ATTACHMENT 1.1

Ablation Process Worker Exposure and Dose Assessment

Prepared for Black Range Minerals, Nucla, Co.
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Contents

Figures

Tables

Ablation Process Worker Exposure and Dose Assessment

1.0 Introduction

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 quantitative estimation of the anticipated occupational doses, including internal and external, to the workers at every step of the AMT operation from ore crushing to preparation of shipping of the post-AMT products. This should also include an estimation of the anticipated gamma exposure rates at every step of the AMT operation.

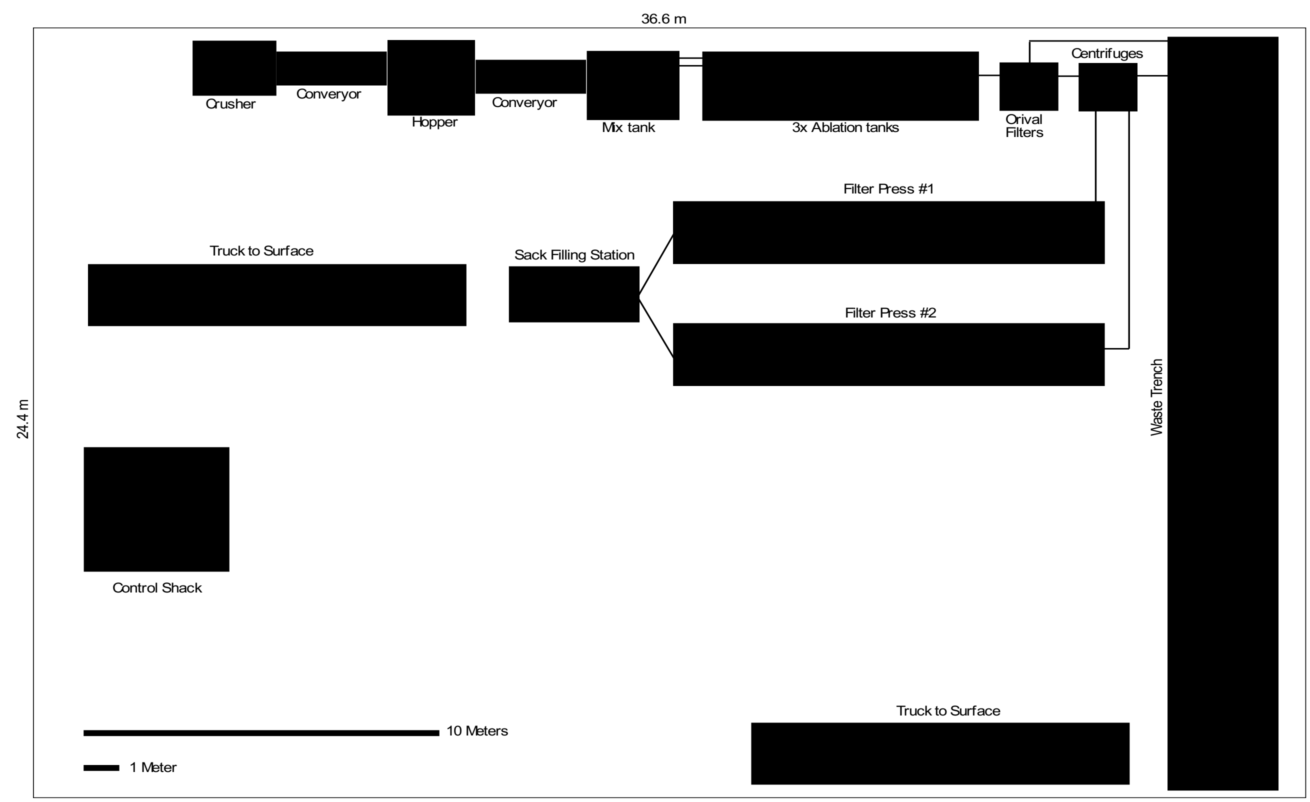
Accordingly, this report presents an estimate of annual worker radiation doses directly resultant from use of the ablation technology in the Sunday mine. Accordingly, it focused on external exposure (from photons emitted from the various process components) and internal exposure (radon / radon progeny) released into the room within which the ablation process will be conducted. Since ablation is an aqueous process, there is little expectation of the evolution of ore dusts associated with the use of the ablation technology once the ore is delivered into it. Dry ore will be initially crushed in an enclosed cone crusher unit and conveyed to the ablation process. This conveyor system will employ local exhausts to minimize the potential for dust generation into the ablation area. See section 4.0 for discussion of the airborne particulate monitoring that will be conducted in this area as well as other elements of the planned occupational radiological monitoring program.

Uranium ore will be initially extracted from stopes and tunnels of the Sunday mine using traditional methods of excavation and blasting. The ore will be delivered to the ablation process, which will be conducted in a large cavern (”ablation room”). Accordingly, this assessment focuses exclusively on potential worker exposure within the ablation room as a direct result of the application of the ablation process. This room is an existing cavern within the Sunday mine and is approximately 36 by 24 by 18 meters high. A plan view of the ablation room and the various process steps and components are depicted in Figure 1. Detail on operation of each stage / step of the ablation system process is provided in Attachments 2.1 through 2.4.

2.0 External Exposure Assessment

An assessment to estimate exposure rates from a total of 14 individual process components (“ sources”) at 24 individual receptor locations within the ablation room was performed with Microshield software (Grove Software, 2014), which was used as the primary modeling code for this effort. In addition, the Monte Carlo N-Particle 5 (MCNP5) v. 1.60 code and data libraries (LANL, 2011) were used to validate the Microshield results and help quantify the conservative protocols inherent to Microshield that typically tend to overestimate exposure rates. A summary of the results of this analysis are presented here. Environmental Restoration Group Incorporated (ERG) of Albuquerque performed the actual modeling based on the input and assumptions provided by SHB Inc. for Black Range Minerals. ERG’s complete report is provided as Attachment 1.

Figure 1: Plan View of Ablation Room Showing Positioning of Major Components



Each source was modeled separately and the exposure rates summed at each receptor location. These results were then combined with worker time – motion estimates to define expected exposure durations for receptor locations of interest to produce the estimates of annual external exposures of the workers. Exposure rates in air in milliRoengens (mR) were then converted to absorbed dose rates in tissue in millirems (mrem) to estimate projected annual doses to workers. This method did not take into account shielding from components or equipment, other than self-shielding from within the component being modeled. This is one of several factors that resulted in conservatisms (“ overestimates”) as summarized and applied here and explained in detail in Attachment 1.

Fourteen components were modeled and each considered a separate “radiation source” with radioactive material contained in its interior or as the component itself (e.g., the waste trench and conveyors). These are generally depicted on Figure 1 and listed individually in Table 1. Important characteristics of these sources included the mass, density, volume, percent solids, and average grade of uranium. Each component was modeled as a cylinder of varying radius and length based on its dimensions as either uncovered ore or a steel cylinder with ore / slurry mixture of various % solids in its interior.

Table 1: Components Modeled

Component	Length (cm)	Radius (cm)	Average U grade of solids (% U)	U-238+D (Bq/cc)*	Solids % in Water
Cone Crusher	235	116.5	0.25	0.13	Dry ore
Conveyor # 1	304	N/A	0.25	60.00	Dry ore
ROM Hopper	244	137.7	0.25	43.37	Dry ore
Conveyor # 2	304	N/A	0.25	60.00	Dry ore
Mix Tank	259	123.0	0.25	0.83	20%
Ablation Units (3)	777	123.0	0.25	0.83	20%
Orival Filters (3)	165	52.1	0.75	1.54	10%
Centrifuge (3)	165	52.1	1	1.03	5%
Filter Press	1219	97.9	1	7.42	75%
Filter Press #2	1219	97.9	1	7.42	75%
Super Sack Filling Station	366	163.2	1	17.78	75%
AMT Slurry Truck #1 to Surface	1066	123.8	1	21.23	75%
Storage Pad for Waste Rock	305	343.5	0.01	1.70	85%
Waste Truck #2 to Underground Emplacement	1066	123.8	0.01	0.21	85%

* Activity per unit volume of component – see discussion below; activity densities of U 235 + D also calculated and used by Microshield but since U 235 activity is only about 2.2 % of that of natural uranium, contribution is small % of that from U 238 + D and not shown here (but see Table 2 of Attachment 1)

To facilitate the modeling effort, the interior of each component was assumed to be filled with slurry or ore; i.e. the material was distributed evenly in its volume, even if based on its mass it would occupy only a portion of the volume. That is, the effective density was reduced while keeping the mass unchanged. The effective density of the material was calculated as the material mass divided by the full volume of the interior of the component. This is another conservative assumption, which results in an average lower effective density and therefore less attenuation of the gamma radiation between the source and receptor. Based on the MCNP5 validation performed (See Attachment 1, Section 3.1) this simplification overestimated exposure rates at receptor locations by as much as 40% or more.

Results in units of exposure rate in air {milliRoentgen per hour (mR/hr)} were plotted and kriged to produce Figure 2, a map depicting the exposure rates (at fixed, grid based receptor locations and interpolated) that are predicted for the ablation technology room. Table 2 lists the exposure rates predicted for each of the 24 receptor locations attributable to each source and presents total exposure rates at each receptor location.

Table 2: Microshield Results

Component	Receptor Location Exposure Rate (mR/hr)											
	1	2	3	4	5	6	7	8	9	10	11	12
Cone Crusher	1.88E-05	1.79E-05	1.12E-05	6.75E-06	4.78E-06	4.06E-06	3.75E-05	3.54E-05	1.64E-05	9.92E-06	7.70E-06	6.44E-06
Conveyor 1	5.27E-05	5.48E-05	5.17E-05	4.06E-05	2.87E-05	2.15E-05	1.06E-04	1.18E-04	9.99E-05	6.32E-05	3.75E-05	2.55E-05
ROM Hopper	3.46E-03	3.65E-03	3.62E-03	3.31E-03	2.55E-03	1.99E-03	6.57E-03	7.85E-03	7.75E-03	5.96E-03	3.78E-03	2.61E-03
Conveyer 2	4.47E-05	5.42E-05	5.63E-05	5.26E-05	4.06E-05	3.09E-05	7.34E-05	1.11E-04	1.22E-04	1.01E-04	6.24E-05	4.13E-05
Mix Tank	2.21E-04	2.98E-04	3.67E-04	3.42E-04	2.71E-04	2.13E-04	3.36E-04	5.46E-04	7.80E-04	6.96E-04	4.63E-04	3.16E-04
Ablation Tanks	5.64E-04	8.34E-04	1.15E-03	1.37E-03	1.31E-03	1.11E-03	6.88E-04	1.22E-03	2.09E-03	2.90E-03	2.66E-03	1.94E-03
Orival Filters	3.47E-05	4.95E-05	7.03E-05	9.36E-05	1.10E-04	1.05E-04	4.16E-05	6.53E-05	1.08E-04	1.76E-04	2.34E-04	2.20E-04
Centrifuges	2.03E-05	2.89E-05	4.14E-05	5.70E-05	6.98E-05	7.37E-05	2.38E-05	3.65E-05	5.95E-05	9.91E-05	1.46E-04	1.58E-04
Filter Press 1	6.45E-03	1.06E-02	1.66E-02	2.23E-02	2.25E-02	1.86E-02	6.89E-03	1.44E-02	3.21E-02	5.72E-02	5.83E-02	3.97E-02
Filter Press 2	6.98E-03	1.32E-02	2.52E-02	3.95E-02	3.98E-02	2.94E-02	5.81E-03	1.43E-02	5.03E-02	1.49E-01	1.53E-01	7.54E-02

Sack Filling Station	1.87E-02	3.03E-02	3.96E-02	3.16E-02	1.96E-02	1.31E-02	2.85E-02	7.10E-02	1.48E-01	7.81E-02	3.09E-02	1.72E-02
Truck # 1	6.06E-02	6.52E-02	4.30E-02	2.25E-02	1.15E-02	7.03E-03	1.73E-01	2.02E-01	8.09E-02	2.51E-02	1.02E-02	5.91E-03
Truck # 2	8.91E-05	1.95E-04	6.88E-04	1.17E-02	1.55E-02	3.88E-03	8.61E-05	1.88E-04	5.12E-04	1.40E-03	1.82E-03	1.12E-03
Waste Trench	4.14E-04	6.15E-04	9.85E-04	1.80E-03	4.46E-03	2.02E-02	4.53E-04	6.94E-04	1.16E-03	2.24E-03	5.58E-03	2.09E-02
Total Exposure Rate	9.76E-02	1.25E-01	1.31E-01	1.35E-01	1.18E-01	9.58E-02	2.22E-01	3.13E-01	3.24E-01	3.23E-01	2.67E-01	1.65E-01

Notes: mR/hr = milliRoentgens per hour

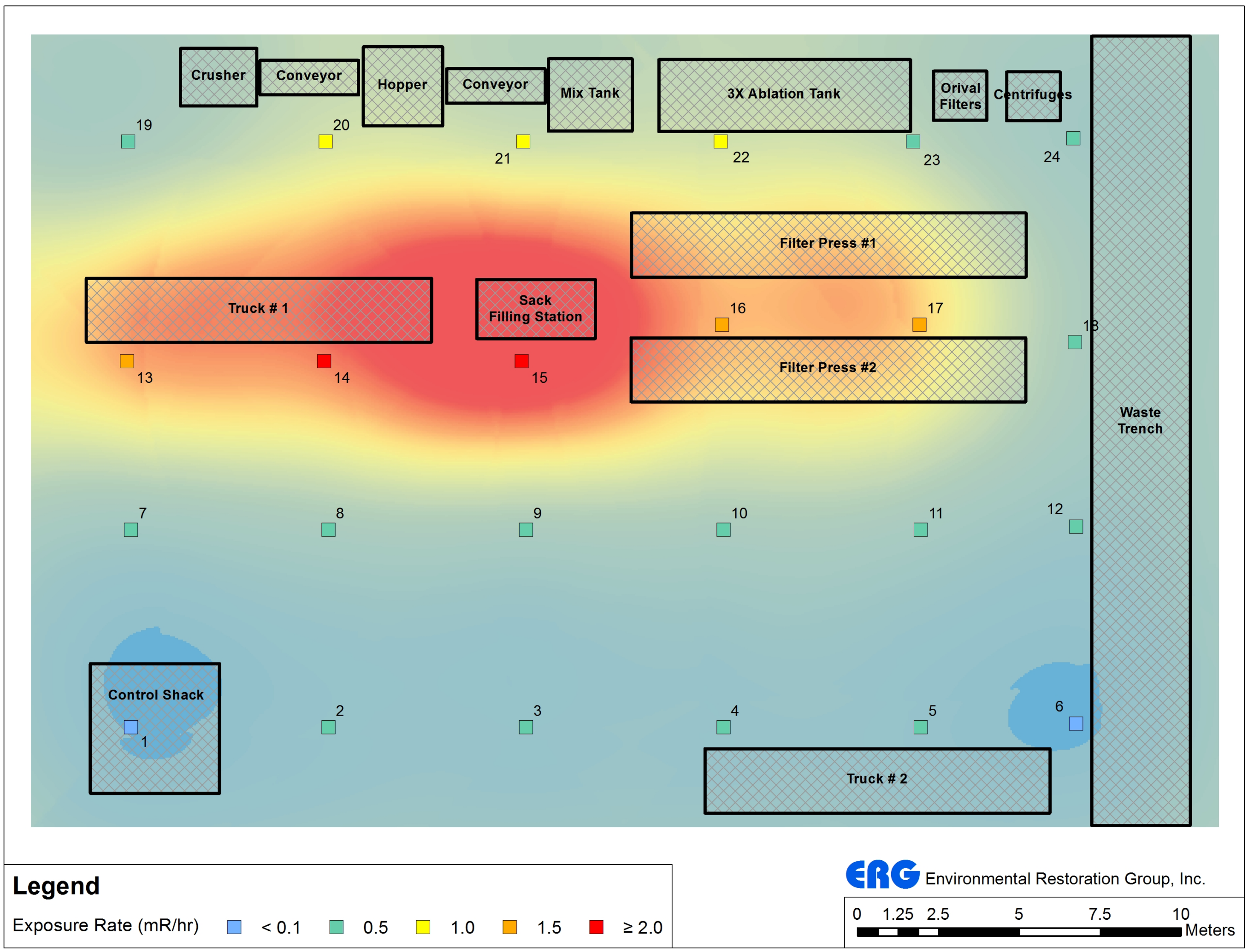
Table 2: Microshield Results (Concluded)

Component	**Receptor Location Exposure Rate (mR/hr)**											
	13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Cone Crusher	8.24E-05	7.55E-05	2.62E-05	2.21E-05	1.44E-05	1.02E-05	4.50E-04	4.44E-04	1.09E-04	4.19E-05	2.19E-05	1.43E-05
Conveyor 1	2.25E-04	3.13E-04	2.01E-04	9.30E-05	4.36E-05	2.70E-05	5.65E-04	6.06E-03	3.92E-04	8.99E-05	3.78E-05	2.22E-05
ROM Hopper	1.20E-02	2.06E-02	1.96E-02	1.13E-02	4.79E-03	3.08E-03	2.25E-02	2.11E-01	1.12E-01	1.65E-02	6.02E-03	3.37E-03
Conveyer 2	1.07E-04	2.44E-04	3.31E-04	2.28E-04	8.95E-05	4.84E-05	1.15E-04	6.60E-04	7.03E-03	3.50E-04	8.54E-05	4.10E-05
Mix Tank	4.67E-04	9.77E-04	1.99E-03	2.04E-03	8.44E-04	4.52E-04	7.06E-04	2.19E-03	2.13E-02	8.56E-03	1.46E-03	6.46E-04
Ablation Tanks	6.93E-04	1.51E-03	3.71E-03	9.59E-03	7.75E-03	3.44E-03	6.27E-04	1.45E-03	6.09E-03	1.12E-01	5.22E-02	4.69E-03
Orival Filters	4.62E-05	7.74E-05	1.48E-04	3.84E-04	8.29E-04	5.94E-04	5.26E-05	9.20E-05	4.95E-04	6.44E-04	1.04E-02	2.74E-03
Centrifuges	2.61E-05	4.19E-05	7.62E-05	1.80E-04	4.51E-04	4.79E-04	2.95E-05	4.90E-05	9.53E-05	2.53E-04	1.64E-03	8.84E-03
Filter Press 1	5.34E-03	1.30E-02	5.36E-02	3.79E-01	3.90E-01	1.04E-01	5.32E-03	1.27E-02	5.53E-02	2.67E-01	2.80E-01	1.02E-01
Filter Press 2	6.01E-03	1.43E-02	7.13E-02	7.21E-01	7.32E-01	1.77E-01	6.55E-03	1.48E-02	3.83E-02	8.00E-02	8.33E-02	4.98E-02
Sack Filling Station	3.70E-02	1.48E-01	1.01E+00	2.15E-01	4.33E-02	2.07E-02	3.07E-02	8.88E-02	2.61E-01	1.04E-01	3.53E-02	1.81E-02
Truck # 1	1.39E+00	1.51E+00	1.63E-01	2.92E-02	1.10E-02	6.39E-03	2.50E-01	3.07E-01	9.51E-02	2.47E-02	9.99E-03	5.83E-03

Truck # 2	9.59E-05	1.83E-04	3.57E-04	5.37E-04	6.13E-04	5.28E-04	9.08E-05	1.43E-04	2.15E-04	2.89E-04	3.11E-04	2.74E-04
Waste Trench	4.53E-04	6.92E-04	1.16E-03	2.22E-03	5.52E-03	2.04E-02	4.14E-04	6.14E-04	9.85E-04	1.80E-03	4.32E-03	1.94E-02
Total Exposure Rate	1.46E+00	1.71E+00	1.33E+00	1.37E+00	1.20E+00	3.38E-01	3.18E-01	6.46E-01	5.98E-01	6.16E-01	4.85E-01	2.16E-01

Notes: mR/hr = milliRoentgens per hour

Figure 2: Mapped Exposure Rates (mR/hr)



2.1 Estimate of Annual External Dose to Workers – Use of Time / Motion Estimates

Several locations were selected within the ablation room as representative locations at which workers would be expected to spend the majority of their time during a typical work period. We have assumed that 3 workers are required to spend 2000 x 3 = 6000 hours per year on the mine property with a significant portion of their time (about 60% - see below) within the ablation room. Table 3 presents these estimates as % of time at each of these locations along with the approximate exposure rates in air at these locations as estimated by Microshield (From Figure 2 and Table 2). Accordingly, this allows us to estimate an "average" annual exposure rate in air associated with the 3 workers. Also note that in some cases, "average" exposure rates were used to represent a general area of the room that encompasses several specific grid locations.

Table 3: Exposure Time Estimates at Primary Locations of Interest

Location Description	Location #s from Figure 2 and Table 2	% Time [(1)]	Average Exposure Rate {milliRoentgens (mR) per hr}	milliRoentgens (mR) per Location per 6000 hour yr.
Back wall including crusher thru centrifuge operations	19 - 24	3.5	0.48	100
Filter presses	16 -17	3.5	1.3	270
Sack filling and truck # 1 loading	13 - 15	3	0.7 [(2)]	120
Waste rock handling areas and truck # 2	5,6,12	17%	0.13	130
Control shack	1	33	0.1	200
Other: external to ablation room; e.g., transport to or on surface, office and personal convenience areas in administration building, etc.	N/A	40	"Background" locations and/or unrelated to ablation system	"0" from ablation operations

[(1)] The basis and assumptions used for the worker time – motion estimates can be provided upon request
[(2)] Since exposure rates calculated by Microshield assume both truck # 2 and sack filling station are both filled to capacity 100% of the time which is not reasonable, the average exposure rate of locations 13 -15 have been reduced by approximately 50%

Accordingly, the total annual exposure in air ("collective exposure") for 6000 hours is estimated to be 820 mR and the average exposure per worker in air on a 2000 hrs. / yr. basis = 273 mR.

2.2 Translating Exposure Rates in Air to Absorbed Dose in Tissue

Two adjustments are made to the previous result:

(1) Removal of conservatisms based on the MCNP5 validation process with a reduction of exposure rate in air by (an average of) 30% to account for shielding and density simplifications discussed above and

(2) Conversion of exposure rates in air in milliRoentgens (mR) / yr. to absorbed dose in tissue (muscle) in millirem (mrem) / yr. by multiplying by 0.87 representing absorbed dose in air / exposure rate in air and then multiplying by 1.05 representing the approximate ratio of mass energy absorption coefficient for tissue divided by the mass energy absorption coefficient for air*.

*Although mass energy absorption coefficients are a function of photon energy, this approximation is reasonable within the energy range of interest. See Cember and Johnson 2009

These adjustments result in an estimated annual absorbed dose to the workers from external exposure = 273 mR/ yr X (0.7) (0.87 mrem/mR in air)(1.05 mrem tissue / mrem air) = 174 mrem per worker.

3.0 Considerations of Potential for Radon and Progeny Exposure of Workers

As previously indicated, ablation is primarily an aqueous process. Similarities with radon emission from uranium mill tailings are considered relevant here since within the various stages of ablated material, all progeny are present in a sandy, moist (or water slurry) matrix. The emission of radon from uranium tailings has been studied and modeled for many years (Chambers 2009, EPA 1986, Nielson and Rogers 1986, Rogers et al 1984, Schiager 1974). Because of the very low diffusion of radon through water (as compared to partially air-filled unsaturated tailings pores), the diffusion of radon through water-covered tailings has been argued to be effectively zero (e.g. Chambers 2009). The EPA has previously assumed zero radon emissions from ponded areas of uranium tailings impoundments (e.g. EPA 1986). This is based on the assumption that the source of radon (radon-222) is primarily the radon from the radium-226 (Ra-226) in the tailings and not from Ra-226 in the water.

The transport of radon produced inside the solid particles of ore is also influenced by the diffusion of radon within the solid particles. After being generated, the radon atoms tend to move away from their original location toward the pore spaces in the ore. Consequently, depending on their original location within the solid phase, the pore distribution, and the moisture content of the ore, the newly created radon atoms may end up within the same solid particle in which they were created, or within the pore spaces of the medium. Drago 1998 presents nominal diffusion coefficients for radon in water and in air as 1.2×10^{-5} cm2/sec and 0.12 cm2/sec respectively.

Since the diffusion coefficient of radon in air is approximately 10,000 times larger than its diffusion coefficient in water, the migration of radon in saturated solids such as the ablation slurries is much different than its migration in unsaturated solids (e.g., from dry ore). The fraction of the total amount of radon produced by radium decay that escapes from the solids particles and gets into the pores of the medium is referred to as the radon emanation coefficient or emanation fraction. The radon emanation coefficient is strongly influenced by the moisture content of the medium, particularly with modest water saturation (up to 10 - 25 % water content). Accordingly, very little radon would be expected to be evolved anywhere within the ablation process (mix tank through super sack loading of the ablated product with 15 % moisture) with the exception of the ablation units themselves. These are a special case as discussed below.

The water spray in the ablation units would be expected to evolve most of the radon that is within the pore spaces of the matrix and that which becomes dissolved in the water from mixing with the ore. Rost (1981) demonstrated the ability of spray aeration to remove radon from well water at private homes in Maine. A one-stage aeration system achieved 75.7% radon removal efficiency. It was assumed that the rate of removal of radon from tailings pond sprinkler systems is similar to the removal rate of radon from spray aeration system described in Rost 1981 (See Chambers 2009). Accordingly it is assumed that 100% of the radon contained in the pore spaces of the mineral grains at that time and the radon dissolved in the water within the ablation units is released during the ablation spraying process. However, these units will be contained and enclosed and locally vented if necessary such that radon escape from the units into the operating areas of the room is expected to be small.

It is also recognized that some radon evolution into the ablation room will occur at the front end of the process from the dry ore prior to contact with water in the mixing tank. However, this ore is relatively of very low grade (average of 0.25 % as compared to circumstances in Canadian underground mines with ore grades typically > 4-5 % average and as high as 20%; – see the companion report, Section 3 of SHB 2016.

Given the relatively low grade of uranium ore and the aqueous nature of the ablation process, evolution of radon into the room (and therefore the potential for ingrowth of progeny) is expected to be less than that which would be expected in traditional underground uranium mining environments, particularly considering the much higher grade ores in the Canadian mines for which associated exposure data is presented in SHB 2016. Nonetheless, general area ventilation systems (as supplemented by local exhaust systems on vessels as necessary) will maintain exposures of workers to radon progeny well below regulatory limits and ALARA. It is expected that annual exposures will be no greater than (or most likely less than) typical average exposures in conventional underground uranium mines of about 0.6 Working Level Months (WLM) per year (See *Section 2 of SHB 2016*)**. Routine monitoring (air sampling) for concentrations of radon progeny will be conducted to ensure ventilation and related controls are adequate to achieve these ALARA objectives (See Section 4.0 below)

** 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 underground 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.

4.0 Worker Exposures and Related Radiological Monitoring

The exposure potential in operating areas and worker doses will be routinely monitored and documented in accordance with standards of practice in the uranium mining industry (ANSI 1973, USDOE 2009, USNRC 1992, IAEA 2004). Worker exposure limits and related criteria that will be enforced will be in accordance with Mine Safety and Health Administration (MSHA) requirements. (e.g. external exposure limits @ 30 CFR 57.5047; radon progeny exposure limits @ 30 CFR 57.5038). The occupational exposure monitoring program will include, at a minimum the following elements:

1. All workers will be assigned OSL / TLD (Optically Stimulated or Thermo-luminescent) personnel dosimeters to monitor and document external exposure to be exchanged initially on a monthly frequency.

2. Routine air sampling for long lived radioactive particulates (dusts), particularly in the dry ore handling area, using combinations of grab, fixed station and/or breathing zone sampling at locations and frequencies to be determined based on initial results.

3. Routine air sampling for radon progeny using Kusnetz, modified Kusnetz or similar industry wide methods (CNSC 2003). Results in Working Level (WL) concentrations will be combined with time - weighted motion studies to assign WL months (WLM) of exposure per year. A conversion of 5mSv (500 mrem) per WLM will be used to assign dose equivalents (ICRP 1993).

4. Routine gamma exposure rate surveys at locations and on a regular frequency based on initial results and anytime process and / or operational details change that could affect exposure rates in working areas.

5.0 Conclusions

Recognizing the traditional uncertainties associated with modeling efforts of this kind and in consideration of the assumptions as stated herein, it is concluded that the projected annual doses to the ablation miners will be quite similar or less than that reported in the literature for conventional uranium miners in recent years. See, e.g., Section 3 and Table 5 of the companion report SHB 2016. Additionally, the occupational exposure radiological monitoring program, as summarized briefly herein, will employ monitoring techniques and associated control procedures consistent with those employed throughout the uranium recovery industry to ensure exposures of workers will be maintained in compliance with regulatory limits (e.g., MSHA) and ALARA.

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