Prediction of the Net Radon Emission From a Model Open Pit Uranium Mine

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ABSTRACT

Radon emission from a model open pit uranium mining operation has been estimated by applying radon exhalation fluxes measured in an open pit uranium mine to the various areas of the model mine. The model mine was defined by averaging uranium concentrations and production and procedural statistics for eight major open pit uranium mines in the Casper, Wyoming area. The resulting emission rates were 740 Ci/AFR during mining operations and 33 Ci/AFR/yr after abandonment of the mine.

INTRODUCTION

In an effort to assess the parameters contributing to radon release in open pit uranium mining operations and to select a representative mine for measurements of radon emission, eight mines in the Casper, Wyoming area were visited in June, 1978. The mines exhibited considerable similarity in that they were all working with relatively dry, sandy roll-front deposits of uranium ore. In discussions with mine managers, characteristic data on production, average ore grade, depth of ore, and other parameters were obtained. A model open pit uranium mine was then defined by the average of the various parameters, and was used with measured radon exhalation fluxes to estimate radon emissions.

A list of mines visited is given in Table I, followed by a list of the means and standard deviations of various mine parameters in Table II. Means given with asymmetric standard deviations resulted from log-averaging of the data in cases where a log-normal distribution better characterized the data from the eight mines. The total U_3O_8 production represented by the eight mines is

approximately 5200 tons/yr, which is about 68% of the total U. S. U_3O_8 production from open pit mines in 1977.¹ Field studies are currently in progress to verify or revise the estimates and assumptions made here.

TABLE I

Open Pit Uranium Mines Used for Averaging for the Model Mine

1 - Federal American Partners	Riverton, Wyoming
2 - Western Nuclear	Jeffrey City, Wyoming
3 - Big Eagle Mine	Jeffrey City, Wyoming
4 - Exxon Highlands Operation	Casper, Wyoming
5 - Morton Ranch Operation	Casper, Wyoming
6 - Bear Creek Uranium Mine	Casper, Wyoming
7 - Pathfinder Shirley Basin Mine	Shirley Basin, Wyoming
8 - Getty Petrotonics Mine	Shirley Basin, Wyoming

TABLE II

Model Mine Parameters Averaged from Eight Open Pit Uranium Mines

Current mine age (June 1978)	0.84	+3.57 -0.68	years
Expected mine life	17.0	+3.8	years
Ore production	1722.0	+611.0	ton/day
Average ore grade	0.114	+0.044	% U_3O_8
Average Hi-grade	0.23	+ .27 - .12	% U_3O_8
Average Lo-grade	0.031	+0.013	% U_3O_8
Depth of overburden	64.6	+26.5	m
Thickness of ore zone	12.2	+25.6 -8.3	m
Ore stockpile residence time	41.0	+78 -27	days
Mining work days/week	5.5	+0.93	days/wk
Overburden/ore ratio ^a	77.0	+36.0	
Number of pits ^a	7.1	+1.1	pits

^a) Data available from only four of the mines

The model open pit uranium mine is defined by the parameters listed in Table II and by various other assumptions required for the radon emission calculations. These assumptions are listed in Table III and vary widely in their impact on the final result.

The model mine consists of a series of pits in various stages of excavation, mining, and reclamation. As illustrated in Figure 1, the overburden from one pit is used to fill a previous pit, leaving an initial overburden pile and a final open pit if no final reclamation is done. One pit is always being actively mined, and the previous and following pits are being filled and excavated concurrently. Ground swell from handling overburden is neglected.

The model mine contains three materials: overburden, initially containing 4 parts-per-million (ppm) U_3O_8 ; ore, containing uranium at the average mill-feed grade; and subore, containing uranium at half the average cutoff ore grade. Subore is also called protore, protore resource, mineral, low-grade, or waste, and varies in grade and disposition at the various mines. Although undisturbed overburden is assumed to average 4 ppm U_3O_8 , its relocation and mixing with low-grade ores increase the effective uranium concentration in at least the top few feet to 20 ppm U_3O_8 . This increased concentration exceeds the ~2X background level sought in many reclamation efforts, but conforms to our initial measurements of exhalation from overburden piles and also to the gamma-ray borehole logs by Kilborn/NUS, Inc., Denver, Colorado.

An individual open pit is modeled as indicated in Figure 2 as an inverted frustum of a right circular cone. The top zone consists entirely of overburden and the bottom zone contains a mixture of overburden, ore, and subore. The ore and subore fractions are assumed to be of equal magnitude, and the subore is set aside indefinitely for possible future use. Although the vertical

pit dimensions were directly averaged over the eight mines, the total pit volumes were calculated from the ore production and overburden/ore ratios for the mines.

TABLE III

Assumptions Made for Calculation of Radon Emission Rates

1. Parameters averaged for the model mine are either normally or log-normally distributed as indicated in Table II.
2. Radium is in equilibrium with uranium.
3. Overburden initially contains 4 ppm U_3O_8 , but reaches 20 ppm in top surface layers through relocation and mixing.
4. Emanated radon is completely released in ore, subore, and overburden loading and dumping operations.
5. Pit surface-to-volume relationship is approximated by an inverted frustum of a right circular cone, whose height equals the sum of the average ore body thickness and overburden thickness, and whose walls have a 45° slope. The mine is comprised of several (7.1) such pits, one of which is continually being actively mined.
6. "Subore" accumulation rate equals the ore production rate.
7. Ore has a constant lateral distribution with depth in the ore zone of the pit.
8. Ore stockpiles are wedge-shaped with 45° sloping sides, reaching a maximum height of 30 ft., a maximum ramp length of 200 ft., and a width of 60 ft.
9. "Subore" accumulates at a constant rate throughout the life of the mine; its pile is round, has 45° sloping sides, reaches 100 ft. in height, and increases in diameter.
10. Numerical constants and parameters have the following values:
 - a. Emanated fraction of ^{222}Rn : $f = 0.2$
 - b. Men/equipment availability: 47 weeks/yr
 - c. Annual reactor fuel requirement: 245 tons U_3O_8 /AFR
 - d. Ore density: 1.5 metric ton/yd³

It was noted that some mines backfill one end of a pit while excavating and mining the other end. Such a practice can minimize the exposed ore surface area and the resulting radon emissions. Although this practice is not represented by the present pit model, the large uncertainty in the estimated ore surface area is sufficient to include the small exposed ore surfaces of such operations.

All emanated radon is considered to be released by the pouring action of loading and dumping trucks. This complete release occurs once in hauling sub-ore and overburden from the pit and twice in hauling ore from the mine to the stockpile and from the stockpile to the mill 41 days later. The radon release during dumping is the only estimate based on an emanation coefficient (0.2); all other estimates are based on measured radon release rates. Radon emission from the milling process or from tailings is ignored since this is considered a separate study.

PRELIMINARY CALCULATIONS

Surface Area of Ore Stockpiles

The total surface area of stockpiled ore is calculated by multiplying the ore production rate by the effective stockpile residence time for equilibrated ore; then dividing the resulting ore volume by the maximum volume of an ore stockpile; and then multiplying the resulting number of stockpiles by the total surface area of an ore stockpile. Thus, with appropriate unit conversions,

$$\text{Production: } (1722 \pm 611 \text{ ton/day}) \left(41 - \frac{3.82}{\ln(2)} \text{ days} \right) \left(\frac{1 \text{ yd}^3}{1.5 \text{ tons}} \right) \left(\frac{0.7646 \text{ m}^3}{\text{yd}^3} \right) = 3.12 \times 10^4 \text{ m}^3$$

$$\text{Piles: } (3.12 \times 10^4 \text{ m}^3) \left(\frac{1 \text{ pile}}{8070 \text{ m}^3} \right) = 3.86 \text{ }^{+8.59}_{-3.24} \text{ piles}$$

$$\text{Area: } (3.86 \text{ piles}) \left(\frac{2420 \text{ m}^2}{\text{pile}} \right) = 9340 \text{ }^{+20800}_{-7840} \text{ m}^2$$

Surface Area of the Subore Pile

By similar calculations, the subore at half the mine's lifetime would contain $(1722 \pm 611 \text{ ton/day})(330 \text{ day/yr})(8.5 \pm 1.9 \text{ yr}) \left(\frac{0.7646 \text{ m}^3}{1.5 \text{ ton}} \right) = 2.46 \times 10^6 \text{ m}^3$. The frustum of a 100-ft high (30.5 m) right circular cone with 45° sloping sides having the above volume would have a base radius of 175 m and a surface area of

$$s = 43000 \text{ m}^2 + 66000 \text{ m}^2 = 109,000 \pm 37000 \text{ m}^2$$

At the end of the model mine's 17-year life, the subore pile would contain $4.92 \times 10^6 \text{ m}^3$, have a base radius of 242 m, and would have a surface area of $202,000 \text{ m}^2 \pm 69000 \text{ m}^2$.

Ore Area in the Open Pit

The volume of an individual open pit is first estimated from the number of pits, the mine lifetime, the ore production rate, the subore/ore ratio, and the overburden/ore ratio as

$$V_p = (1722 \pm 611 \text{ tons/day})(330 \text{ day/yr})(17.0 \pm 3.8 \text{ yr}) \left(2 + \frac{77 \pm 36 \text{ tons overburden}}{\text{ton ore}} \right)$$

$$\left(\frac{0.7646 \text{ m}^3}{1.5 \text{ ton}} \right) \left(\frac{1}{7.1 \pm 1.1} \right) = 5.48 \times 10^7 \pm 3.54 \times 10^7 \text{ m}^3$$

Modeling the pit as a conic section (Figure 2), the total pit volume, V_p , and the surface area of the ore-bearing zone, S_o , may be calculated as

$$V_p = \frac{\pi(h_1 + h_2)}{3} (r_1^2 + r_1 r_2 + r_2^2)$$

$$\text{and } S_o = \pi h_2 \sqrt{2} (r_2 + r_3) + \pi r_2^2 \text{ where}$$

$$r_1 = r_2 + (h_1 + h_2) \text{ and } r_3 = r_2 + h_2$$

Solving the various pit radii from the pit volume and the overburden and ore-zone heights ($h_1 = 64.6 \text{ m}$ and $h_2 = 12.2 \text{ m}$), the radii illustrated in Figure 2 are $r_1 = 514.5 \text{ m}$, $r_2 = 437.7 \text{ m}$, and $r_3 = 449.9 \text{ m}$. The resulting ore-zone surface area is thus

$$S_o = 48100 \text{ m}^2 \text{ (sides)} + 602,000 \text{ m}^2 \text{ (bottom)} = 650,000 \begin{matrix} +495,000 \\ -448,000 \end{matrix} \text{ m}^2$$

and the ore zone volume is

$$V_o = \frac{\pi h_2}{3} (r_3^2 + r_2 r_3 + r_2^2) = 7.55 \times 10^6 \text{ m}^3 \begin{matrix} + 17.0 \times 10^6 \\ - 7.6 \times 10^6 \end{matrix}$$

Since the ore occupies $5.48 \times 10^7 \text{ m}^3 \div 79, 694000 \text{ m}^3$, and the subore occupies an equal volume, the ore zone also contains overburden accounting for a volume of

$$7,550,000 \text{ m}^3 - 2(694000 \text{ m}^3) = 6,162,000 \text{ m}^3,$$

or 82% of the ore zone volume. Assuming a constant lateral ore distribution with depth, the exposed ore surface area is estimated as

$$S_{\text{ore}} = \left(\frac{694000 \text{ m}^3 \text{ ore}}{7,550,000 \text{ m}^3 \text{ ore zone}} \right) (650000 \text{ m}^2 \text{ ore zone}) = 59700 \text{ m}^2 \begin{matrix} + 55500 \\ - 52300 \end{matrix}$$

with an equal area consisting of subore.

Surface Area of Overburden Dump and Reclaimed Pits

The total area of exposed overburden at the half-life of the mine is estimated as the sum of the exposed surface areas of the reclaimed pits plus that of the active open pit, that of a developing pit, and that of the overburden pile. Assuming the terrain was flat before the mine development, an additional area equal to the surface increases due to the pit and overburden pile must also be considered to account for the increased background exhalation of radon. Referring to Figure 2, the overburden surface areas are thus

$$\text{One reclaimed pit: } \pi r_1^2 = 0.83 \begin{matrix} + 0.67 \\ - 0.61 \end{matrix} \text{ km}^2$$

One active or developing open pit or one overburden pile:

$$\pi r_3^2 + \pi (h_1 + h_2) \sqrt{2} (r_1 + r_2) = 0.96 \begin{matrix} + 0.57 \\ - 0.52 \end{matrix} \text{ km}^2 \text{ each}$$

Total overburden surface area:

$$\left(\frac{7.1-1}{2} \right) (0.83 \text{ km}^2) + 3(0.96 \text{ km}^2) = 5.41 \begin{matrix} + 1.91 \\ - 1.80 \end{matrix} \text{ km}^2$$

Surface increase for a single open-pit or overburden pile:

$$\pi r_3^2 + \pi (h_1 + h_2) \sqrt{2} (r_1 + r_2) - \pi r_1^2 = 0.13 + \frac{0.88}{0.81} \text{ km}^2 \text{ each}$$

At the end of the mine lifetime, if the last pit were left open, the overburden surface area would be increased by $(7.1-1)/2$ more reclaimed pit surfaces but would not include the area of a new developing pit. The final overburden area would thus equal:

$$5.41 \text{ km}^2 + \left(\frac{7.1-1}{2} \right) (0.83 \text{ km}^2) - 0.96 \text{ km}^2 = 6.98 + \frac{4.24}{3.86} \text{ km}^2.$$

Area of Original Land Surface Affected by the Mine

At the half-life of the mine, the area of original land surface affected by the model mine consists of one pit area for the open pit, one for excavation of a new pit, one for the overburden dump, and $\frac{7.1-1}{2}$ for the reclaimed pits. An additional area is covered by the subore pile. The area of original surface affected is thus

$$\left(3 + \frac{7.1-1}{2} \right) \pi r_1^2 + \pi (175 \text{ m})^2 = 5.1 \text{ km}^2$$

The corresponding area at the end of the mine lifetime is equal to the number of pit areas plus the area covered by the overburden and subore piles,

$$(7.1 + 1) \pi r_1^2 + \pi (242 \text{ m})^2 = 6.9 \text{ km}^2$$

Radon Exhalation Rate

Various estimates of radon exhalation rates have been made for ore and soil surfaces, some of which are listed in Table IV. The rates we have measured in an open pit uranium mine using charcoal collection devices are of comparable magnitude to the other estimates, and include surfaces having a four-fold range in mean moisture content. Our average measured exhalation rate was used in the present calculations as $0.0965 \pm 0.0363 \text{ Ci/m}^2 \text{ yr } \% \text{ U}_3\text{O}_8$.

TABLE IV

Estimates of the Radon Flux Exhaled from the Ground Surface

<u>Flux</u> <u>(pCi/cm² sec % U₃O₈)</u>	<u>Surface</u>	<u>Reference</u>
0.31 ± 0.12	Ore in open-pit mine	This work
0.33	Tailings	Silker et al ²
0.26	Subore in open pit	Wilde ³
0.24	Soil	Junge ⁴
0.25 ^a	Soil	Wilkening and Hand ⁵
0.062	Soil	Clements and Wilkening ⁶

^a(0.25 pCi/cm² sec %) x (0.0004% U₃O₈) = 1 pCi/m² sec, the background exhalation rate used in the generic environmental impact statement on uranium milling.⁷

NET RADON EMISSION FROM THE ACTIVE MODEL MINE

The following calculations summarize the net quantities of radon released by the model mine.

1. Surface Exhalation from Active Open Pit

$$\text{Ore: } (59700 \text{ m}^2)(0.0965 \text{ Ci/m}^2 \text{ yr \%})(0.114\% \text{ U}_3\text{O}_8) = 657 \begin{matrix} + 706 \\ - 676 \end{matrix} \text{ Ci/yr}$$

$$\text{Subore: } (59700 \text{ m}^2)(0.0965 \text{ Ci/m}^2 \text{ yr \%})(0.0155\% \text{ U}_3\text{O}_8) = 89 \begin{matrix} + 97 \\ - 93 \end{matrix} \text{ Ci/yr}$$

$$\text{Overburden: } (960000 \text{ m}^2)(0.0965 \text{ Ci/m}^2 \text{ yr \%})(0.0020-0.0004\% \text{ U}_3\text{O}_8) = 148 \begin{matrix} + 104 \\ - 98 \end{matrix} \text{ Ci/yr}$$

2. Radon Release in Truck Loading and Dumping

$$\text{Ore: } (0.114\%)(0.0055 \text{ Ci/m}^3 \%)(0.2)(1722 \text{ ton/d})(2 \text{ trips})$$

$$\left(\frac{0.7646 \text{ m}^3}{1.5 \text{ tons}} \right) (5.5 \text{ d/wk})(47 \text{ wk/yr}) = 57 \pm 31 \text{ Ci/yr}$$

$$\text{Subore: } (0.0155\%)(0.0055 \text{ Ci/m}^3 \%)(0.2)(1722 \text{ ton/d})(1 \text{ trip})$$

$$\left(\frac{0.7646 \text{ m}^3}{1.5 \text{ tons}} \right) (5.5 \text{ d/wk})(47 \text{ wk/yr}) = 4 \pm 1 \text{ Ci/yr}$$

Overburden: $(0.0020\%)(0.0055 \text{ Ci/m}^3 \text{ \%})(0.2)(1722 \text{ ton/d})(1 \text{ trip})$

$$\left(\frac{77 \text{ tons ob}}{\text{tons ore}}\right) \left(\frac{0.7646 \text{ m}^3}{1.5 \text{ ton}}\right) (5.5 \text{ d/wk})(47 \text{ wk/yr}) = 38 \pm 28 \text{ Ci/yr}$$

3. Surface Exhalation from Ore Stockpile

$$(9340 \text{ m}^2)(0.0965 \text{ Ci/m}^2 \text{ yr \%})(0.114\% \text{ U}_3\text{O}_8) = 103 \pm \frac{236}{103} \text{ Ci/yr}$$

4. Surface Exhalation from Dump Pile

$$\text{Subore: } (109000 \text{ m}^2)(0.965 \text{ Ci/m}^2 \text{ yr \%})(0.0155\% \text{ U}_3\text{O}_8) = 163 \pm 107 \text{ Ci/yr}$$

$$\text{Overburden: } (960000 \text{ m}^2)(0.0965 \text{ Ci/m}^2 \text{ yr \%})(0.0020\text{--}0.0004\% \text{ U}_3\text{O}_8) = 148 \pm \frac{104}{98} \text{ Ci/yr}$$

5. Surface Exhalation from Refilled Pits

$$\left(\frac{7.1-1}{2} \text{ pits}\right) (830000 \text{ m}^2/\text{pit})(0.0965 \text{ Ci/m}^2 \text{ yr \%}) (0.0020\text{--}0.0004\% \text{ U}_3\text{O}_8) = 391 \pm \frac{348}{323} \text{ Ci/yr}$$

6. Surface Exhalation from New Pit Being Excavated

$$(960000 \text{ m}^2)(0.0965 \text{ Ci/m}^2 \text{ yr \%})(0.0020\text{--}0.0004\% \text{ U}_3\text{O}_8) = 148 \pm \frac{104}{98} \text{ Ci/yr}$$

7. Exhalation Due to Increased Land Surface Area

Open pit, developing pit, and dump pile:

$$(3)(130000 \text{ m}^2)(0.0965 \text{ Ci/m}^2 \text{ yr \%})(0.0004\% \text{ U}_3\text{O}_8) = 15 \pm \frac{102}{94} \text{ Ci/yr}$$

$$\text{Total} \quad 1961 \pm \frac{861}{795} \text{ Ci/yr}$$

In terms of annual reactor fuel requirements, this amounts to

$$(1961 \text{ Ci/yr}) \left(\frac{1 \text{ yr}}{330 \text{ d}}\right) \left(\frac{1 \text{ d}}{1722 \text{ tons}}\right) \left(\frac{1 \text{ ton ore}}{0.00115 \text{ ton U}_3\text{O}_8}\right) \left(\frac{245 \text{ tons U}_3\text{O}_8}{\text{AFR}}\right) = 742 \pm \frac{326}{301} \text{ Ci/AFR}$$

NET RADON EMISSION AFTER THE ACTIVE MINING PERIOD

If no attempt were made at final reclamation of the model mine, it would continue to emit radon from the last pit, presumably left open, from the re-filled pit surfaces, and from the subore pile, which presumably accumulated throughout the life of the mine and was never used. The following calculations estimate these releases.

1. Exhalation from One Unreclaimed Open Pit

$$\text{Subore: } (59700 \text{ m}^2)(0.0965 \text{ Ci/m}^2 \text{ yr } \%)(0.0155\% \text{ U}_3\text{O}_8) = 89 \text{ }^{+97}_{-93} \text{ Ci/yr}$$

$$\begin{aligned} \text{Overburden: } (960000 \text{ m}^2)(0.0965 \text{ Ci/m}^2 \text{ yr } \%)(0.0020 - 0.0004\% \text{ U}_3\text{O}_8) \\ = 148 \text{ }^{+104}_{-98} \text{ Ci/yr} \end{aligned}$$

2. Exhalation from Refilled Pit Surfaces

$$\begin{aligned} (7.1\text{-}1 \text{ pits})(830000 \text{ m}^2/\text{pit})(0.0965 \text{ Ci/m}^2 \text{ yr } \%)(0.0020 - 0.0004\% \text{ U}_3\text{O}_8) \\ = 782 \text{ }^{+696}_{-646} \text{ Ci/yr} \end{aligned}$$

3. Exhalation from Dump Piles

$$\text{Subore: } (202000 \text{ m}^2)(0.0965 \text{ Ci/m}^2 \text{ yr } \%)(0.0155\% \text{ U}_3\text{O}_8) = 302 \text{ }^{+199}_{-199} \text{ Ci/yr}$$

$$\begin{aligned} \text{Overburden: } (960000 \text{ m}^2)(0.0965 \text{ Ci/m}^2 \text{ yr } \%)(0.0020 - 0.0004\% \text{ U}_3\text{O}_8) \\ = 148 \text{ }^{+104}_{-98} \text{ Ci/yr} \end{aligned}$$

4. Exhalation Due to Increased Land Surface Area

Open pit and dump pile:

$$(2)(130000 \text{ m}^2)(0.0965 \text{ Ci/m}^2 \text{ yr } \%)(0.0004\% \text{ U}_3\text{O}_8) = 10 \text{ }^{+68}_{-63} \text{ Ci/yr}$$

$$\text{Total } 1479 \text{ }^{+748}_{-699} \text{ Ci/yr}$$

Since the total production of the mine was

$$(1722 \text{ ton/d})(330 \text{ d/yr})(17.0 \text{ yr}) \left(0.00114 \frac{\text{ton U}_3\text{O}_8}{\text{ton ore}} \right) \left(\frac{1 \text{ AFR}}{245 \text{ ton U}_3\text{O}_8} \right) = 45 \pm 26 \text{ AFR,}$$

the continued emission of radon would amount to

$$\frac{1479 \text{ Ci/yr}}{45 \text{ AFR}} = 33 \pm 25 \text{ Ci/yr/AFR}$$

Radon emission from the abandoned model mine would probably decrease somewhat with time due to several natural reclamation effects which would occur. Since the pits are generally below the water table, the bottom of the abandoned pit would soon become covered with water, greatly reducing radon exhalation. The steep pit walls would also slough, depositing relatively uncontaminated surface rock on the ore-zone rock in the pit bottom. Covering of refilled pit surfaces with topsoil or other "clean" material would greatly reduce lingering radon emissions and is a standard practice at many of the mines comprising this model. The subore pile, if accumulated, is also subject to reclamation in mine plans.

COMPARISON OF NET RADON EMISSION WITH BACKGROUND LEVELS

The previous calculations of the net radon emission of the model open pit uranium mine may be put in perspective with the normal or background radon emission rate of the affected land areas by the following estimates. For the active mining period, the original undisturbed land would have emitted radon at the rate of

$$(5.1 \times 10^6 \text{ m}^2)(0.0965 \text{ Ci/m}^2 \text{ yr } \%)(0.0004\% \text{ U}_3\text{O}_8) = 197 \text{ Ci/yr}$$

The model mine has thus increased the background radon emission rate of the 5.1 km² (~2 sq. miles) affected area by a factor of

$$1 + \frac{1961 \text{ Ci/yr (active mine)}}{197 \text{ Ci/yr (no mine)}} = 11$$

during the active mining period.

Similarly, the total land affected by the entire mining operation would have emitted radon at the rate of

$$(6.9 \times 10^6 \text{ m}^2)(0.0965 \text{ Ci/m}^2 \text{ yr } \%)(0.0004\% \text{ U}_3\text{O}_8) = 266 \text{ Ci/yr.}$$

The entire operation thus raised the radon emission rate of the 6.9 km² (2.7 sq. mile) affected area by a factor of

$$1 + \frac{1479 \text{ Ci/yr (after mining)}}{266 \text{ Ci/yr (no mining)}} = 6.6 \text{ for the post-mining period.}$$

Since all eight of the open pit uranium mines comprising the model lie within an 80-mile radius of Casper, Wyoming, the impact of the model mine on an area of this size may be of interest. Assuming the area to have a background radon emission rate equivalent to the 4 ppm U₃O₈ level, the model mine would increase the radon emission of the Casper vicinity by a factor of

$$1 + \frac{(2 \text{ mi}^2)(11)}{\pi (80 \text{ mi})^2} = 1.001, \text{ or } 0.1\%,$$

during active mining, and

$$1 + \frac{(2.7 \text{ mi}^2)(6.6)}{\pi (80 \text{ mi})^2} = 1.0009, \text{ or } 0.09\%$$

after cessation of mine activities. Similar estimates indicate the model mine would increase the natural radon release of the State of Wyoming by a factor of 1.0002, or 0.02%.

SUMMARY

Active mining in the model open pit uranium mine causes net radon releases of 2000 Ci/yr, compared to 200 Ci/yr naturally exhaled radon from the 5.1 km² mine area. In terms of annual reactor fuel requirements, this is equivalent to 740 Ci/AFR produced by the mine. Radon releases would continue at a reduced rate after the 17-year lifetime of the mine. Assuming no final reclamation of the pit, subore, or overburden surfaces, the abandoned mine would continue to release 1500 Ci/yr, assuming no changes in the physical environment with time. This may be compared with ~270 Ci/yr naturally

exhaled radon from an equivalent undisturbed 6.9 km² area. The continuing radon releases due to the model mine are equivalent to 33 Ci/yr per AFR produced by the mine.

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FIGURE 1. Model open pit uranium mining operation

FIGURE 2. Schematic open pit

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