categories according to the tasks they perform in the CamRad database; dose trends have been reviewed by dose group and by dose component. Table 10 contains the average and maximum TEDE dose by worker category for the years 2014 through 2016. Table 11 contains the breakdown of the average dose by dose component. Table 12 contains the percentage of average TEDE by component.

The most noticeable trends from the data in Table 10 are a drop in the total number of personnel working on-site and a downward trend in the maximum TEDE. The average TEDE has remained somewhat more constant over the last three years, however there was also a slight drop in the overall average TEDE in 2016. The downward dose trend is likely related to the drop in production and the decrease in the average uranium concentration in the eluate. Looking by category, most groups have remained relatively constant, however there was a drop in the doses for the Plant and Restoration worker categories. Again this is likely due to reduced uranium production at the facility. The dose to the Laboratory group appears higher in 2016, however this was actually because these workers were assigned radon daughter and airborne uranium doses for the time. In previous years they had only been assigned a gamma dose. This change was because the lab is a restricted area and therefore, under License Condition 9.2, their time is now assigned to the plant for dosimetry. As an additional note, the increase in time assigned to the plant for some worker categories may have offset a decrease in average dose, causing the average TEDE to appear less impacted by the production decrease than the maximum.

Figure 3 shows the breakdown of the average TEDE by dose component for each worker category. For most groups, radon daughter dose contributed the most, with the exception of the Plant workers, for whom the gamma and radon daughter doses were comparable. As expected the Plant and Maintenance workers had the highest overall doses due to time spent in the main plant. The lab group is now the next highest, however this is primarily because they are assigned full time hours in the plant.

Table 11 provides the data for average dose by component over time. Over the last three years, there has been a drop in the average doses from both radon daughter and gamma components. The drop in these components was the apparent driver for the overall average TEDE drop. The airborne uranium dose was also lower in 2016 compared with 2015, however both years were somewhat higher than 2014.

The breakdown of the percent of TEDE by component, Table 12, has remained relatively constant over the previous three years. Radon daughter dose makes up the majority (50% or more) of the TEDE, with gamma second and airborne uranium third. While doses do appear to be trending down, the breakdown of the dose has not changed substantively.

Table 10. Total Effective Dose Equivalent (TEDE) by worker classification for 2014- 2016.

	2014			2015			2016		
Work Group	# of workers	Average TEDE (rem)	Maximum TEDE (rem)	# of workers	Average TEDE (rem)	Maximum TEDE (rem)	# of workers	Average TEDE (rem)	Maximum TEDE (rem)
Administration	4	0.07	0.18	4	0.07	0.23	4	0.06	0.19
Laboratory	2	0.02	0.03	2	0.02	0.03	2	0.15	0.15
Maintenance	3	0.19	0.30	3	0.20	0.30	3	0.18	0.21
Plant	16	0.25	0.44	11	0.29	0.39	10	0.21	0.32
Restoration	3	0.21	0.31	3	0.16	0.25	3	0.11	0.17
SHEQ	6	0.11	0.25	5	0.11	0.22	5	0.09	0.18
Wellfield	17	0.12	0.27	14	0.14	0.28	13	0.11	0.19
Overall	**51**	**0.16**	**0.44**	**42**	**0.17**	**0.39**	**40**	**0.13**	**0.32**

Figure 3: Breakdown of TEDE by Worker Category

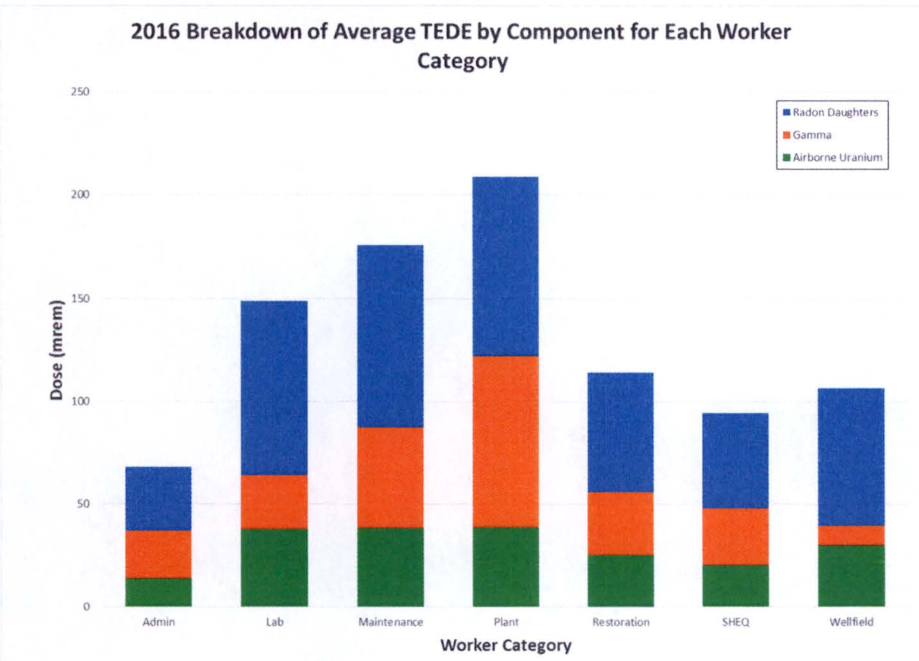


Table 11. Average Dose (mrem) by Component for 2014 - 2016

Dose Component	2014	2015	2016
Radon Daughters	92	95	67
Airborne Uranium	24	37	30
Gamma	52	47	39

Table 12. Percent of TEDE by Component for 2014 - 2016

Dose Component	2014	2015	2016
Radon Daughters	55%	53%	50%
Airborne Uranium	15%	21%	22%
Gamma	31%	26%	28%

The annual dose is reported to each employee in a Cameco-specific format that includes the same information as is provided on the NRC Form 5 Occupational Dose Record for a Monitoring Period. As was noted in the previous ALARA report, the Cameco form does not report the eye or shallow equivalent doses. The shallow dose is imported into the CamRad database and is available for trending and reporting. The shallow dose was reviewed as was found to be comparable to the deep dose equivalent and well below applicable dose limits.

2.1.5 Personal Contamination Surveys and Material Release Surveys

A sampling of the Surveys of Material Release forms from each quarter of 2016 were reviewed and found to be accurate and complete. In the addition, radiological monitoring associated with shipments of radioactive materials in 2016 were reviewed and also found to be acceptable. The site procedures related to both transport of radioactive material (CBR-RPP-009) and contamination control (CBR-RPP-005) were reviewed. These documents describe the basis and process for performing the measurements. Frisker station records were reviewed, no issues were identified. In addition, it was confirmed that the RSO or designate performs a monthly review of the records from the frisker stations.

2.2 Safety Meeting Minutes, Attendance Records, and Training Program Records

2.2.1 Safety Meeting Records

"All Hands" safety meetings are held monthly. Records of the meetings were reviewed. The safety meeting records are complete and indicate a variety of topics covered. The dates and topics discussed at the meetings are given in Table 13.

Table 13. Safety meeting date and topics during 2016.

Date	Subjects	Attendees
1/15/2016	Slips, Trips and Falls	37
2/02/2016	Use of Experience; MSHA Fatalgram, Loaded Dump Truck Climbing Up Hill; use care when driving	30
3/17/2016	Safety Awareness: Safety Pictionary (General, Radiation, Mine Safety Topics)	27
4/26/2016	Annual Refresher Training: DOT/HazMat, OSHA, SHEQ, BMP, SPCC, SWPPP, Radiation Safety, CPR, Fire Extinguisher	20

4/28/2016	Annual Refresher Training: DOT/HazMat, OSHA, SHEQ, BMP, SPCC, SWPPP, Radiation Safety, CPR, Fire Extinguisher	20
5/5/2016	Safety Awareness Activity: Loss of limb Pinata	30
6/22/2016	Take Safety Home and Heat Stress	23
7/27/2016	Focus on Safety while Managing Change	29
8/24/2016	Summary of recent safety incidents.	24
9/8/2016	On the job fatalities	na
10/26/2016	Get ready for ice and winter weather; slips, trips, falls.	24
11/30/2016	Slips, Trips and Falls and Winter driving	27
12/21/2016	Slips, Trips and Fall: Snow Policy	21

2.2.2 Radiation Worker Training

Introductory radiation safety training is conducted for all new employees according to materials reviewed by the auditors. Rad worker refresher training is conducted in April every year. A quiz is administered at the end of training. A sample of completed tests was reviewed by the auditors. As part of the refresher training, the RSO conducts a "Rad Bowl" competition, to test the workers knowledge. The training program is adequate and meets the requirements of Regulatory Guide 8.31.

2.2.3 Planned Task Observation

The RSO conducts a "Planned Task Observation" quarterly to evaluate the performance of the HPTs. Table14 lists the topics covered by the evaluations in 2016.

Table 14. Topics covered in Planned Task Observation evaluations in 2016.

Date	Evaluator	Task Observed
3/29/16	Tami Dyer	Monthly radon samples
6/30/16	Tami Dyer	Lucas cell measurements
9/13/16	Tami Dyer	Isotopic sampling
12/22/16	Tami Dyer	Radon measurement during well bleeding

2.3 Inspection Reports

2.3.1 Routine Inspections

Daily walk-through inspections are conducted in the plant. Each walk-through inspection log covers a full week. The area owner/operator fills out the checklist, and initials the form. The RSO then uses that checklist for her walk-through and then signs the form. All checklists from 2016 were reviewed and the timelines required by the license were met.

The RSO or her qualified designee performs a weekly inspection of the site accompanied by the Restoration Manager or Plant Supervisor. Representative copies of the form were reviewed.

The inspection is documented in a memo to the Restoration Manager, which is printed and kept on file, and a monthly inspection form, both of which are signed by the RSO. The inspections are compliant with Regulatory Guide 8.31.

As per License Condition 9.7, the site was permitted to identify one or more qualified designees for perform daily inspections in the absence of the RSO and HPTs. The training program as well as the results of exams and on the job training (proficiency checks) were reviewed and found to be present for all designees. As previously noted, during the review of inspection records it was found that the requirements for review by the RSO or HPT were met.

Recommendation 4: It would be good practice to have an explicit place on the daily inspection form for the RSO to indicate a review was performed, instead of just initialing below the operators checkmark column.

2.3.2 NRC Inspections

The last annual NRC inspection took place March 8-10, 2016. There were two Severity Level IV violations identified in the inspection report:(1) a failure to sample the underdrains for a leaking pond and (2) a failure to submit a corrective action plan for the pond. The site provided a response to the NRC to address these violations on May 18th, 2016 and a follow-up was sent on December 21st, 2016. In addition two self-identified violations (Non-Cited Violations in the report) were noted and categorized as Severity Level IV, these were: (1) a failure to secure a controlled area to prevent access or removal of material and (2) a failure to perform and document alpha and beta contamination monitoring of all personnel leaving a restricted area. These Non-Cited Violations were addressed and corrected prior to the inspection and were closed by the NRC with no further action.

2.3.3 ALARA Audit

The 2015 ALARA Audit was conducted by Sopris Environmental and Two Lines, Inc. in February of 2015. The recommendations from that audit are discussed in Section 2.12.

2.4 Radiological Survey and Monitoring Data

2.4.1 Quarterly gamma exposure rate surveys

Quarterly gamma exposure surveys are conducted outside the CPP, RO facility and the Well Houses. The maximum exposure rates at various locations inside and outside the plant are recorded and compared with the previous month's data. All Well Houses with exposure rates above 5 mrem/hr are posted as Radiation Areas. No areas outside the Well Houses had exposure rates exceeding 2 mrem/hr.

The maximum exposure rates measured outside the CPP and the RP facility are given in Table 15.

Table 15. 2016 Maximum measured outside gamma dose rate (mrem/hr).

	Maximum outside measured dose rate (mrem/hr)	
Quarter	**CPP**	**RO plant**
January	0.9	0.5
February	0.6	0.4
March	0.6	0.4
April	0.6	0.4

2.4.2 Contamination Surveys

Routine alpha and beta removable contamination surveys are performed monthly in the restricted and unrestricted areas. Representative records were reviewed. No significant issues were identified.

Locations within the unrestricted area are sampled on set schedule, as well as a focus on transition points out of the restricted area to ensure that contamination is not being tracked. There were no elevated samples in the unrestricted zone. Some samples within the restricted zone were elevated. In these cases, the area operator was notified and the contamination was cleaned up.

2.5 Radiation Work Permits (RWPs)

Thirteen Radiation Work Permits (RWPs) were issued in 2016. RWPs are issued for non-routine activities that involve the potential for significant exposure to radioactive materials and for which there are no standard operating procedures. The 2016 RWPs are listed in Table 16. RWPs describe the activity, personnel involved, radiological data and protective equipment required. The RWPs were reviewed to confirm that those individuals on the permit had read and signed the permit form. Participants did so by initialing the RWP in the Personnel section after their printed or written names. It was noted that all RWPs were in ink following the issuing of that recommendation in the 2015 ALARA report. The review of RWPs also confirmed that they included the identification of protective measures, requirements for PPE had been specified, where necessary, and monitoring had been performed.

RWPs for which there is worker dose are entered into CamRad. RWPs in CamRad appeared to be entered correctly.

Recommendation 5: site should consider defaulting the indicator for use in dosimetry to be checked at all times and manually removed if it is not applicable to use a result for dose calculation purposes.

Table 1. Radiation Work Permits issued during 2016.

RWP #	Description of work	Date Initiated	Date Terminated	Record complete?
RWP 16-1	Add isolation valve to upflow bleed flow meter for easier service	12/01/2016	04/03/2016	yes
RWP 16-2	Enter and inspect interior walls of resin trailer and repair	19/01/2016	04/03/2016	yes
RWP 16-3	Open up conditioning tank 1 and 2 in Pond Water Treatment and cleanout	19/01/2016	04/03/2016	yes
RWP 16-4	Replace Filter media an Precip A demister	01/02/2016	04/03/2016	yes
RWP 16-5	Repair flanges inside Resin trailer	18/02/2016	04/03/2016	yes
RWP 16-6	Fill Resin Trailer and Pressure Test	19/02/2016	04/03/2016	yes
RWP 16-7	Clean sludge out of Pond #4	06/06/2016	14/10/2016	yes
RWP 16-8	Replace baghouse blowdown diaphragms	07/07/2016	08/08/2016	yes
RWP 16-9	Weld piece of 2 inch square tubing on bottom of roll-off	23/08/2016	01/09/2016	yes
RWP 16-10	Repair Pond #4. Patch holes, rebuild corners, inspect and repair underdrains	03/10/2016	28/10/2016	yes
RWP 16-11	Change out Toyo pump and put backup pump in	25/10/2016	05/12/2016	yes
RWP 16-12	Clean, inspect and Repair DF-2	08/11/2016	30/12/2016	yes
RWP 16-13	Inspect membranes in the last stage in the 100GPM R.O.	13/12/2016	30/12/2016	yes

2.6 Safety and Environmental Review Panel (SERP)

The SERP is tasked with approving changes in the facility or procedures as described in the license application and conduct tests or experiments not described in the license application as long as conditions specified in License Condition 9.4. (Amendment 1) are met. License Condition 9.4D defines the purpose and makeup of the SERP. The SERP approved six actions in 2016 briefly described in Table 17.

Table 17. 2015 SERP actions.

SERP Evaluation Number	Date	Action Taken
SERP 16-01	1/13/16	Replacement of Mine Unit 5 Baseline Restoration Well
SERP 16-02	2/26/16	Revise Figures 1, 2 and 5 in the Evaporation Pone Onsite Inspection Program
SERP 16-03	6/9/16	Revisions to the Approved License Renewal (November 2014)
SERP 16-03 (revised)	10/3/16	Revisions to the Approved License Renewal (November 2014) – include addition of "Designated Operator"
SERP 16-04	6/29/16	Revisions to the Approved License Renewal (November 2014)
SERP 16-05	6/29/16	Organizational Change to the Security Plan LC 10.8

2.7 Environmental Radiological Effluent and Surveillance Data

As part of the environmental monitoring program, airborne radionuclide concentrations and direct gamma radiation dose rates are measured quarterly at three air monitoring stations around the permit area boundary, one at the site boundary, three at residences and one background location. Radon gas concentration is measured semi-annually at the same locations. The measured concentrations and the gamma exposure rate are used to calculate the potential dose to a member of the public.

2.7.1 Radon Gas

Radon gas concentrations are measured using the Landauer, Inc. RadTrak alpha track detector. The detectors are exchanged semi-annually with a minimum detectable concentration of 2E-10 μCi/mL (0.2 pCi/L). Starting in 2014, three detectors were deployed at each monitoring location to assess reproducibility. The annual average radon concentrations for 2014, 2015 and 2016 are given in Table 18. As an additional note, beginning in 2017 with the new license amendment, 6 track etch cups will be places at the background and maximum receptor location to help reduce uncertainty and any potential issues with outliers.

In 2016, annual average radon concentrations were approximately equivalent to previous. Beginning in 2014 Landauer, Inc. adjusted their procedure for handing the RadTrak detectors prior to deployment. Previously, the detector material had been stored for a period up to a year or more prior to deployment in the field and some of the packaging leaked prior to deployment resulting in spuriously high radon measurements. Current procedures have resulted in more stable radon concentration measurements. Triplicate measurements for 2015 and 2016 indicated reasonable consistency. As a result of this increased stability, all locations other than the background and maximum receptor station will return to using only one track etch cup.

Table 2. Annual average environmental radon concentration in air.

Station	2014 (µCi/mL)	2015 (µCi/mL)	2016 (µCi/mL)
AM-1 (residence)	3E-10	3E-10	3E-10
AM-2 (permit area boundary)	4E-10	4E-10	4E-10
AM-3 (permit area boundary)	3E-10	3E-10	2E-10
AM-4 (permit area boundary)	3E-10	3E-10	3E-10
AM-5 (residence)	4E-10	5E-10	3E-10
AM-6 (background)	3E-10	3E-10	3E-10
AM-8 (site boundary)	3E-10	5E-10	3E-10
AM-9 (nearest resident)		6E-10	4E-10

2.7.2 Radionuclides in Airborne Particulate Matter

Particulates are collected on a quarterly basis on filters at the same locations as the radon concentrations. (The filters are exchanged weekly but composited quarterly.) The flow rate is approximately 50 liters per minute (L/m). The filters are analyzed for uranium, Ra-226, Pb-210 and Th-230 and derived values for Th-230 and Po-210, and the resulting concentrations in air are listed in Table 19. (The measured Th-230 concentrations are not included in the annual dose to the public and are not listed in Table 19.)

The radionuclide concentrations in airborne particulate matter are very comparable for all four years at all eight locations. The Ra-226 values in 2016 appear slightly lower, however, this is due to use of ½ DL for samples that are less than DL rather than the DL value. Results remain very low and there are no observable trends.

Table 19. Annual average radionuclide concentrations in airborne particulate matter.

Year	Annual Average Ra-226 Conc. (µCi/mL)				Annual Average Pb-210 Conc. (µCi/mL)			
Location	**2013**	**2014**	**2015**	**2016**	**2013**	**2014**	**2015**	**2016**
Effluent Limit	*9E-13*				*6E-13*			
AM-1	1E-16	1E-16	1E-16	7E-17	2E-14	2E-14	2E-14	1E-14
AM-2	1E-16	1E-16	1E-16	6E-17	1E-14	2E-14	2E-14	2E-14
AM-3	1E-16	1E-16	1E-16	1E-16	2E-14	1E-14	2E-14	1E-14
AM-4	1E-16	1E-16	1E-16	6E-17	2E-14	2E-14	2E-14	2E-14
AM-5	1E-16	2E-16	1E-16	5E-17	2E-14	2E-14	2E-14	1E-14
AM-6	1E-16	1E-16	1E-16	5E-17	2E-14	2E-14	2E-14	2E-14
AM-8	1E-16	1E-16	1E-16	6E-17	2E-14	2E-14	2E-14	2E-14
AM-9			1E-16	1E-16			2E-14	2E-14

Year	Annual Average U-nat Conc. (µCi/mL)			
Location	**2013**	**2014**	**2015**	**2016**
Effluent Limit	*9E-14*			
AM-1	1E-16	1E-16	8E-17	2E-16
AM-2	2E-16	2E-16	3E-16	3E-16
AM-3	1E-16	1E-16	2E-16	1E-16
AM-4	1E-16	1E-16	1E-16	2E-16
AM-5	1E-16	2E-16	2E-16	2E-16
AM-6	1E-16	1E-16	7E-17	1E-16
AM-8	1E-16	1E-16	1E-16	1E-16
AM-9			1E-16	1E-16

2.7.3 Direct Gamma Radiation

Direct gamma radiation doses at the nine air monitoring stations are measured using Landauer, Inc. dosimeters. The dosimeters are exchanged quarterly. The total annual gamma doses are given in Table 20. Annual gamma doses for 2016 are somewhat lower than the two previous years at approximately half of the stations.

Table 3. Annual measured gamma dose (mrem/yr) 2013 - 2016.

	Annual Dose (mrem/y)			
Year/Station	**2013**	**2014**	**2015**	**2016**
AM-1	31.0	29.0	30.0	25.8
AM-2	30.7	37.7	31.6	25.9
AM-3	39.9	38.0	33.7	32.3
AM-4	27.0	30.0	29	23
AM-5	34.4	38.1	32.6	28.2
AM-6	28.2	35.1	33.3	21.1
AM-8	47.0	43.2	37.9	38.7
AM-9			16.3	31

A concern was raised by the NRC in an email to the site regarding subtraction of deployment and/or transient control badges from the results of the environmental monitoring stations. The process was investigated as part of this audit to address the question. The site is provided with both a deployment and a transient dosimeter by the provider. The process used by the dosimeter provider, Landauer, is to subtract the deployment badge result from the badges used for environmental monitoring. If the deployment badge is lost, damaged, etc. the transient badge result is subtracted instead. If neither is available to be read, the average of a set number of previous quarter's background results is subtracted. Only one of the badge results is subtracted, not multiple. The purpose of these deployment and transient badges is to subtract off any radiation that was accumulated on the environmental badges during times when they were not deployed to ensure that only dose accumulated while in the prescribed monitoring location is returned to the site as a final result. In the case of environmental badges that are intended to be measuring the gamma dose for the full deployment time (3 months), the only dose that should be subtracted is the dose that is accumulated before it is deployed (in transit from Landauer to site and while at site until deployed) and after it is collected (while at site after collection and from site to Landauer). The site reported that in order to try to prevent any dose accumulating on the deployment and transit badges while the environment badges are deployed they are stored in a shielded container to try to prevent any accumulation of dose during this time. This process is technically correct. However, it appears the explanation in the semi-annual report was either incorrect or misleading. It is recommended that the explanation be revised to reflect the process more accurately.

The storage area and actual dose accumulated on the deployment and transient badges was also reviewed. The container is too small to take a measurement inside with the lid on, however a recent deployment badge result was used to try to infer the exposure rate it was subjected to. The deployment badge read 35 mrem. Assuming that it only accumulated exposure for 20 days (10 days before and after deployment for transit and temporary storage), the exposure rate is 0.073 mrem/hr. This is a relatively high dose rate, given that it should only have been exposed to background conditions during those 20 days, and indicates that the shielding on the storage container may not be sufficient. It is important to note that as long as the dose result from all badges remains positive, the difference between the background station and the environmental stations is still the same, regardless of the deployment badge value, because it is subtracted from all badges equally. Therefore the net gamma dose at the maximum receptor will not change, just the gross values of each station will be impacted.

Recommendation 6: Revise the text of Appendix J of the semi-annual report to clarify the usage of the deployment and transient badges.

Recommendation 7: It is recommended that the storage container for the deployment and transient badges be increased to try to reduce the ambient exposure rate as much as possible.

2.7.4 Emissions Calculation

As per license amendment 1 of SUA-1534, a new airborne effluent monitoring program was approved for the site in late 2016 for compliance with 10 CFR 40.65 requirements. Technical review of this program by the NRC was completed and approved in January of 2016. Sampling commitments for this new monitoring plan are as follows:

Sample Type	Location	Frequency
Radon Gas	Main Plant - tanks	Specified tank vents – quarterly
	Main Plant – general area	6 specified locations - semi-annually
	Wellfield	Venting well head - quarterly
	Wellhouse	4 production and 4 restoration wellhouses – semi-annually
	Spills	As required
Radon Daughters	Main Plant - tanks	Specified tank vents – quarterly
	Main Plant – general area	Routine sampling as per approved schedule
	Wellhouse	4 production and 4 restoration wellhouses – semi-annually
Particulate	Main Plant	Semi-annually (routine locations) for 2 years, annually after that
	Wellhouse	4 production and 4 restoration wellhouses – semi-annually

These samples were reviewed to confirm if they were collected as per the schedule and that the results were included in the semi-annual report. All samples were collected according to the schedule with the exception of the following - main plant tank samples of radon and radon daughters in the first quarter, shaker deck vent samples and a venting well head in the first quarter. These missed sampled were self-identified in 2016. Some minor typographic issues were noted in the second semi-annual report. Specifically, there appears to be a typo in the RL column of the In Plant Isotopic Air Samples table - the RL values appear to be one order of magnitude higher than they should be compared to previous semi-annual reports - and the Lead 210 emissions from the wellhouses was calculated for the second half of the year, but not included in the full year total table (pg 41).

Table 21 summarizes the year end emissions results. The tanks clearly contribute the vast majority of the emissions. A review of the tanks sampling data indicated that they are more stable than the auditor would have expected, however, use of a maximum result rather than an average or a sample during varying conditions (i.e. different operation condition each quarter) over the course of the year will inherently overestimate emissions. During 2016, use of the maximum resulted in a semi-annual emissions rate approximately 50% higher than from the average.

It is worth noting that if the average had been used rather than the maximum, the calculated emissions would have been 5788 Ci/yr, which is very comparable to the calculated emissions of 5216 Ci/yr from the previous approved methodology.

Table 21. Emissions in Ci/Yr by Source 2016

Source	Radon Progeny	Radon Gas	Particulate	Total by Source	% by Source
Plant	0.44	2.70	0.00	**3.1**	**0.03%**
Wellhouses	0.23	4.66	0.00	**4.9**	**0.04%**
Well Fields (Wellheads)	N/A	1.34E-04	N/A	**0.0**	**0.00%**
Tanks/vents	544.37	11015.25	N/A	**11559.6**	**99.93%**
Spills (enter manually)	0.00	0.00	0.00	**0.0**	**0.00%**
Deepwells			8.91E-07	**0.0**	**0.00%**
Total by Type	**545.04**	**11022.61**	**0.00**		
Total Emissions for Full Year		**11567.65**	**Ci**		

2.8 Instrument Calibration Records

Instrument calibration records were reviewed. The instruments and sources are listed in a table with calibration dates. Most of the radiation detection instruments are sent to the manufacturer (Ludlum Measurements) for calibration. The auditors checked the calibration dates on the instruments in service and determined that all are in current calibration. The instrument calibration records are contained in notebooks.

Proper operation of the instruments used for personal scanning at the south plant location ("primary bunker") and the RO facility is verified weekly. The verification for the south plant instrument includes battery check and instrument alpha and beta efficiency checks as well as calculation of the maximum allowable alpha and beta counts for a 0.5 minute count time and the minimum detectable activity in disintegrations per minute per 100 cm^2. The spreadsheet calculations were checked and found to be accurate. A Ludlum Model 3030 in the bunker has been set up to count both alpha and beta and integrate the total counts for each 30-sec count, making it easier for workers to scan out of the restricted area. Measurements of alpha and beta on each hand, each foot and clothing are recorded on the log sheet. The bunker also contains a Ludlum Model 2224-1 with an alpha/beta probe that may be used as needed. The correction factor for the efficiency includes both the instrument efficiency and a factor to take into account the area of the detector. The spreadsheet calculations were checked and found to be accurate.

High voltage verification and reliability factor checks are performed after calibration or repair or if the instrument response is questionable. The reliability factor calculation was checked and found to be accurate.

2.9 Source Leak Tests

The Crow Butte facility has no radioactive sources that require leak testing. The only sources on site are exempt instrument check sources.

2.10 Review of Radiation Protection Records

In addition to those already discussed, radiation protection records related to addition areas of the program were reviewed, as detailed below. While it was noted in the previous ALARA report, it remains true that all records that were requested we readily available, clear and in good order.

Best Practice 1: The records were readily available, clear, and in good order facilitating the audit and other uses of the information.

2.10.1 Respiratory Protection

The Respiratory Protection Program was reviewed. Full face piece air purifying respirators are used in situations where respiratory protection is required. When the dryer is operating, the dryer room is designated as an Airborne Radioactivity Area and respiratory protection is required. The Respiratory Protection Program includes evaluation of medical fitness for respirator use, fit testing and training. Cameco uses Legends Butte Health Services in Crawford, Nebraska as the medical provider. Respirator training is included in the annual rad worker training. Respirator training and medical evaluation records were reviewed and are in good condition.

2.10.2 Visitor Records

Visitors to the Cameco Crow Butte facility are not badged or issued personal dosimeters. Passes are issued to site visitors at the time of entry. Visitors are escorted when entering the Restricted Areas of the site. If the visitor enters the restricted area, the escort takes exposure rate measurements during the visit. Doses are estimated based on the measured exposure rates and recorded on the visitor pass.

Contractors and other individuals who may be on the site for an extended period of time must receive documented Hazard Recognition and Safety Orientation. The training, that includes radiation hazards, must be renewed annually and allows the individual unescorted access to specific work areas on the site. Contract workers who will enter the restricted area receive additional training from the RSO or HPT. Training and orientation is documented on the Hazard Recognition Recognition/Safety Orientation form.

2.10.3 Equipment Release Surveys

Equipment and materials to be released for unrestricted use are surveyed for total contamination and wipe tested for removable contamination. Total contamination surveys for alpha and beta radiation are performed using a Ludlum Model 43-93 alpha/beta probe. Beta surveys were initiated in November 2014. The action limit is 750 dpm per 100 cm^2. Removable contamination surveys (wipe tests) are required when the action limit is exceeded. The Reg. Guide 8.30 release criterion for uranium and its decay products is 1000 dpm alpha per 100 cm^2 and 5000 dpm per 100 cm^2 total (fixed plus removable) alpha. The release criteria for beta radiation are the same. A representative sample of release surveys was reviewed and found to be compliant with these requirements.

2.10.4 Annual Review of Operating Procedures

The applicable operating procedures are reviewed annually by the RSO. The review is documented on a log sheet with the date the procedure was reviewed and the initials of the reviewer. The RSO reviewed all of the operating procedures in 2016. Documents are maintained electronically in Management Document System (MDS), official reviews and approvals are tracked within that system as well. All site documents in MDS were reviewed and found to have been approved in that system as per the required annual schedule at the time of the assessment.

2.11 Unusual Events

There were no unusual events reported during 2016 that required reporting.

2.12 Review of 2015 ALARA Audit Recommendations

Recommendation 1: Clarify worker categories for dose trending purposes.

Response: This was completed in 2016.

Recommendation 2: License Condition 11.2 states that "the licensee shall submit the results of the annual review of the radiation protection program content and implementation performed in accordance with 10 CFR 20.1101 (c). These results shall include an analysis of dose to individual members of the public consistent with 10 CFR 20.1301 and 10 CFR 20.1302 and a land use survey." The auditors disagree with the NRC's interpretation that the dose calculation and land use survey should be performed by the auditors. Rather, it is recommended that the licensee calculate the doses and perform the land use survey, which would then be reviewed by the auditors and attached to the ALARA Audit Report as an appendix.

Response: The licensee performed these calculations and they were available for the auditors review.

Recommendation 3: Cameco should consider revising the uranium inhalation dose calculation to use the effective dose ALI (2 μCi) as long as the TEDE is less than 1 rem per year. However, on average, this adjustment would reduce the average calculated dose by only about 10%.

Response: At this time, the site has decided to continue with use of 1 μCi as the ALI as the difference in dose is small and this value is somewhat conservative.

Recommendation 4: Monthly Radiation Safety Summary reports should be signed and dated by the RSO.

Response: This has been implemented.

Recommendation 5: RWPs were created using handwritten pencil. It is recommended that RWP be typewritten or handwritten in ink.

Response: RWPs completed after the 2015 ALARA report was received were in pen.

3.0 SUMMARY OF 2016 AUDIT FINDINGS AND RECOMMENDATIONS

3.1 Findings

There were no negative findings from this audit

3.2 Opportunities for Improvement

Recommendation 1: Include two significant figures in the airborne contaminant and radon concentrations in the Public Dose report.

Recommendation 2: It is recommended that additional detail be added to Section 1.6.7 of CBR-RPP-008 to provide more guidance on the process for calculating and assigning a dose from bioassay samples.

Recommendation 3: It is recommended the site consider use of the database for all sample entries and develop suitable reports for printing and record keeping purposes to improve efficiency and reduce potential for error.

Recommendation 4: It would be good practice to have an explicit place on the daily inspection form for the RSO to indicate a review was performed, instead of just initialing below the operators checkmark column.

Recommendation 5: site should consider defaulting the indicator for use in dosimetry to be checked at all times and manually removed if it is not applicable to use a result for dose calculation purposes.

Recommendation 6: Revise the text of Appendix J of the semi-annual report to clarify the usage of the deployment and transient badges.

Recommendation 7: It is recommended that the storage container for the deployment and transient badges be increased to try to reduce the ambient exposure rate as much as possible.

3.3 Best Practices

Best Practice 1: The records were readily available, generally well written, and in good order facilitating the audit and other uses of the information.

4.0 REFERENCES

[NRC] Nuclear Regulatory Commission. 2002. Information Relevant to Ensuring that Occupational Radiation Exposures at Uranium Recovery Facilities Will Be As Low As Reasonably Achievable. Regulatory Guide 8.31. Revision 1. May.

[NRC] Nuclear Regulatory Commission. 2014. Bioassay at Uranium Mills. Regulatory Guide 8.22. Revision 2. May.

[NRC] Nuclear Regulatory Commission. 2014. Evaluation of Uranium Recovery Facility Surveys of Radon and Radon Progeny in Air and Demonstration of Compliance with 10 CFR 20.1301. Revised Draft for Comment FSME-ISG-01. March.

APPENDIX A

Occupational Dose Trends

Trends in occupational radiation doses for the past 14 years are shown in the tables and figures below. The average and maximum annual exposures and doses for the past 14 years are given in Table A-1. The average and maximum annual doses from exposure to uranium in airborne particulate matter are given in Figure A-1. The average and maximum annual doses from inhalation of radon decay products are given in Figure A-2. The average and maximum annual doses from direct radiation are given in Figure A-3. The average and maximum Total Effective Dose Equivalent (TEDE) values are shown in Figure A-4.

The average annual doses from the three pathways have remained relatively consistent for the past four years. Maximum doses appear to have deceased since the years 2009 through 2011 reflecting attention to ALARA issues. All pathways showed a decrease in 2016, primarily due to reduced activities.

Note: There may be some slight discrepancies between the values represented in the figures and the values given in the text of the ALARA audit report, primarily due to rounding issues.

Table A-1: Average and Maximum Annual Employee Exposure and Dose

ANNUAL EMPLOYEE EXPOSURE AND DOSE

Average and Maximum

Year	Airborne Uranium-µCi		Radon Daughters-WLM		Deep Dose-rem		TEDE-rem	
	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum
2003	5.53E-03	1.28E-02	0.208	0.402	92	238	0.380	0.759
2004	3.76E-03	9.17E-03	0.181	0.312	121	276	0.367	0.678
2005	5.88E-03	1.94E-02	0.101	0.213	118	425	0.274	0.675
2006	6.94E-03	2.14E-02	0.161	0.283	88	252	0.323	0.713
2007	4.26E-03	1.05E-02	0.116	0.224	82	250	0.248	0.576
2008	3.55E-03	1.66E-02	0.104	0.244	48	184	0.197	0.524
2009	4.75E-03	2.35E-02	0.157	0.297	62	197	0.281	0.681
2010	4.54E-03	2.32E-02	0.190	0.375	62	226	0.322	0.713
2011	4.11E-03	1.55E-02	0.217	0.435	56	268	0.309	0.842
2012	4.52E-03	1.33E-02	0.126	0.223	69	316	0.243	0.661
2013	3.29E-03	1.56E-02	0.066	0.116	58	262	0.153	0.446
2014	4.89E-03	1.63E-02	0.074	0.137	52	196	0.164	0.437

2015	7.33E-03	1.58E-02	0.076	0.133	47	184	0.168	0.389
2016	5.98E-03	1.00E-02	0.054	0.091	39	160	0.133	0.323

Figure A-1: Annual Airborne Uranium Exposure
Maximum Allowable = 1 µCi

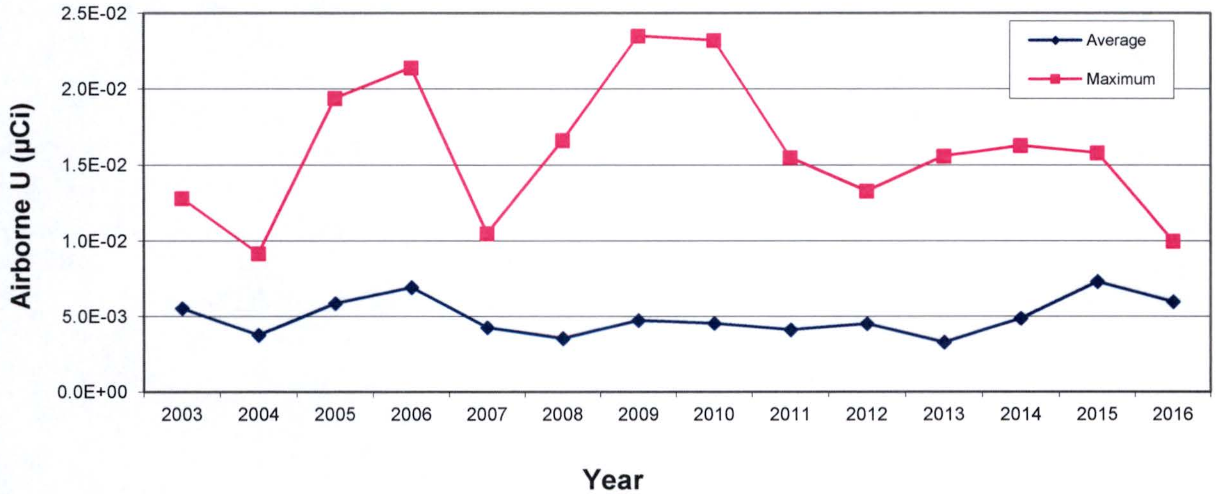
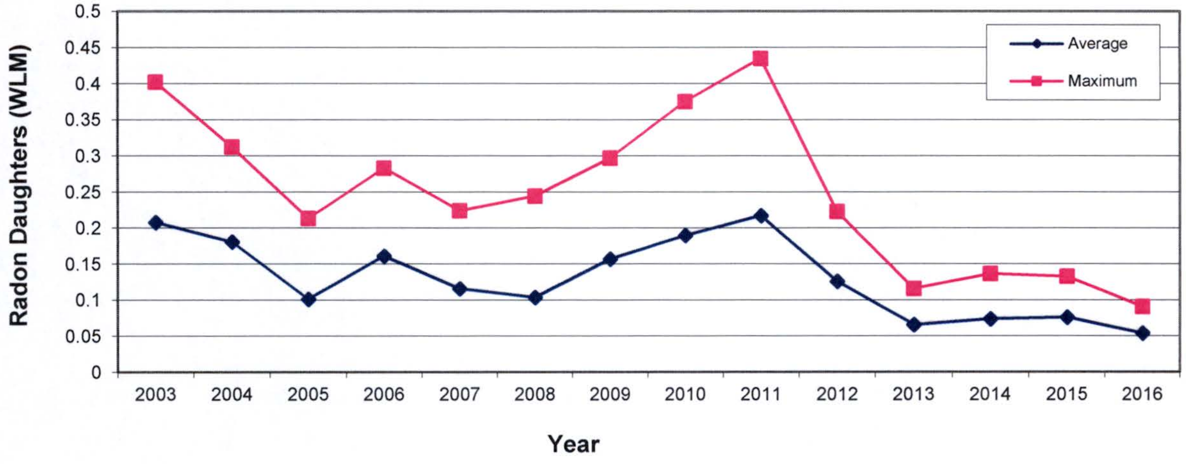


Figure A-2: Annual Radon Daughter Exposure
Maximum Allowable = 4.000 WLM



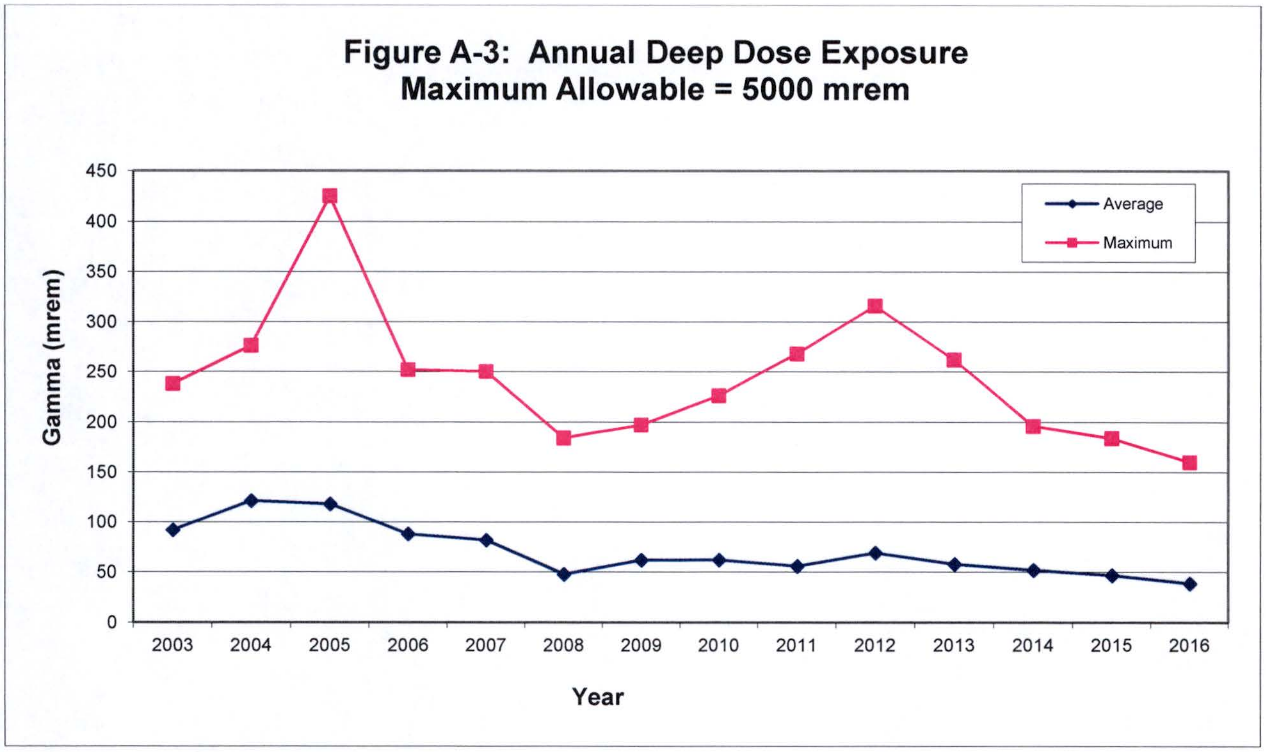


Figure A-3: Annual Deep Dose Exposure
Maximum Allowable = 5000 mrem
Gamma (mrem)
450
400
350
300
250
200
150
100
50
0
Average
Maximum
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
Year

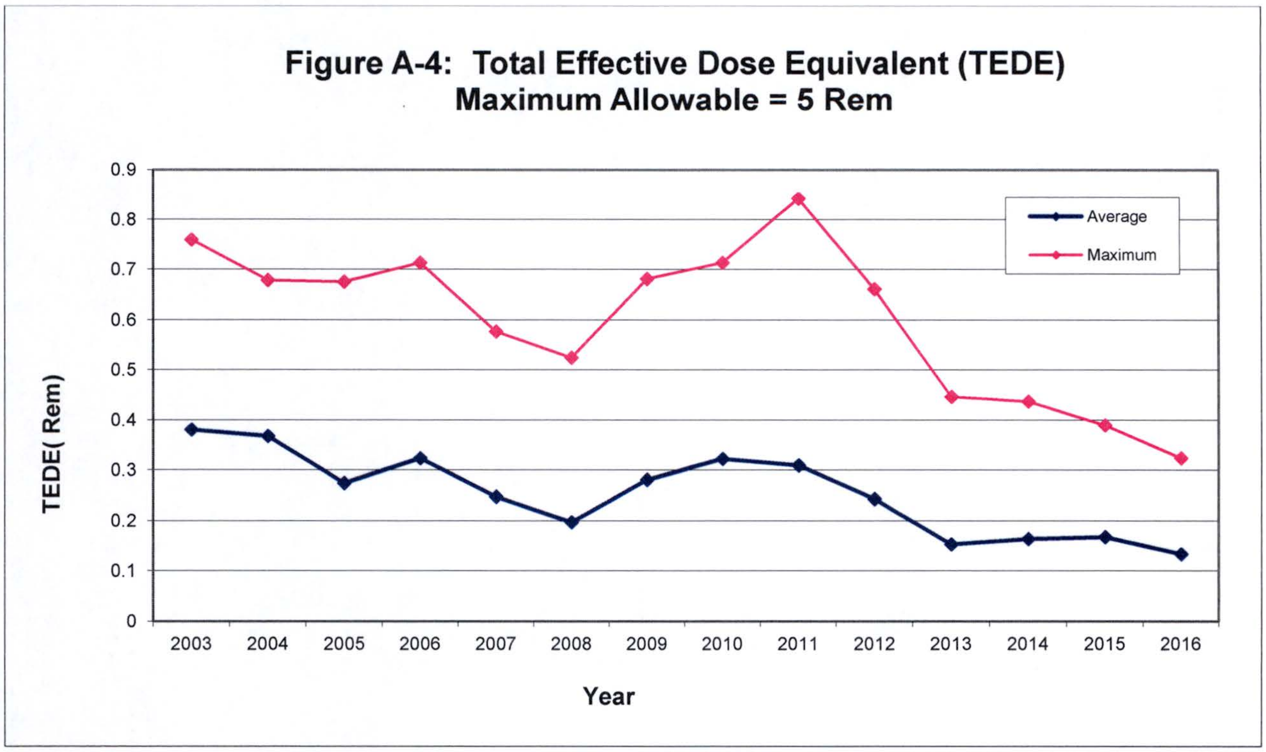


Figure A-4: Total Effective Dose Equivalent (TEDE)
Maximum Allowable = 5 Rem
TEDE(Rem)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Average
Maximum
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
Year

APPENDIX B

Public Dose Calculations

2016 DOSE TO PUBLIC CALCULATIONS

Monitoring Location/Parameter		Average Concentration/Annual Gamma Dose	Net Average Concentration/Annual Gamma Dose Above Background	10 CFR 20 App. B, Table 2 Values	Occupancy Factor	Indoor Equilibrium Factor	Dose to the Public mrem/yr[1]
AM-6	Uranium (µCi/ml)	1.E-16		9.E-14			
Background	Radium-226 (µCi/ml)	9.E-17		9.E-13			
	Lead-210 (µCi/ml)	2.E-14		6.E-13			
	Radon-222 (µCi/ml)	2.E-10		1.E-10			
	Gamma (mrem/yr)	21.1		--			
	TEDE (mrem/yr)						**Background**
AM-1	Uranium (µCi/ml)	2.E-16	5.E-17	9.E-14			0.03
Permit Area Boundary	Radium-226 (µCi/ml)	1.E-16	1.E-17	9.E-13			0.00
	Lead-210 (µCi/ml)	1.E-14	0	6.E-13			0.00
	Radon-222 (µCi/ml)	3.E-10	2.E-11	1.E-10	1.00	0.50	5.00
	Gamma (mrem/yr)	26	4.8	--			4.80
	TEDE (mrem/yr)						**9.83**
AM-2	Uranium (µCi/ml)	3.E-16	2.E-16	9.E-14			0.08
Permit Area Boundary	Radium-226 (µCi/ml)	1.E-16	8.E-18	9.E-13			0.00
	Lead-210 (µCi/ml)	2.E-14	3.E-15	6.E-13			0.21
	Radon-222 (µCi/ml)	4.E-10	1.E-10	1.E-10	1.00	0.50	30.00
	Gamma (mrem/yr)	26	4.9	--			4.90
	TEDE (mrem/yr)						**35.19**
AM-3	Uranium (µCi/ml)	1.E-16	0	9.E-14			0.00
Permit Area Boundary	Radium-226 (µCi/ml)	2.E-16	6.E-17	9.E-13			0.00
	Lead-210 (µCi/ml)	2.E-14	2.E-15	6.E-13			0.19
	Radon-222 (µCi/ml)	2.E-10	5.E-12	1.E-10	1.00	0.50	1.25
	Gamma (mrem/yr)	32.3	11.2	--			11.20
	TEDE (mrem/yr)						**12.64**
AM-4	Uranium (µCi/ml)	2.E-16	8.E-17	9.E-14			0.04
Permit Area Boundary	Radium-226 (µCi/ml)	9.E-17	0	9.E-13			0.00
	Lead-210 (µCi/ml)	2.E-14	2.E-15	6.E-13			0.19
	Radon-222 (µCi/ml)	3.E-10	7.E-11	1.E-10	1.00	0.50	17.50
	Gamma (mrem/yr)	23	2.E+00	--			1.90
	TEDE (mrem/yr)						**19.63**
AM-5	Uranium (µCi/ml)	2.E-16	8.E-17	9.E-14			0.04
Residence	Radium-226 (µCi/ml)	9.E-17	0	9.E-13			0.00
	Lead-210 (µCi/ml)	2.E-14	3.E-15	6.E-13			0.21
	Radon-222 (µCi/ml)	3.E-10	1.E-10	1.E-10	1.00	0.50	27.50
	Gamma (mrem/yr)	28.2	7.1	--			7.10
	TEDE (mrem/yr)						**34.85**
AM-8	Uranium (µCi/ml)	1.E-16	3.E-17	9.E-14			0.01
Site Boundary	Radium-226 (µCi/ml)	8.E-17	0	9.E-13			0.00
	Lead-210 (µCi/ml)	2.E-14	3.E-15	6.E-13			0.21
	Radon-222 (µCi/ml)	3.E-10	7.E-11	1.E-10	1.00	0.50	17.50
	Gamma (mrem/yr)	38.7	17.6	--			17.60
	TEDE (mrem/yr)						**35.32**
AM-9	Uranium (µCi/ml)	1.E-16	3.E-17	9.E-14			0.01
Nearest Downwind Residence	Radium-226 (µCi/ml)	1.E-16	4.E-17	9.E-13			0.00
	Lead-210 (µCi/ml)	2.E-14	0	6.E-13			0.00
	Radon-222 (µCi/ml)[2]	4.E-10	1.E-10	1.E-10	0.75	0.50	22.5
	Gamma (mrem/yr)	31	9.9	--			9.9
	TEDE (mrem/yr)						**32**

Notes

TEDE Total Effective Dose Equilent (mrem/yr)

< One or more of the Lower limits of Detection used to determine average concentrations

1 $Dose\ from\ Radionuclides\ (mrem/yr) = \frac{Average\ Concentration\ above\ Background * 50\ mrem}{10\ CFR\ 20\ AppB\ Table\ 2\ value\ in\ \mu Ci/ml}$

2 $Dose\ from\ Radon\ 222\ with\ Daughters\ (mrem) = \frac{Average\ Concentration\ above\ Background * 50\ mrem * Occupancy\ Factor * Equilibrium\ Factor}{10\ CFR\ 20\ AppB\ Table\ 2\ value\ in\ \mu Ci/ml}$

APPENDIX C

Land Use Survey

Interoffice Memo

Cameco Resources
Crow Butte Operation

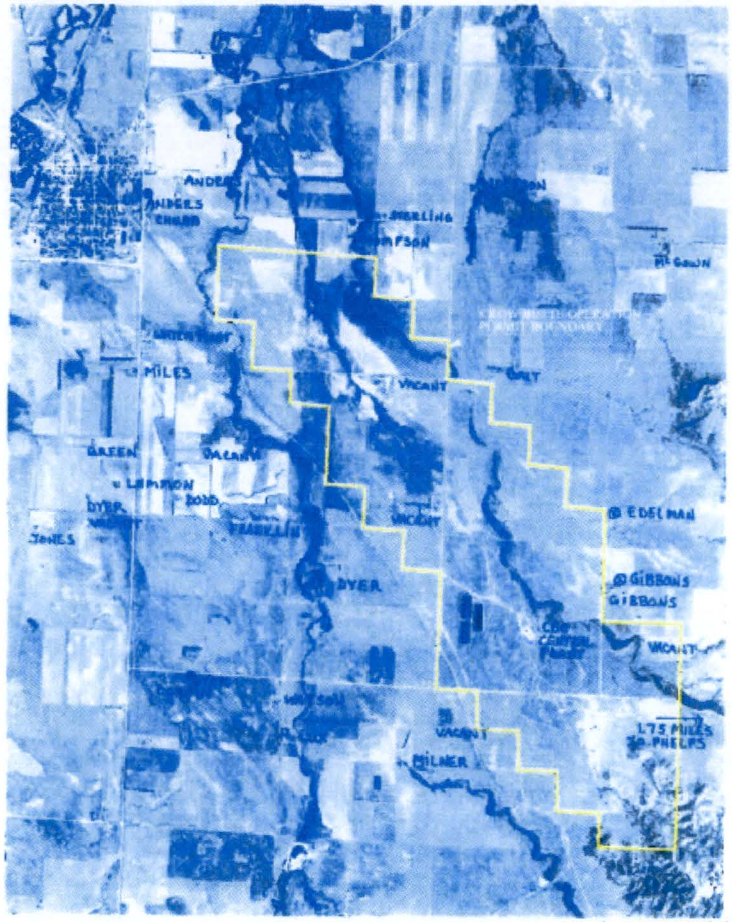
Date: February 14, 2017

To: File

From: Larry Teahon, SHEQ Manager LT
Tami Dyer, Radiation Safety Officer TD

Re: License Renewal (November 2014) License Condition 11.2, Land Use Survey

Source Material License SUA-1534 (Renewed November 2014) License Condition 11.2 requires the licensee to conduct an annual land use survey. This survey was conducted by the Radiation Safety Officer and SHEQ Manager using aerial maps, interviews and ground verification. Attached is an aerial photo of the survey. No new occupied structures were identified that would affect dose to the public of the nearest resident to the Crow Butte operation.



2016 LAND USE SURVEY
LICENSE CONDITION 11.2
2/14/17