

APPENDIX A

RADON EMISSIONS FROM THE CROW BUTTE PROJECT

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**Calculation of Annual Radon Emissions
Crow Butte Project
5,000 gpm Upflow with 1,000 gpm Restoration**

- 1) To calculate Radon release from leaching assuming that U-238 is in equilibrium with all its decay products:

$$\text{Ci/M}^3 = 761 \text{ pCi/g ore} \times 1.89 \text{ g/cm}^3 \times 0.2 \times 0.71/0.29 \times 10^{-6} = 7.04 \times 10^{-4} \text{ Ci/m}^3$$

Where:

0.2	=	Emanating Power
0.71	=	1 - Porosity
0.29	=	Porosity

The yearly release is then:

$$7.04 \times 10^{-4} \text{ Ci/m}^3 \times 18925 \text{ lpm} \times (0.72) \times 365 \text{ d/yr} \times 1.44 = 5042 \text{ Ci/yr}$$

Where:

18925	=	liters per minute
0.72	=	$1 - e^{-(\lambda t)}$
	=	$1 - e^{-(0.1812)(7d)}$
	=	$1 - e^{-(1.27)} = 1 - 0.28$
1.44	=	constant

- 2) The Radon release from start-up is given by:

$$7.04 \times 10^{-4} \text{ Ci/m}^3 \times 34 \text{ acres} \times 4074 \text{ m}^2/\text{acre} \times 1.52 \text{ m} \times 0.29 = 43 \text{ Ci/yr}$$

Where:

4074	=	m ² /acre
1.52	=	Thickness of orebody in meters
0.29	=	Porosity

The total release of Radon from the start-up solution and production lixiviant solution is:

Start-up solution	43 Ci/yr
Production	5042 Ci/yr
	5085 Ci/yr

- 3) The Radon release from restoration is given by:

$$7.04 \times 10^{-4} \text{ Ci/m}^3 \times 3785 \text{ lpm} \times 365 \text{ d/yr} \times (0.99) \times 1.44 \\ = 1387 \text{ Ci/yr} + 43 \text{ (start-up)} = 1430 \text{ Ci/yr}$$

Where: 3785 = Restoration flow in liters per minute
 0.99 = $1 - e^{-(kt)}$
 = $1 - e^{-(0.181)(35)}$
 = 0.99
 1.44 = constant

The total release from this 34 acre in situ mining operation is then:

Production	-5042
Start-up	- 43
Restoration (Includes Start-up)	<u>-1430</u>
	6515 Ci/yr

4) Actual Radon Release to the Environment

With 5,000 gpm being processed by upflow ion exchange columns it is expected that all of the Radon will be released to the environment and that 25% of the Radon (1260 Ci) will be released in the wellfield and 75% (3782 Ci) will be released in the plant vent.

During restoration 1,000 gpm of recovered water will be processed by pressurized downflow ion exchange (IX) columns. After IX treatment, 400 gpm will be treated by reverse osmosis (RO). Only a small fraction of the contained Radon will be released during ion exchange and virtually all of the contained Radon will be released during RO treatment. The actual release of the source term of 1,430 Ci of Radon/yr (including start-up) will be as follows:

- 25% of the 1,430 Ci will be released in the wellfield which is 358 Ci/yr
- 10% of the Radon in the 600 gpm to be treated by pressurized IX (NOTE: All of the Radon in the 400 gpm treated by IX-RO will be released).

The calculation for the Radon release from the 600 gpm treated by pressurized IX follows:

$$1430 \text{ Ci/yr} - 358 \text{ Ci/yr (Wellfield loss)} \times \frac{600 \text{ gpm}}{1000 \text{ gpm}} \times 0.10 \text{ (fraction of Radon released)} = 64 \text{ Ci/yr}$$

The calculation for the release of 100% of the Radon in the 400 gpm to be treated by RO follows:

$$1430 \text{ Ci/yr} - 358 \text{ Ci/yr (Wellfield loss)} \times \frac{400 \text{ gpm}}{1000 \text{ gpm}} = 429 \text{ Ci/yr}$$

A summary of the actual Radon releases to the environment follow:

	Ci/yr Released
• 5,000 gpm upflow	
Plant Vent	3782
Wellfield	1260
• Start-up	43
• 1,000 gpm	
Restoration	<u>852</u>

TOTAL RADON RELEASE TO THE ENVIRONMENT 5937 Ci/yr