ATTACHMENT 1.3

COMPARISON OF WORKER AND PUBLIC DOSES FROM CONVENTIONAL URANIUM MINING AND MILLING IN NORTH AMERICA

PREPARED FOR BLACK RANGE MINERALS NUCLA, COLORADO

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COMPARISON OF WORKER AND PUBLIC DOSES FROM URANIUM MINING AND MILLING IN NORTH AMERICA

Preface: This assessment was performed to respond to the Colorado Department of Public Health and Environment 's (CDPHE) letter to Black Range Minerals of 13 August 2016 in which CDPHE requested that Black Range Minerals provide:

A comparison of the above estimation and evaluation (Ed note: of projected worker and public doses – See Attachments 1.1 and 1.2) *between the AMT operation and other traditional ore mining operations and uranium milling operations*

1.0 Introduction – We Live in A Radioactive Environment

The magnitude and variability of natural background radiation can be used as a benchmark to provide some perspective on the radiation doses received from uranium mining and milling. This is particularly relevant since a large percentage of our background radiation exposure is a direct result of naturally occurring uranium and its decay products in the soil and rocks under our feet and in the food and water we consume every day.

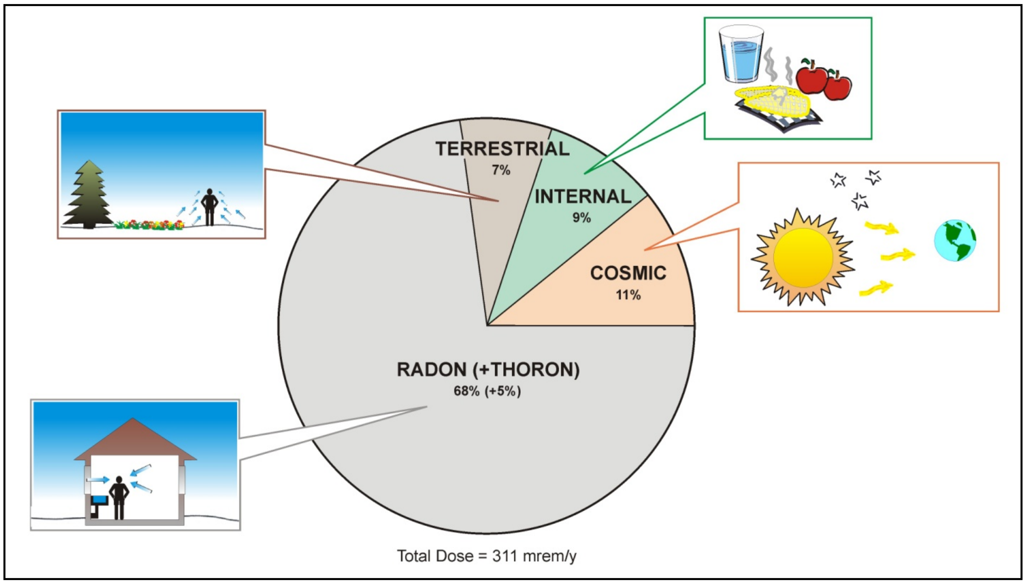
Natural background radiation exposure to humans is ubiquitous, unavoidable and highly variable depending on where you live. (In the present context, "radiation" is assumed to mean ionizing radiation, as opposed to microwaves, radio waves, ultraviolet radiation and other forms of non-ionizing radiation.) People are exposed to cosmic radiation from solar radiation and outer space (galactic cosmic radiation, a constant field of radiation in outer space that is constantly bombarding the earth's atmosphere and magnetic field). Humans are constantly immersed in a field of cosmic radiation that varies with elevation (higher doses from cosmic radiation are found at higher elevations). Naturally occurring radioactive materials are present in the earth, in the houses we live in and in the buildings where we work, as well as the food and drink we consume. There are radioactive aerosols and gases in the air we breathe and even our own bodies contain naturally occurring radioactive elements. The level of this inescapable natural "background" radiation exposure varies greatly from place to place. For example, according to the U.S. National Council on Radiation Protection and Measurements (NCRP 1987), background soil in the U.S. contains a mean of 3.1 parts per million (ppm) of uranium (and 6.5 ppm of thorium) although much higher concentrations, especially in areas of mineralization, are not uncommon (NCRP 2009, UNSCEAR 2000). A square mile of the earth's surface one foot deep, just about anywhere in the temperate zones, contains over a ton of uranium.

Natural background radiation, which comes from a number of sources, typically results in a dose rate of roughly about 200 to 400 millirem per year (UNSCEAR 2000), although some places in the world, including parts of the U.S., experience much higher exposure rates. The average annual exposure from natural background radiation in the U.S. (311 millirem/y) is shown in Table 1 and Figure 1 (NCRP 2009).

Table 1: Exposure to Natural Background Radiation in the United States

Source of Exposure	Average in U.S. millirem/y) (%)
Internal, inhalation (radon and thoron)	228 (73%)
External, cosmic (space)	33 (11%)
Internal, ingestion (food and water)	29 (9%)
External, terrestrial	21 (7%)
Total	311 (100%)

Figure 1: Natural Background Radiation in the United States



According to the NCRP, exposure to radon (or specifically, Rn-222), primarily while indoors, is responsible for almost 70% of the average dose from background radiation, although radon doses are highly variable. In the U.S., the average indoor radon concentration at home is 46.3 becquerels per cubic meter (Bq/m^3) (1.25 picocuries per liter (pCi/L)), and the average outdoor concentration is 15 Bq/m^3 (0.40 pCi/L) (NCRP 2009).

Our lifestyles, where we choose to live, what we eat and drink, has a much larger impact on our radiation exposure than control at the regulatory limits for public exposure from the operation of uranium mines and mills. The basic public exposure regulatory limits that operating uranium fuel cycle facilities must comply with are 100 millirem per year from all sources including radon and 25 millirem / year excluding radon. Examples of Federal and Colorado radiation exposure limits for occupational workers and the public are presented in Table 2.

Table 2: Example Federal and Colorado Radiation Exposure and Dose Limits Applicable to Uranium Mining and Milling

Exposure Condition	Limit	Regulatory Reference
Worker Annual Radiation Exposure	5000 millirem /year	USNRC: 10 CFR 20.1201, *Occupational Dose Limits; Colorado: 6 CCR 1007-1 Part 4.4.1, Occupational Dose Limits;* USMSHA: 30 CFR 57.5047
Worker Annual Radiation Exposure	4 Working Level Months (WLM) of Exposure to radon decay products	USMSHA: 30 CFR 57.5038 USNRC: 10 CFR 20, Appendix B, Table 1; *Colorado:* 6 CCR 1007-1 Part 4, Table 4B1
Worker Annual Radiation Exposure	5 Rem / year (5000 millirem /y) gamma radiation exposure	USMSHA: 30 CFR 57.5047
Radiation Exposure Limit for Members of the Public - General	100 millirem / year including radon	USNRC: 10 CFR 20.1101, *Radiation Dose Limits for Individual Members of the Public;* Colorado Department of Public Health and Environment: 6 CCR 1007-1 Part 4.parapraph 4.14.1, *Radiation Dose Limits for Individual Members of the Public*

Compare the public exposure limits in Table 2 to the annual radiation doses we receive as citizens of planet Earth as depicted in Table 1 and Figure 1 above.

Natural radiation exposure can vary considerable from place to place across the United States or over relatively small areas within a region. This is due to effects of elevation (higher cosmic radiation exposure at higher elevations), greater levels of naturally occurring radioactive elements in soil and water in mineralized areas (e.g. igneous formations in Rocky Mountains) and other factors like local geology and chemistry. This is depicted in Table 3, which allows comparison of average annual background radiation exposure for the US (from Table 1 and Figure 1 above) relative to annual averages for all of Colorado, Leadville, Colorado (high elevation and mineralization) and several other

States. This table shows the major components of natural background radiation, including terrestrial radiation (uranium, radium, thorium and potassium 40 in soil, rocks and water), cosmic radiation (high energy rays from space) and internal radiation (from food, water and radon gas from natural uranium decaying in the ground).

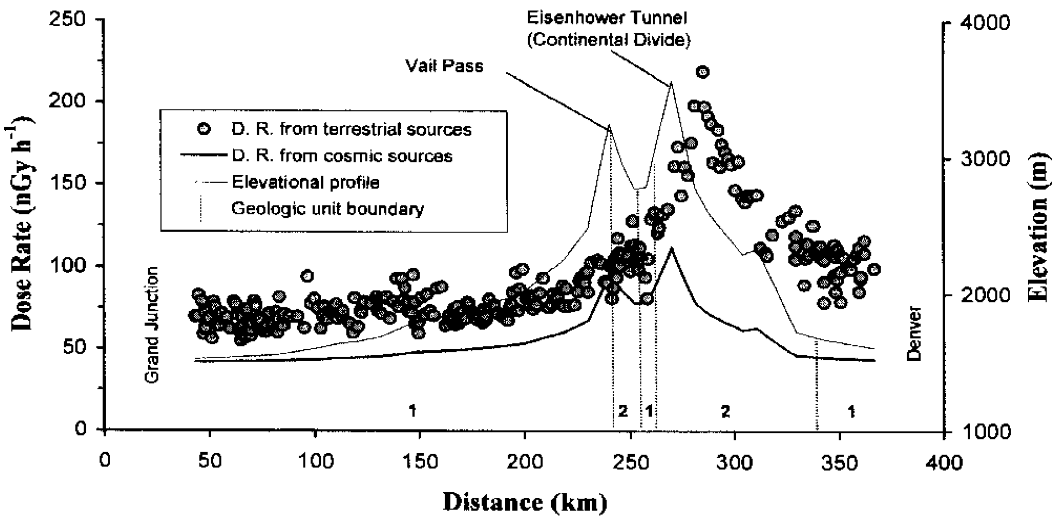
The data in Table 3 demonstrates that the differences in annual background exposure based on where one chooses to live and what we choose to eat and drink has a much greater impact on public exposure than the regulatory dose limits discussed above. An additional perspective is depicted in Figure 2, which shows the change in radiation exposure rate due to a variation in elevation and mineralization as one travels across the Interstate 70 corridor through the Rocky Mountains between Denver and Grand Junction, Colorado.

Table 3: Comparison Of Average Radiation Backgrounds In US vs. Colorado (Units of millirem/yr)

Source	**Colorado Avg.**[a]	**Florida Avg.**[a]	**Illinois Avg.**[a]	**Leadville Avg.**[b]
Cosmic Radiation	49	27	28	85
Terrestrial Radiation	39	13	24	97
Internal Radiation including Radon Inhalation, Food and Water Ingestion	300	54	181	344
Totals	387	93	233	526

[a] From USEPA 2005 [b] From Moeller 2006

Figure 2: Variability of Terrestrial and Cosmic Radiation Background Across The Interstate 70 Corridor Of Colorado (units of nanograys per hour) Moving a hundred miles can change exposure by a factor of 4). (Stone, 1999)



Another perspective on the variability and potentially elevated nature of natural background radiation is provided in the US DOEs Uranium Leasing Program Final Programmatic EA (DOE 2007). Mine sites on the DOE lease tracts comprise rocks and soils that can contain elevated levels of naturally occurring radioactive material (uranium and thorium series decay chains). For example, background levels of radium-226 are normally present in soil in trace concentrations of about 1 - 2 picocurie per gram (pCi/g). However, background concentrations within ore-bearing formations may be as high as hundreds of thousands of picocuries per gram. In the DOE lease tracts, the concentration of radium-226 in mine-waste-rock piles is about 110 pCi/g. Table 4 presents a summary of radiation doses from natural background for the nation and representative doses for the region containing the uranium lease tracts.

Table 4: US DOE Uranium Lease Tract Natural Background Radiation Dose

(Reproduced from DOE 2007)

Source	U.S. Average Natural Background Radiation Dose (millirem/yr)	Uranium Lease Tract Natural Background Radiation Dose (millirem/yr)
Cosmic and cosmogenic radioactivity	28	68
Terrestrial radioactivity	28	74
Internal radioactivity	40	40
Inhaled radioactivity	200	260
Rounded Total	300	440

2.0 Overview – Occupational Radiation Exposure of Uranium Miners and Millers in North America

There is considerable data on the radiation doses arising from the mining and milling of uranium, both in the U.S. and in Canada that present an informative perspective relative to the Western Uranium Sunday Mine Project. All the data (U.S. and Canadian) show that the doses from modern day uranium mining are low and well within regulatory limits, and projected worker doses at the Sunday Mine Project are expected to be similar or less (See companion report SHB 2016) For example, a summary of this data is presented in Table 4 for both U.S. and Canadian uranium mill workers. The remainder of this section presents detailed data for Canadian Uranium miners and millers followed by similar, although much more limited data for US Uranium miners and millers due to a much smaller uranium recovery industry in the US relative to Canada, over the last 2 decades.

However, it must be noted that some difficulties were experienced in attempts to acquire occupational exposure data from US sources. For example, to obtain underground uranium miner exposure data from the US Department of the Interior, Mine Safety and Health Administration (MSHA), we were told that a Freedom for Information Act (FOIA) request was necessary. This was formally submitted in December 2015. MSHA has indicated it may take up to 6 months to obtain this information. The status of this FOIA request was last investigated on 21 March 2016 and still indicates an August 2016 resolution date.

Additionally, one of only two of the uranium mills that have operated in the US during the last 15 – 20 years was not willing to provide the occupational exposure data for their millers since this data only exists in raw form within personal exposure files at the mill site. More on these circumstances are discussed in Section 4.2.2.

Nonetheless, given the large # of workers at Canadian uranium mines and mills (compared to the relatively small size of the US industry and worker population) and the extensive nuclear worker data base maintained by Health Canada, the absence of this US data does not result in any material deficiencies in the ability to establish with confidence typical occupational exposures associated with the uranium mining and milling industry in North America in recent years.

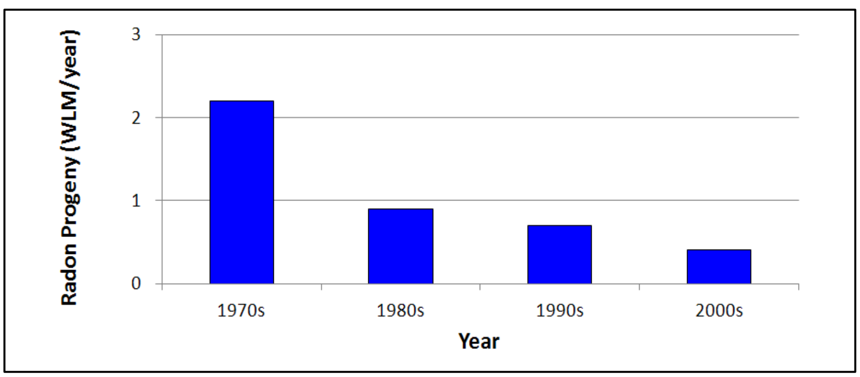
Table 5: Historical Doses to Uranium Mill Workers [a]

Source	Average Total Annual Dose (mrem/y)	Comments
USNRC 1980 (NUREG 0706)	380	Data for 17 U.S. uranium mills circa 1975[b]
Canada 2010 to 2014	110	Data from Health Canada (2016)
U.S. natural background radiation	311	U.S. average (NCRP No.160, 2009)

[a] Doses to workers exclude doses from natural background radiation.
[b] Doses to workers at modern mills are less – see Tables 5 and 6 and discussion in text.

Exposure to radon was the major health risk to the early uranium miners. In the early days of uranium mining, the exposures of miners to radon were much higher than exposures to modern uranium miners. This was due to poor ventilation in the early mines and lack of the robust regulatory controls in place today. The radiation dose is actually due to the short-lived decay products of radon, referred to as "radon progeny", measured in units called "working level months" (WLM). [One WLM is exposure to 100 pCi/L of radon (in equilibrium with its short-lived decay products) for one working month (170 h).] Figure 3 below shows how the exposures of miners in Canada have decreased over time from historically very high levels to the currently low levels in modern mines (Lane 2007). The exposure of the earlier miners decreased from more than 400 WLM per year in the 1940's to about 2 WLM per year by early 1970. Exposures are even lower today, at an average of about 0.5 WLM per year, or about 800 times less than the early mining days. In fact, a study of miners in Saskatchewan (SENES 2003), commissioned by the Canadian Nuclear Safety Commission, found that modern uranium miners may receive more radon progeny exposures from their homes and the natural environment than from occupational exposures.

Figure 3: Average Radon Decay Product Exposures in Canadian Uranium Mines in the Past (1970s to 2000s)



As a point of comparison, it is not uncommon in the U.S. for natural radon levels in our homes to be near or in excess of USEPA's recommended 4 pCi per liter standard recommended for mitigation. About 6% of homes in the U.S. exceed this concentration (Marcinowski *et al*. 1994). This concentration corresponds to an indoor exposure of about 0.6 WLM per year, or comparable to the average occupational radon exposure of modern uranium miners. In other words, millions of Americans receive similar annual exposures from radon in their homes as the average underground uranium miner receives from his or her occupational exposure inside the mine. .

It is also interesting to note that according to the Colorado Department of Public health and Environment, (http://co-radon.info/CO_general.html), between one-third and one -half of the homes in Colorado have radon levels in excess of the EPA recommended action level of 4 picocuries (pCi) of radon per liter of air which corresponds to an indoor exposure (70% occupancy) of about 0.6 WLM per year or about the same as the average occupational radon exposure of uranium miners. Additionally, given that the population of Colorado is approximately 5.4 million (http://www.census.gov/quickfacts/table/PST045215/08,00) it follows that between 1.7 and 2.6 million Coloradans receive the same or higher radiation exposure each year from radon as the average uranium miner.

Recently reported exposure data on Canadian uranium miners published by the Canadian Nuclear Safety Commission (similar to the USNRC) is also instructive. The Fact Sheet entitled *Uranium Mining and Milling: The Facts on a Well-Regulated Industry* (CNSC 2012) states: *In 2010, the average annual dose to miners was 1.37 mSv* (137 millirem) *and the maximum dose was 10.7 mSv (1070* millirem*), well below the CNSC annual limit of 50 mSv* (5000 millirem – same as USNRC and Colorado limit for workers).

3.0 Canadian Uranium Miners and Millers

In Canada under Canadian Nuclear Safety Commission (CNSC) regulations (similar to the US Nuclear Regulatory Commission), both uranium mills and mines are licensed facilities. Accordingly, worker exposure data from both types of facilities has to be reported annually to the CNSC. Occupational exposure data for all Canadian nuclear workers is collected, organized and managed by Health Canada's National Dosimetry Services (NDS). This data includes doses from radon progeny and gamma radiation exposures. Annual reports on occupational exposures are available at http://www.hc-sc.gc.ca/ewh-semt/occup-travail/radiation/regist/index-eng.php. However, the last annual report of occupational exposure data was published in 2009 (Health Canada 2009). Health Canada's NDS was contacted in attempt to obtain more recent data and for explanation of the job categories used and NDS was willing to provide more updated data (through 2014) for the uranium mining and milling job categories of interest (Health Canada 2016). The data for the years 2010 - 2014 as provided by Health Canada directly to us is presented in Table 5.

In Health Canada 2009 (last full occupational exposure report published), the uranium miners industry category was defined with both miner and miller job functions. The average annual effective dose in mSv reported for uranium miners and millers are required to include (CNSC 2009) doses from photons (labeled in reports as “external”), radon progeny, long-lived radioactive dust and radon gas (in some cases).

Radon progeny doses have been converted from Working Level Months (WLM), which are in most cases calculated by the mines on the basis of area monitoring (per ICRP 1993). Radon progeny exposures have been converted to equivalent doses using 5 mSv/WLM, in accordance with the radiation protection regulations under the Canadian *Nuclear Safety and Control Act*.

Radon progeny typically accounts for about 50% of the dose. Even for the relatively high grade uranium facilities in Canada, the data clearly demonstrate that the doses received by workers at modern day uranium mines and mills are low and well within regulatory limits.

For the most “highly exposed” category in each year 2010 - 2014 (“underground uranium miners” – see Table 5), the recent data provided to us by Health Canada NDS indicates that the average annual exposure over those 5 years is less than 2 mSv (200 millirem). As in the US, the single year dose limit for these workers is 50 mSv (5000 millirem).

Table 6: Doses to Canadian Uranium Mine and Mill Workers For Selected Job Categories, 2010- 2014 (Health Canada 2016)

	2010		2011		2012		2013		2014	
	Mean mSv	Count	Mean mSv	Count	Mean mSv	Count	Mean mSv	Count	Mean mSv	Count
U Mill Workers	1.05	340	1.07	298	1.05	322	1.15	308	1.18	321
U Mine Support Workers	1.04	408	0.91	532	0.65	779	0.65	1108	0.87	524
Uranium Mine Surface Worker	0.42	81	0.19	90	0.18	107	0.22	67	0.4	33
Underground Miner	2.29	622	2.17	648	1.76	677	1.49	688	1.91	551

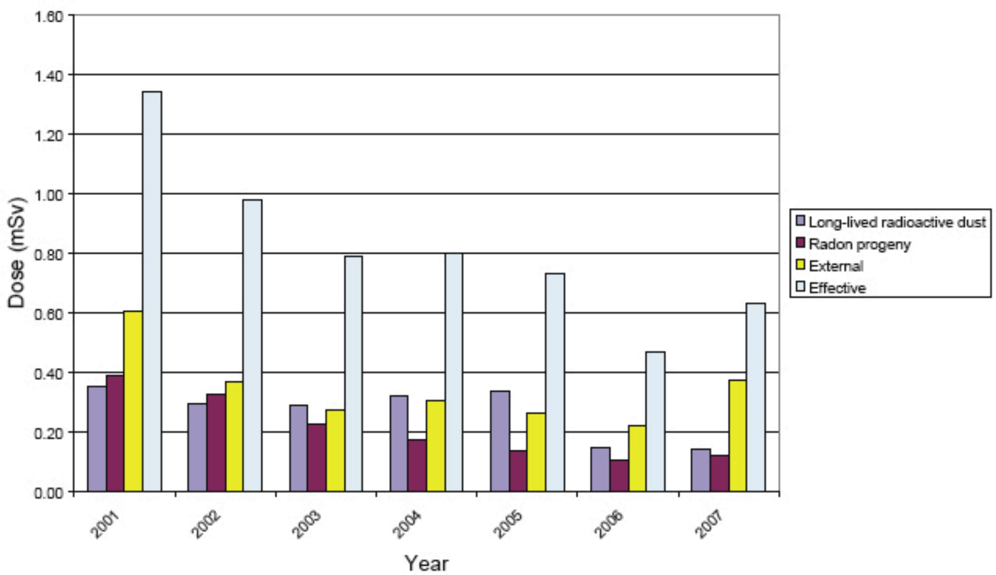
3.1 Canadian Uranium Mine and Mill Workers – Specific Examples

CNSC 2009 also presents annual worker exposure data for all licensed nuclear facilities in Canada on a facility specific basis, including uranium mines and mills. Note that uranium mines are licensed facilities under Canadian Nuclear Safety Commission (CNSC) regulations. An example of this data for a large uranium mine and a large conventional uranium mill operation are presented below.

3.1.1 Key Lake Uranium Mill

Cameco Corporation operates mining facilities in Key Lake, located in north central Saskatchewan. The Key Lake operation includes two mined-out open pit mines (used for tailings management), a mill and two dry tailings management facilities. Mining began in 1983 and ceased in 1997; the mill continued to process ore from the McArthur River mine during the reporting period. The annual production of this mill in recent years has been 18 – 20 million pounds U_3O_8[1]. Historical worker doses are presented in Figure 4.

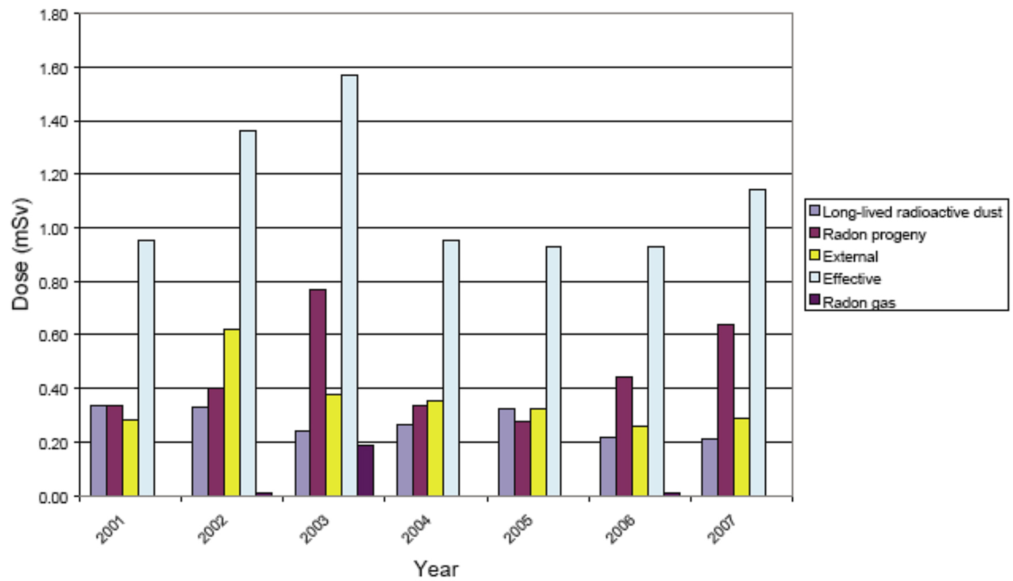
Figure 4: **Average Dose Trends for the Key Lake Operation (CNSC 2009)**.



3.1.2 McArthur River Underground Uranium Mine

Cameco Corporation operates the McArthur River underground mine in north central Saskatchewan. Ore from the mine, which began production in 1999, is processed at the Key Lake Mill (see above), located 80 km south of McArthur River. In 2012, McArthur River was the world's largest producing uranium mine, accounting for 13% of world mine production. Historical worker doses are presented in Figure 5.

Figure 5: **Average Dose Trends for the McArthur River Operation (CNSC 2009)**



4.0 US Uranium Mine and Mill Workers

4.1 US Uranium Miners

The Mine Safety and Health Administration was contacted for information about historical data on uranium miner occupational exposures. Mine operators are required to maintain accurate records of employee exposures to potentially toxic materials or harmful physical agents and submit this data annually to MSHA on Form 4000-9. Specific information required by the form with respect to each person's time-weighted current and accumulative exposure to concentrations of radon daughters shall be recorded in accordance with 30 CFR 57.5040(b).

However, we were informed that although this data is known to exist at least back to about the year 2000, it requires a formal Freedom of Information Act (FOIA) request, which was submitted through the Department of Labor FOIA office on December 10, 2015, requesting copies of Form 4000-9 from 2005 thru 2014. The FOIA tracking system was last queried on March 21, 2016 which indicated an action completion estimated of August 12, 2016. However, it is noted MSHA indicated the requested information could be provided directly, without a FOIA, if requested by a State or Federal Agency.

4.2 US Uranium Millers

It must be recognized that during the last 20 + years, only two conventional uranium mills have operated in the US, the Cotter Corporation Canon City mill and the White Mesa mill in Blanding Utah (now owned by Energy Fuels) [1]. Since shortly after 2006 when the Canon City mill ceased operation, the White Mesa mill has been the only operating conventional uranium mill in the US. Accordingly, recent occupational exposure data for US uranium millers is quite limited.

[1] The only currently operating conventional U mill in US, White Mesa in Blanding Utah, has annual capacity of about 8 million pounds U_3O_8, although has not produced more than about 2 - 3 million pounds annually in recent years.

4.2.1 Cotter Corporation Uranium Mill, Canon City, Colorado

A specific, fairly recent example in the U.S. is data from the Cotter Corporation uranium mill near Canyon City, Colorado for the year 2005[2] (Cotter Corporation 2006a). During the first half of 2005, renovation of mill circuits continued from 2004. More consistent operation of all circuits occurred as the year progressed. The milling facility received uranium-vanadium ore from Cotter's western slope mines and fed approximately 46,000 tons to the crushing circuit during 2005. In addition, the yellowcake precipitation circuit was operated every month except November with drying and packaging operations conducted in April, July and August. Approximately 126,000 pounds of uranium was shipped to the conversion facility during the year. Approximately 46,000 tons of uranium ore was processed by the mill in 2005.

Employee doses were calculated for 167 employees during that calendar year. There were 47 employees who worked under 500 hours (average 237 hours), 31 employees who worked from 500 to 999 hours (average 704 hours) and 89 employees who worked 1,000 hours or more (average 2061 hours). The maximum external dose of any worker during 2005 was 577 millirem (5.77 mSv), about 10% of the annual limit under USNRC and CDPHE regulatory limits for millers (10 CFR 20.1201; 6 CCR 1007-1, Section 4.6 respectively). This dose data is summarized in Table 6.

[2] 2005 is considered the last representative fully operational year for the Canon City Mill prior to initiation of shutdown and decommissioning activities (personal communication, Jim Cain, Cotter Corporation, December 2015).

Table 7: Summary of Annual Radiation Doses to Workers at the Canon City Uranium Mill for the Calendar Year 2005 (Cotter Corporation 2006)

Total Effective Dose Equivalent – TEDE [3] (millirem /y)	<500 Hours	500 to 999 Hours	>999 Hours
Average	30	110	261
Standard Deviation	25	49	96
Median	30	107	247
Maximum	107	254	577

Note: Hours refer to hours worked during the year 2005.

4.2.2 White Mesa Uranium Mill (Energy Fuels), Blanding Utah

The State of Utah does not require occupational exposure data to be summarized and submitted annually. We were informed that although data for individual workers must be made available for State inspectors at the mill, it does not need to be summarized or "sanitized" in any way (i.e., protecting identity of individual workers) (Johnson 2015). Energy Fuels was contacted for access to this data in December 2015 but it has not as yet been forthcoming. This is understandable if in fact the data only exists as individual personnel records and would need to be "sanitized" for public release.

5.0 Radiation Exposures to Members of the Public from Uranium Mining and Milling

5.1 Introduction

Although the data above refer to mine and mill workers, information from both Canada and the U.S. indicate that doses to members of the public due to uranium facilities are also well controlled.

In Canada, radiation doses to members of the off-site public are small fractions of background levels and well below (typically < 5%) the CNSC regulatory dose limit of 1 mSv/y (100 millirem y). As an example, the maximum radiation dose to members of the public due to a high grade uranium mine

[3] For the Canon City Milling Facility, the TEDE (Total effective Dose Equivalent) was calculated as a combination of the Deep Dose Equivalent (DDE - as measured by TLD badges) plus the Committed Effective Dose Equivalent (CEDE - for airborne particulate) as estimated from breathing zone, general air samples and radon-222 and radon-220 which were estimated by means of working level (WL) measurements.

and mill facility in Canada was estimated at 0.063 mSv / year (6.3 millirem /year - AREVA Resources 2007). Studies have shown that uranium mining and milling activities, even from high grade mines, do not increase radon levels above background levels in the environment away from the mine site (CNSC 2012) which indicates *"... human exposure to radon and radiation from modern uranium mining is very low and does not increase the risk of cancer"*.

In the U.S., a number of public health studies relative to uranium mining and milling have been published. For example, a study of people in Montrose County Colorado with a long history of uranium mining did not find elevated cancer rates over a 50 year period (1950-2000), and found no evidence that uranium mining affected the health of local residents (Boice *et al.* 2007a). A study of mortality among residents of Uravan, Colorado who lived near a uranium mill found no evidence that environmental radiation exposures above natural background associated with the uranium mill operations increased the risk of cancer (Boice *et al.* 2007b). Similarly, a study in Texas found no impacts on cancer rates in people living next to uranium mining and milling activities over a period of 50 years, suggesting that the uranium mining and milling operations had not increased cancer rates among residents (Boice et al 2003).

5.2 Specific Estimates of Public Exposure from US Uranium Mines and Mills

5.2.1 Example: La Sal Uranium Mine Complex, Utah

The La Sal Mine is an active underground uranium mine in Utah, which will mine over 100,000 tons of ore during the life of the mine and has an annual ore production rate greater than 10,000 tons. Like all operating uranium mines in the US, it is subject to US EPA regulations at 40 CFR Part 61, Subpart B – National Emission Standards for Hazardous Air Pollutants and approval under a 40 CFR 61.08 permit issued by the Utah Department of Environmental Quality, Division of Air Quality. Accordingly, annual reports summarizing assessment of compliance with 40 CFR 61, Subpart B must be submitted each year to the State of Utah. For the operations in 2012, results of calculations of offsite radiological dose to a number of nearby public receptors was performed using both the COMPLY – R and AERMOD computer codes (Energy Fuels 2013).

COMPLY-R (USEPA 1989) is the EPA's reference model for assessing the dose due to radon from mine emissions. EPA's regulatory air dispersion code AERMOD (USEPA 2004) was used to estimate atmospheric dispersion. AERMOD is a steady state Gaussian plume dispersion model that can be used to assess pollutant concentrations from a wide variety of complex industrial settings including multiple stacks, fugitive emissions, and building wake effects. Potential doses to nearby receptors in the vicinity of the mine using both COMPLY-R and AERMOD for operations in 2012 were based on radon monitoring results from a number of mine vent emissions from January through December 2012 These results are reproduced from Energy Fuels 2013 and presented in Table 8.

Table 8: Public Dose Estimates (millrem / year) For The La Sal Mine Complex as a Result of Operations During Calendar Year 2012 (Energy Fuels 2013)

Receptor	Description	COMPLY-R	AERMOD
R1	Residence #1	16.0	8.19
R1b		9.4	5.21
R2	Residence #2	15.8	7.15
R3	Residence #3	10.6	3.61
R4	Livestock	3.8	6.44
R5	Church	5.2	8.73
R6	Post Office	3.8	6.46
R7	Maintenance Shed	5.3	9.39
R7b		1.2	2.14
R8	La Sal School	7.2	7.04
R9	Residence #4	5.8	6.33
R10	Residence #5	3.0	4.13

5.2.2 Example: Former Operation of the Sunday Mine, Colorado

In accordance with the requirements set forth in 40 CFR 61.24, the former operator of the Sunday Mine submitted annual compliance reports to the USEPA for the years 2008, 2009 and 2010. The reports for these years were reviewed (Dennison Mines 2009, 2010, 2011) which provided estimates of public exposure from radon released from a number of vents of the Sunday mine complex during each year. Under 40 CFR 61.22, emissions of radon-222 to the ambient air from an underground uranium mine shall not exceed those amounts that would cause any member of the public to receive in any year an effective dose equivalent of 10 millirem per year. Further, 40 CFR 61.23(a) provides that compliance with this emission standard shall be determined and the effective dose equivalent calculated by the US EPA computer code COMPLY-R. The maximum public dose reported for each year to the maximally exposed member of the public (nearest residence about 6500 meters distance) was 0.5, 7.5 and 0.7 mrem respectively.

Similarly to the La Sal Mine Complex descried above, the US EPA's COMPLY-R reference model (prev. cit.) was used for assessing the dose due to radon from mine emissions. For the year 2010, EPA's regulatory air dispersion code AERMOD (prev. cit.) was also used to estimate atmospheric dispersion. The results of this analysis for a number of public receptor locations is reproduced from Denison Mines 2011 and depicted in Table 9,

Table 9: Public Exposure Estimated for the Sunday Mine Complex, 2010

Receptor	Description	2010-Emissions-5months Dose mrem/year-Flat
R1	Possible Receptor 26	0.078
R2	Possible Receptor 20	0.400
R3	Possible Receptor 21	0.100
R4	Possible Receptor 1	0.700
R5	W48km	0.100
R6	Possible Receptor 15	0.200
R7	Possible Receptor 12	0.075
R8	Possible Receptor 8	0.079
R9	N48km	0.027
R10	Possible Receptor 10	0.065
R11	Possible Receptor 4	0.026
R12	Possible Receptor 3	0.040
R13	Possible Receptor 7	0.400
R14	Possible Receptor 32	0.300
R15	Possible Receptor 29	0.300
R16	Possible Receptor 33	0.200

Dose estimates from these models, based on empirical measurements of radon release rates from the approximately 15 vents monitored during 2010 indicate that the dose due to radon to the maximally exposed receptor would be about 0.7 millirem/year resulting from the 5 months of operation of the Sunday mine complex during 2010. The mine was active only through the period January – May 2010. However, it should be noted that the COMPLY – R results are historically considered conservative and will overestimate dose, largely from conservatism in the air dispersion modeling. Accordingly the 0.7 millirem / year at the R4 location is likely to be an overestimate. Similarly, the 7.5 mrem result for the year 2009 would also be considered an overestimate.

Regarding implication for the operation of the Sunday mine today, these results are instructive. Considering results for all three years of operation and for which compliance reports were available, it is indicated that the Sunday mine has historically easily complied with the 10 mrem / year limit. Ignoring the assumed conservatism and taking into account that in 2010, the Sunday mine operated for only 5 of 12 months, the annual dose estimate on a full time operational basis would simply be 12/5 X 0.7 = 1.7 millirem / yr. However, based on actual measurements of radon emission from mine vents that will be performed during operations, engineering / design adjustments can be made that will ensure compliance to the 10 millirem / yr. limit as may be necessary (increase vent / stack heights, use of "high tops" on vents, charcoal beds for radon capture, etc.). Accordingly, the maximum exposure to an actual member of the public from operation of the Sunday mine with ablation mining will be ≤ 10 mrem / year.

5.2.3 Example: Cotter Corporation Uranium Mill, Canon City, Colorado

A fairly recent example of offsite public radiation exposure from a U.S. conventional uranium mill is data from the Cotter Corporation uranium mill near Canon City, Colorado for the year 2005[4] as presented in Cotter 2006b. Approximately 15 specific public area receptors and associated locations were used and doses calculated for adults, teens, children and infants using Argonne National Laboratory's MILDOS - AREA computer code (ANL 1998). The MILDOS-Area code is the most appropriate code to use for calculating doses from uranium mill emissions since it was developed specifically for that purpose. MILDOS-Area has been updated on a regular basis to take into account changes in dose conversion factors and operations. Results of this analysis were presented in Cotter 2006b and is reproduced below in Table 10.

Table 10: **Estimates of Radiation Doses to Members of the Public from Cotter 2005 Mill Operations**

Location	mrem/yr			
	Infant	**Child**	**Teen**	**Adult**
Nearest Resident	5.6	4.6	4.2	4.0
Nearest DW Resident	0.2	0.1	0.1	0.1
NONAC	1.7	1.5	1.5	1.5
Team Track	2.5	2.3	2.2	2.2
Shadow Hills	4.9	4.4	4.1	4.1
Lincoln Park	3.4	3.3	3.2	3.2
Brookside	2.9	2.8	2.7	2.7
Eagle Heights	2.5	2.2	2.0	2.0
Golf Course Club House	19.5	18.3	17.9	17.6
Shadow Hills Lot 8	6.6	6.1	5.9	5.8
Wolf Park – Gere	5.2	4.3	4.0	3.8
Shadow Hills – Lot 7	6.1	5.5	5.4	5.3
Shadow Hills – Lot 6	6.1	5.6	5.4	5.3
Wolf Park – Shiloh	5.4	4.3	3.9	3.7
Eagle Drive	2.6	2.3	2.1	2.1
Dawson Ranch-Blue Grouse	2.1	1.8	1.7	1.6

Estimated radiation doses to members of the public due to 2005 operations [4] and material storage at Cotter Corporation's Cañon City mill are below the criteria set in EPA, NRC and CDPHE regulations. In all cases the incremental doses are within the range of background variability across the US, and in no case did the estimated effective dose or dose to any single organ exceed 25 millirem per year (40 CFR 190). The effective doses from airborne particulate matter were below the 10 CFR 20

[4] See discussion in section 4.2.1 regards to relevance of the data from 2005

constraint level of 10 milllirem per year. The maximum calculated effective dose to any adult member of the public from all sources including radon decay products was much less than the 10 CFR 20 and 6 CCR 1007-1 Part 4 dose limit (100 millirem / year).

5.2.4 US Nuclear Regulatory Commission NUREG 1910 – Public Doses from In Situ Uranium Recovery Facilities

In the US Nuclear Regulatory Commission's *Generic Environmental Impact Statement for In Situ Uranium Recovery Facilities* (USNRC 2009 – NUREG 1910), annual historical dose estimates to offsite individuals were shown for various in situ uranium recovery facilities. This data is presented in Table 9 below, reproduced from Table 4.2.2 of USNRC 2009. All doses reported are well within the 10 CFR Part 20 annual radiation dose limit for the public of 1 mSv [100 millirem /yr] and within the EPA fuel cycle annual limit (40 CFR 190) of 0.25 mSv [25 millirem], which does not include dose due to radon and its progeny. NRC concluded that radiological doses from normal operations are expected to have a *SMALL impact on the general public*.

Table 11: Public Doses from Uranium In Situ Leach facilities (USNRC 2009)

Facility	Offsite Maximum Dose (mSv/mrem)	Description of Receptor	Reference
Crow Butte	0.317/31.7	0.4 km [0.25 mi] northeast of Central Plant site	Crow Butte Resources, Inc.*
Crow Butte	0.058/5.8	Closest resident downwind of North Trend Satellite Plant	Crow Butte Resources, Inc.*
Smith Ranch/ Sunquest Ranch	0.175/17.5	Nearest resident	NRC, 2007†
Smith Ranch/ Vollman Ranch	0.135/13.5	Nearest resident	NRC, 2007†
Reynolds Ranch	0.04/4	Nearest resident at Reynolds Ranch	NRC, 2006‡
Reynolds Ranch	0.27/27	Unoccupied Mason House	NRC, 2006‡
Gas Hills	0.07/7	Hypothetical individual on eastern boundary	NRC, 2004§
Christensen Ranch	0.006/0.6	Adult nearest resident	NRC, 1998‖
Irigaray	0.004/0.4	Adult nearest resident	NRC, 1998‖

*Crow Butte Resources, Inc. "License Renewal Application: SUA–1534." Crawford, Nebraska: Crow Butte Resources, Inc. 2007.
†NRC. "Environmental Assessment Construction and Operation of *In-Situ* Leach SR–2 Amendment No. 12 to Source Materials License No. SUA–1548 Power Resources, Inc. Smith Ranch-Highland Uranium Project (SR_HUP) Converse County, Wyoming." Docket No. 40-8964. Washington, DC: NRC. 2007.
‡NRC. "Environmental Assessment for the Addition of the Reynolds Ranch Mining Area to Power Resources, Inc.'s Smith Ranch/Highlands Uranium Project Converse County, Wyoming." Source Material License No. SUA–1548. Docket No. 40-8964. Washington, DC: NRC. 2006.
§NRC. "Environmental Assessment for the Operation of the Gas Hills Project Satellite *In-Situ* Leach Uranium Recovery Facility." Docket No. 40-8857. Washington, DC: NRC. 2004.
‖NRC. "Environmental Assessment for Renewal of Source Material License No. SUA–1341. Docket No. 40-8502. Washington, DC: NRC. 1998.

6.0

Conclusions and Some Perspectives

6.1 General Conclusions

Based on the data made available and reviewed regarding occupational and public radiation exposure associated with modern uranium mining and milling operations in North America, the following is suggested:

- Occupational exposures to uranium miners and millers are consistently maintained well below the occupational exposure limits established by the associated regulatory agencies in both the US and Canada.
- Even in the highest exposure categories (underground miners, mill ore handlers and "yellowcake" workers) the mean annual occupational exposures are typically no more than 2 -3 mSv / year (200 – 300 millirem /year), which is < 10% of the occupational annual exposure limit of 50 mSv (5000 millirem) per year.
- The average annual exposures of underground uranium miners to radon progeny, typically the highest exposure source in the highest exposure category for either miners or millers, is about 0.6 Working Level Months (WLM) per year.
- This is about the same annual exposure received in homes at a radon concentration of 4 pCi / liter, which has been for many years EPA's recommended "mitigation" limit.
- According to the CDPHE, that level of exposure occurs in 40 - 50% of the homes in Colorado and therefore approximately 1.7 to 2.6 million Coloradans receive the same or higher radiation exposure each year from radon as the average underground uranium miner.
- Exposures to the public from uranium mines and uranium recovery facilities (mills and ISRs) are consistently maintained well below annual regulatory limits (e.g., Total Effective Dose Equivalent of 100 millirem - 10CFR20 and 6 CCR 1007-1 Part 4; Dose Equivalent of 25 millirem w/o radon – 40 CFR 190; 10 millirem from radon from mine vents – 40 CFR 61, Part B)
- Annual exposures to the public from uranium mines and mills are small fractions of natural background and in fact can be small fractions of the variability of natural background exposure across the US depending on where in the US one chooses to live. Based on the data reviewed as summarized within this report, annual exposures to the maximally exposed members of the public are consistently below regulatory compliance limits [5]

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[5] e.g., 10 millirem / yr (radon from mine vents – USEPA 40 CFR 61, Subpart B; 25 mrem / yr DE (w/o radon) – USEPA 40 CFR 190; 100 mrem year TEDE – USNRC 10 CFR 20.1101 and CDPHE 6 CCR 1007-1 Part 4, para. 4.14.1

6.2 Some Perspectives on Uranium Mill Job Categories that Typically Receive the Highest Annual Doses - Implication for Projected Doses from Use of Ablation Mining**.**

Several former conventional uranium mill health physicists were contacted to obtain input based on their experiences regarding what areas of milling operations / job categories typically receive the highest annual doses. All four individuals indicated that “yellowcake workers” and “ore handlers” would be their candidates. In the case of workers at the back end of the milling process who handle and package uranium concentrates, both external exposure (gamma) associated with large quantities of uranium concentrate (“yellowcake”) and the potential for exposure to long live radioactive dusts from yellowcake handling would be the dominant exposure pathways. Similarly, for ore handlers, external exposure to large quantities of ore during handling and feeding the mill as well as potential for inhalation of ore dusts would be the dominant exposure pathways. It is recognized that the ore grades involved would be a major variable in the potential exposures of ore handlers (higher grade, more uranium and gamma emitting progeny resulting in greater annual exposures). However, the individuals contacted estimated that based on their experience over many years, typical exposures for this labor category would be several mSv / year (200 - 400 hundred millirem / year). For example, note that in the data set provided by Health Canada (see Table 5) the labor category “ U Mill Workers” would include this subcategory of “ore handlers”. This category has the second highest annual average exposures following the “underground U miners” category and is typically a few mSv (a few hundred millirem) per year.

With the use of ablation techniques during uranium mining, the feed to the mill does not require extensive handling of large quantities of dry rock (ore). The ablation “product” will be much smaller volume in a paste form (20-30% water by mass), essentially eliminating the need for extensive ore handling by workers at the front end of the mill. Accordingly, the use of ablation would be expected to “save” most of the several hundred millirem / year exposure to each ore handler. Under the assumption that a large (1000 -1500 tons / day ore feed) mill would employee 5 – 10 full time ore handlers, the use of ablation mining could save 15 - 20 mSv + (several thousand millirem) collective dose per year at the mill.

6.3 Radiological Characteristics of the Ablation Mining Product (“Ablation Paste”)

As discussed in Attachments 2.1 through 2.4, the impact caused by the slurry stream disassociates most of the mineralized portions of the matrix material (outer layers, i.e., the “patina”) from the grains of a sandstone host rock. This results in a major portion of the mineralized material contained in a small volume which is the purpose of the AMT. It is reasonable to assume that the radiological character of the ablated product contains the majority of the uranium along with the associated uranium series progeny in which natural radionuclide equilibrium has been maintained. In other words, all that the ablation process will do is decrease the mass of the radiologically barren portions of the host rock and hence increase the “uranium grade” of the ore, including the radioactivity associated with all of natural uranium's progeny at the expected equilibrium concentrations. Accordingly, the external exposure rate assessment that was performed (See SHB 2016) included consideration of all photons expected to be associated with uranium progeny at equilibrium with the assumed grade of the uranium ore that occurs at each stage of the process.

In addition to maximizing the calculated radiological exposure rates associated with the process, there is a regulatory consideration that is noted. The uranium ("source material") is not separated from its progeny by the ablation process. It therefore appears from a scientific perspective, that 11.e. (2) byproduct material (e.g., "tailings" as defined in Section 11.e (2) of the US Atomic Energy Act) is not produced [6]. Accordingly, use of ablation technology does not appear to be " uranium milling". With the use of water and a high velocity impact, the ore grade is enhanced by a physical separation process. The activity ratios of uranium to its progeny (degree of equilibrium) is not altered by the process, and the full equilibrium condition remains as it occurs in nature in both the ablated slurry product and the low level, resultant concentrations of uranium and progeny in the "waste rock" that is returned to the mine.

6.4 Comparison of Projected Occupational and Pubic Exposures from Use of the Ablation Technology in an Underground Uranium Mine

In accordance with the historical data from numerous literature sources that were reviewed and the results of the worker dose assessment that was performed (SHB 2016), the following general conclusions are presented for consideration:

(1) Projected worker doses associated with the application of the ablation mining technology in the Sunday mine are expected to be comparable (or lower) than historical doses reported in recent years for conventional miners and millers (See SHB 2016)
(2) The Ablation slurry product will "save" 15 – 20+ mSv (several thousand millirem) collective dose to workers per year at a conventional mill. This is as a direct result of the significant reduction in material handling requirements, i.e., the several thousands of tons per day of uranium ore (rock) that needs to be crushed and sorted by ore handlers to feed the mill vs. the relatively small volume of "ablation paste" that can be fed to the mill via automated processes.

[6] Section 11.e of the US Atomic Energy Act provides several definitions of the term "byproduct material'; definition (2) states "the tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content". Since the uranium progeny remain with the uranium in the ablation process, the "science" suggests that the waste rock left behind contains very little residual radioactive material (in fact, much less than the original natural ore) and therefore is not, nor does it need to be from a radiation safety perspective, "licensed byproduct material".

(3) Public doses are limited by 40 CFR 61, Subpart B to ≤ 10 mrem / year from radon releases from mine vents. Annual compliance reports submitted to the US EPA by the former operator of the Sunday mine (2009 – 2011) reported exposures in each of these years ≤ the 10 mrem limit based on empirical measurements of radon releases from multiple vents. For reasons explained herein, radon source terms associated with operation of the ablation mining technology are expected to no greater than or less than during previous recent operation of the Sunday mine.

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