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SOME TECHNICAL CONSIDERATIONS REGARDING URANIUM EXPLORATION SAFETY ISSUES

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SOME TECHNICAL CONSIDERATIONS REGARDING URANIUM EXPLORATION SAFETY ISSUES

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Exploration Safety, Legislative Council
Mining Committee, State of Wisconsin

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PREFACE

This report is meant as a starting point for a technical evaluation of any potential radiologic hazard associated with uranium exploration drilling. It was originally prepared as a memorandum to the Subcommittee on Uranium Exploration Safety, Legislative Council Mining Committee, dated July 22, 1980. The memorandum outlined the technical issues related to uranium exploration as first presented to the Subcommittee by the author in public testimony on May 3, 1980. This report has been slightly modified from the original memorandum principally by the addition of an illustration and rearrangement of the major sections.

INTRODUCTION

Public concern over potential radiological hazards from uranium exploration drilling have prompted a review by state agency personnel of these potential hazards. The purpose of this review is to characterize the extent and nature of the hazard, if any, to exploration geologists, drilling personnel, and members of the general public. This report outlines calculations of potential radiological exposures to individuals as a consequence of drilling into uranium-bearing materials. These calculations and the assumptions upon which they are based are tailored to situations reasonably expected in northern Wisconsin. Such calculations are predicated on the fact that radiological exposures are, indeed, predictable and measurable. Calculations of this nature and their ultimate value are defined by the assumptions which underly them.

The basis of calculations of potential radiological exposure is the nature of the uranium-bearing material encountered in a drilling operation, using as model deposits those uranium occurrences that could reasonably be expected in northern Wisconsin. To outline a range of potential exposures, it is necessary to define both a "typical" deposit and a "high-grade" deposit. A typical deposit is modelled after a common uranium orebody occurring in a geologic setting similar to northern Wisconsin. A high-grade deposit is modelled after the richest orebody currently mined in rocks similar to those present in the Wisconsin Northwoods. The high-grade deposit represents a "worst case" with respect to potential radiological exposures of individuals.

Three drilling methods are used for uranium exploration in northern Wisconsin and all three must be modelled for computational purposes. The drilling methods vary with respect to potential for radiological exposure and impact on the environment.

Individuals potentially exposed to radiological hazards as a consequence of uranium exploration include drilling personnel, exploration geologists, and members of the general public. Because the nature of potential exposures among individuals in the three groups is different, all three must be treated separately. In addition to these varying opportunities for radiological exposure, the storage and study of uranium-bearing material poses another means of potentially significant impact (primarily for the exploration geologist).

The three primary factors involved in these calculations of potential radiological exposure are: (1) nature of material encountered in drilling, (2) nature of drilling methods used, and (3) various opportunities for exposure of individuals likely to be involved in uranium exploration. All of these factors are outlined and constitute the assumptions that define the applicability of the ensuing calculations.

DEFINITION OF MODEL DEPOSITS

For the purpose of this report, the model deposits selected for evaluation of potential radiologic impact on individuals are patterned after the Cluff Lake (Saskatchewan, Canada) uranium orebodies. These orebodies occur in a geologic setting somewhat akin to parts of northern Wisconsin and include the richest uranium orebody currently being mined, known as the "D" orebody. The "D" orebody averages 7% U_3O_8 over 7 to 8 meters thick (Harper, 1978). This orebody is the model "high-grade" deposit, since the unconformity-related uranium occurrence is a potential type of occurrence for Wisconsin uranium. Because the "D" orebody includes the richest ore in commercial production over the interval of interest, using it as a model "high-grade" deposit establishes a "worst case" for evaluating potential radiologic impact as a consequence of drilling.

The "N" orebody at Cluff Lake occurs in igneous and metamorphic rocks with uranium concentrated particularly along shear or fault zones. Average ore grade is 0.3% U_3O_8. Ore intersections encountered by drilling range from less than one to more than 20 meters, depending on the orientation of the borehole to the trend of the uraniferous zones (see Harper, 1978, fig. 7). Since the ore grade is comparable to ore grades encountered in other geologic settings having some potential for occurrence in Wisconsin (for example, the Schwartzwalder mine in Colorado and the Spokane Mountain uranium deposit in Washington), 0.3% U_3O_8 is selected as a "typical" ore grade for potential Wisconsin uranium deposits. A "typical" ore intersection is set at five meters and is arbitrarily selected by visual examination of ore intersections for the Cluff Lake "N" orebody (Harper, 1978, fig. 7).

In summary, the high-grade deposit is defined as 7% U_3O_8 over a thickness of 8 meters. The typical deposit is defined as 0.3% U_3O_8 over a thickness of 5 meters.

Wisconsin has no known uranium occurrences approaching economic significance. Therefore, selection of a "typical" or "high-grade" deposit for modelling is purely arbitrary. The average ore grade for uranium mining in the United States is currently 0.15%.

DESCRIPTION OF DRILLING METHODS

The three principal methods of uranium exploration drilling encountered in northern Wisconsin are diamond-core, rotary-mud, and rotary-mud drilling. Because these methods vary in terms of their potential for exposing exploration workers or the general public to radiation, the methods are described and outlined for the purpose of this report. Actual conditions encountered will vary somewhat from the conditions outlined here, but every effort has been made to select typical drilling situations.

Diamond-core Drilling

Diamond coring has the objective of acquiring a solid cylinder of the rock for purposes of analysis from a geologic as well as ore mineralogy perspective. The core is cut by the rotation of a diamond-studded bit that grinds up a portion of the rock surrounding a more or less solid core of rock material. The core is then brought to the surface in a metal core barrel, which is opened to allow the core to slide into core boxes. This handling is performed by drilling personnel. The exploration geologist will take the core, usually after a brief on-site examination, to a core storage/study facility or office for careful study. Core is removed frequently from the drill site.

The drilling into solid rock requires cooling of the drill bit by circulating a water/mud mixture into and out of the borehole. Commonly, a settling pit is created near the borehole to allow the mud slurry to enter, rock chips to settle out, and mud slurry to recirculate back into the borehole (Fig. 1). Rock cuttings brought to the surface with the mud are commonly sampled (removed) from the mud slurry at the point where the slurry enters the mudpit. Upon abandonment the settling pit is covered by soil material in concern with the reclamation of the entire drill site.

Rotary-mud Drilling

Rock chips, also known as cuttings, are recovered in this type of drilling. Often, the borehole itself may be the object of drilling. More commonly lower cost rotary-mud drilling is used in the upper portions of the drill hole, through the overburden, and where the interval of interest is encountered, then diamond-core drilling may be used. Cuttings retrieved for examination represent a small percentage of the cuttings produced, probably no more than five percent.

Settling pits are used with rotary-mud drilling similar to diamond coring. The mud slurry circulated to cool the rotary bit seals the borehole to prevent the inflow of water from the material being penetrated. The loss of drilling fluids into porous rock or the introduction of excessive amounts of water into the hole is not desirable, so the driller commonly allows the mud to seal the borehole. Occassionally, a cement mixture may be pumped into intervals that are particularly troublesome with respect to drilling fluid loss. The hole is then redrilled through the hardened cement leaving only the cement behind that seals the borehole.

Rotary-air Drilling

Compressed air is sometimes used to cool a rotary bit and bring rock cuttings to the surface in uranium exploration. This method results in the lowest drilling costs per foot of hole drilled.

The principles of this method of drilling are the same as with rotary-mud and diamond-core drilling, but some differences are important. The penetration rate (how quickly the rock is drilled through) is about twice as fast as for rotary-mud drilling and four times as fast as for diamond coring. Settling pits are not typically used. In northern Wisconsin, water influx into the boreholes is sufficiently rapid so as to create a mud slurry and thus eliminates

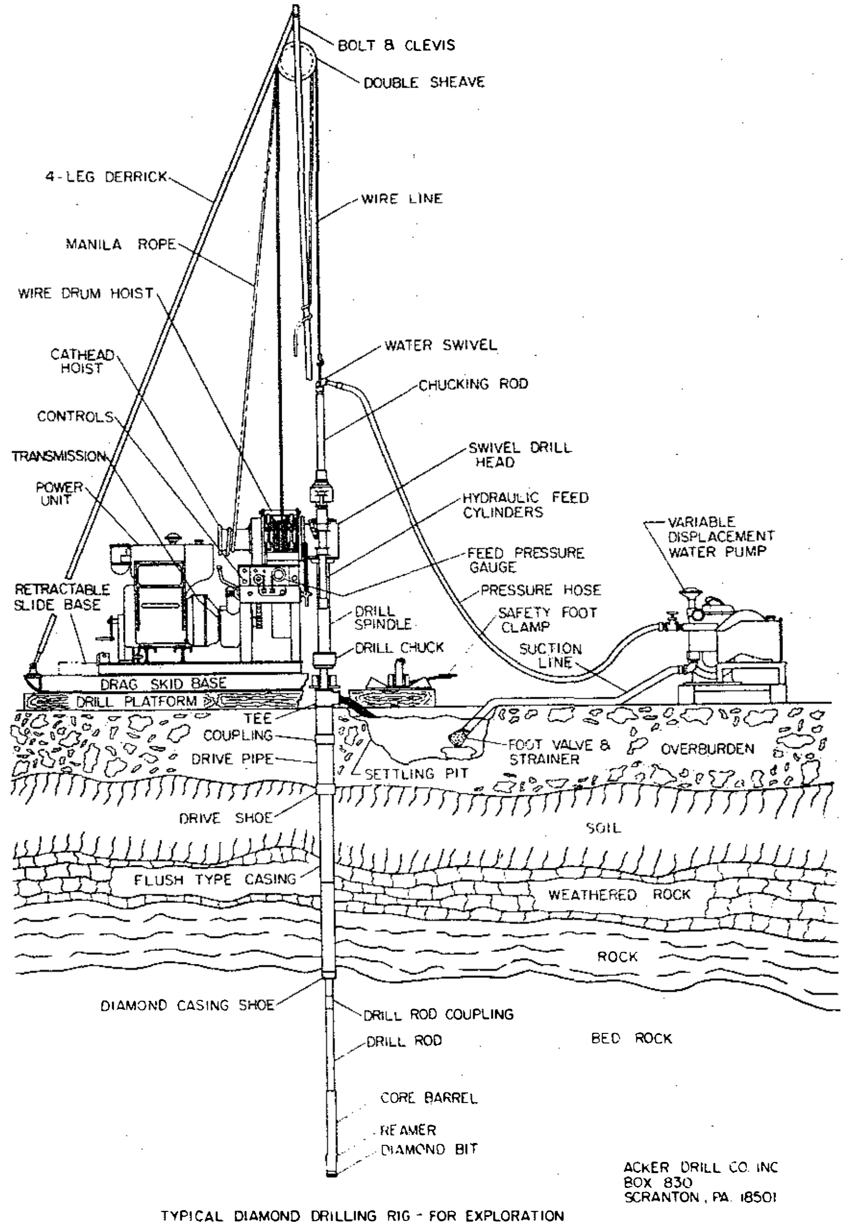

Figure 1. A skid-mounted diamond drilling rig used for metallic mineral exploration. Other types include truck-mounted and tractor (tread)-mounted rigs. Illustration courtesy of Acker Drill Co., Inc. (Acker, 1974).

drilling dust, but if allowed to go out uncontained, the slurry will spread out over the ground about a drill site (Wilson, 1980). Boreholes for both rotary-air and rotary-mud drilling are commonly larger in diameter than those associated with diamond-core drilling.

Drilling Specifications

The following specifications are used in this report to model the potential exposure of individuals to uranium-bearing material:

<u>diamond-core drilling</u>

hole diameter = 75.7 millimeters (mm) ("NX" size)
core diameter = 54.7 mm ("NX" size)
length of core (high-grade) = 8 meters (m)
length of core (typical) = 5 m
penetration rate = 4 m per hour
settling pit dimensions = 5 m (length) x 2 m (wide) x 2 m (deep)

<u>rotary-mud drilling</u>

hole diameter = 150 mm (nominal 6 inches)
hole length of interest (high-grade) = 8 m
hole length of interest (typical) = 5 m
penetration rate = 8 m per hour
settling pit dimensions = 5 m x 2 m x 2 m

<u>rotary-air drilling</u>

hole diameter = 150 mm
hole length of interest (high-grade) = 8 m
hole length of interest (typical) = 5 m
penetration rate = 16 m per hour
air movement rate = 420 cubic feet per minute (cfm) at 250 pounds per square inch (psi)

OPPORTUNITIES FOR SIGNIFICANT RADIOLOGICAL EXPOSURE

The potential exposure of individuals to radiation resulting from uranium exploration varies with the individual's opportunity for exposure. Among uranium exploration workers, those opportunities for exposure vary from drilling personnel to exploration geologists. Among the general public, those individuals in proximity to the drill site have a greater opportunity of exposure, but this opportunity is generally restricted by the remote location of uranium exploration in northern Wisconsin. The activity in and about the drill site itself, as a result of the exploration company's desire to restrict outside access for reasons of safety and proprietary concerns, further serves to limit public access to drilling locations.

Drilling personnel exposure is limited to external exposure from the core and cuttings and to inhalation of radon gas and its daughters. Inhalation of dust is not a common problem, even with rotary-air drilling, according to Wilson (1980). Drillers do get dirty running a drill rig but it is impossible to evaluate how much of the dirt may result from uranium-rich materials and so this probably insignificant source of external exposure is not modelled in this report. Radon inhalation occurs primarily with rotary-air drilling, as both rotary-mud and diamond-core drilling use mud/water slurries which entrap the highly soluble radon gas.

The exposure of the exploration geologist to radiation results from external exposure to core and cuttings during handling and transport from the drill site, as well as during study and analysis in a storage/study facility. The storage/study facility is used to support an exploration program by providing a place where core and cuttings may be housed in secure location (safe from the weather and safe from competitors) and also provides a location for more detailed study of the material. The exploration geologist is typically the individual curating the materials housed within the facility. Specifications used to estimate radiation hazard to the exploration geologist resulting from external exposure are included in this report for study of samples in a storage/study facility. No attempt is made herein to model external exposure in such a facility from radioactive materials not actually being studied because of the variability in the physical arrangement of such facilities. A brief discussion of radon concentrations in storage/study facilities is included in this report.

General public exposure to radiation as a result of uranium exploration may result from (1) settling pits, (2) radon emanation from drill holes, and (3) contamination of groundwater. Potential radiologic exposure is external exposure in the case of settling pits and a person standing over such a site, inhalation exposures as a result of breathing radon (and daughters), and ingestion exposures as a result of drinking well water that has been contaminated with uranium as a consequence of uranium drilling. See the following section of this report (Calculations of Exposures of Individuals) for calculations of general public exposure.

Specifications for Exposure (Exploration Workers Only)

The following specifications are used to calculate the exposure of any drilling personnel or exploration geologist to potential radiological hazards as a consequence of uranium exploration.

<u>drilling personnel</u>

- exposure to core = 30 minutes at 1 meter average distance (core is boxed a short distance away from drill platform)
- exposure to cuttings = 2 hours at 1 meter (rotary-air only, since cuttings are entrapped in mud with other drilling methods)
- exposure to dust = none (see Wilson, 1980)
- exposure to radon = 30 minutes (high-grade); assuming 50% of radon in rock is released and comes to surface atmosphere (rotary-air only). Entire radon release is diluted by compressed air used to raise cuttings to surface. (Assume 19 minutes for typical deposits.)

exploration geologist

exposure to core (handling) = 1 hour at 1 meter
exposure to cuttings (handling) = 1 hour at 1 meter with 5% of cuttings handled (rotary-mud and rotary-air drilling only)
exposure to core for study (high-grade) = 6 hours at 1 meter average distance
exposure to core for study (typical) = 4 hours at 1 meter average distance
exposure to cuttings for study (high-grade) = 6 hours at 1 meter average distance (rotary-mud and rotary-air drilling only)
exposure to cuttings for study (typical) = 4 hours at 1 meter average distance (rotary-mud and rotary-air drilling only)

Comments on Specifications for Exposure

Radon emanation from boreholes produced by rotary-mud and diamond core drilling is considered insignificant because of the slow rate of radon emanation and coating of the borehole with mud. Radon gas is heavier than air and this further suggests radon release from a borehole is not significant. In addition, boreholes are not left open for any significant period of time in Wisconsin as per the Wisconsin Department of Natural Resources' requirements for temporary and permanent abandonment of drill holes.

Radon impact to the driller assumes dispersion of the air in and about the drill site as a result of normal air movement. Thus, the total radon impact results from radon brought to the surface over the length of time it takes the drill bit to move through the uranium-bearing material. The air in the worker's breathing zone is assumed to have in any particular minute the radon that has been released by the drill bit in the previous minute's drilling. Thus, the compressed air continuously replenishes the radon supply in the breathing zone, but the concentration remains constant as the previously released radon moves out of the breathing zone, is diluted by the atmosphere, and is dispersed away from the drill site and drilling personnel.

The radon is assumed to be in equilibrium with its daughter products for the purpose of calculating working levels (WL) of exposure of the drilling personnel. This assumption is plainly inaccurate and over-estimates the individual's exposure. However, the assumption greatly simplifies the calculation and is in keeping with the spirit of this report to assume the "worst case" situation where there is any question of the amount of exposure, in order to over-estimate the hazard to individuals.

Radon exposure to the exploration geologist handling core and cuttings in the open air is insignificant, but radon levels in a storage/study facility may pose a potential hazard. This hazard is not significant if the facility is well-ventilated. Measurements of radon in a core shack in British Columbia at an exploration site showed 0.005 WL, which is one-fourth of the Canadian federal limit of 0.02 WL for a member of the general public (British Columbia and Yokan Chamber of Mines, 1980). Ore grades associated with this exploration site are lower than those modelled for this report, however. No further attempt is made here to evaluate the potential exposure to radon in a storage/study facility, but adequately ventilated facilities probably pose no hazard to workers.

CALCULATIONS OF EXPOSURES OF INDIVIDUALS

External exposure from core and cuttings is estimated using Schiager (1979) and the relationship that one kilogram of 0.2% U_3O_8 ore at a distance of one meter gives an exposure rate of 0.0005 mR/hr. For comparison, the normal background exposure rate is 0.01 to 0.02 mR/hr (Schiager, 1979). The milliroentgen exposure rate can be generally equated to a millirem dose rate thereby giving the gamma radiation dose from handling 1 kg of 0.2% U_3O_8 at an average distance of 1 m to be equal to 0.0005 mrem/hr. Therefore, to calculate external exposure to an individual from core and cuttings, the amount of core and cuttings, average distance of exposure, and duration of exposure are the critical parameters to estimate.

The volume of core and cuttings derives from the length of the interval of interest (thickness of ore zone) and the size of the borehole. Therefore, for diamond-core drilling, the volume of core obtained is...

$$(54.7\ \text{mm}/2)^2 \times 3.14 \times \text{length of interval}$$

and the volume of cuttings obtained is...

$$[(75.7\ \text{mm}/2)^2 - (54.7\ \text{mm}/2)^2] \times 3.14 \times \text{length of interval.}$$

The mass of the core and cuttings obtained is determined by assuming an average rock density of 2.7 g/cm^3. This rock density approximates the density of granitic rocks, such as those in which uranium mineralization might occur in Wisconsin.

The average ore grade for the high-grade deposit is 7% U_3O_8 or 35 times greater than the 0.2% U_3O_8 used for the basic relationship of exposure rate to ore grade and volume at a distance of 1 meter. The typical deposit ore grade of 0.3% U_3O_8 is 1.5 times greater than the grade used in the basic relationship. Average distance of exposure and duration of exposure for individuals have been outlined in a previous section.

Diamond-core Drilling

Driller exposure to core (high-grade deposit):

Amount of core =
$(54.7\ \text{mm}/2)^2 \times 3.14 \times 8\ \text{m} \times 2.7\ g/cm^3 = 51$ kg
Ore grade = 7% U_3O_8 (35 times)
Average distance of exposure = 1 meter
Average time of exposure = 30 minutes (0.5 hr)

51 kg x 35 x 0.5 hr x 0.0005 mR/hr = <u>0.45 mrem</u>

Driller exposure to core (typical deposit):

Amount of core =
$(54.7\ \text{mm}/2)^2 \times 3.14 \times 5\ \text{m} \times 2.7\ g/cm^3 = 32$ kg
Ore grade = 0.3% U_3O_8 (1.5 times)
Average distance of exposure = 1 meter
Average time of exposure = 30 minutes (0.5 hr)

32 kg x 1.5 x 0.5 hr x 0.0005 mR/hr = <u>0.01 mrem</u>

Geologist exposure to core (high-grade deposit):

Amount of core = 51 kg
Ore grade = 7% U_3O_8 (35 times)
Average distance of exposure = 1 meter
Average time of exposure for handling = 1 hour
Average time of exposure for study = 6 hours

51 kg x 35 x (1 + 6) hours x 0.0005 mR/hr = 6.2 mrem

Geologist exposure to core (typical deposit):

Amount of core = 32 kg
Ore grade = 0.3% U_3O_8 (1.5 times)
Average distance of exposure = 1 meter
Average time of exposure for handling = 1 hour
Average time of exposure for study = 4 hours

32 kg x 1.5 x (1 + 4) hours x 0.0005 mR/hr = 0.12 mrem

Rotary-mud Drilling

Driller exposure to cuttings (high-grade and typical deposits) is insignificant.

Geologist exposure to cuttings (high-grade deposit):

Amount of cuttings =
$(150\ mm/2)^2$ x 3.14 x 8 m x 2.7 g/cm^3 = 382 kg
Ore grade = 7% U_3O_8 (35 times)
Average distance of exposure = 1 meter
Average time of exposure for handling = 1 hour
Average time of exposure for study = 6 hours
Percentage of cuttings examined = 5%

382 kg x 35 x (1 + 6) hours x .05 x .0005 mR/hr = 2.3 mrem

Geologist exposure to cuttings (typical deposit):

Amount of cuttings =
$(150\ mm/2)^2$ x 3.14 x 5 m x 2.7 g/cm^3 = 239 kg
Ore grade = 0.3% U_3O_8 (1.5 times)
Average distance of exposure = 1 meter
Average time of exposure for handling = 1 hour
Average time of exposure for study = 4 hours
Percentage of cuttings examined = 5%

239 kg x 1.5 x (1 + 4) hours x .05 x .0005 mR/hr = .04 mrem

Rotary-air Drilling

Driller exposure to cuttings (high-grade deposit):

Amount of cuttings =
$(150\ mm/2)^2 \times 3.14 \times 8\ m \times 2.7\ g/cm^3 = 382\ kg$
Ore grade = 7% U_3O_8 (35 times)
Average distance of exposure = 1 meter
Average time of exposure = 2 hours

382 kg x 35 x 2 hr x .0005 mR/hr = 13.4 mrem

Driller exposure to cuttings (typical deposit):

Amount of cuttings =
$(150\ mm/2)^2 \times 3.14 \times 5\ m \times 2.7\ g/cm^3 = 239\ kg$
Ore grade = 0.3% U_3O_8 (1.5 times)
Average distance of exposure = 1 meter
Average time of exposure = 2 hours

239 kg x 1.5 x 2 hr x .0005 mR/hr = 0.36 mrem

Geologist exposure to cuttings (high-grade deposit):

Amount of cuttings = 382 kg
Ore grade = 7% U_3O_8 (35 times)
Average distance of exposure = 1 meter
Average time of exposure for handling = 1 hour
Average time of exposure for study = 6 hours
Percentage of cuttings examined = 5%

382 kg x 35 x (1 + 6) hours x .05 x .0005 mR/hr = 2.3 mrem

Geologist exposure to cuttings (typical deposit):

Amount of cuttings = 239 kg
Ore grade = 0.3% U_3O_8 (1.5 times)
Average distance of exposure = 1 meter
Average time of exposure for handling = 1 hour
Average time of exposure for study = 4 hours
Percentage of cuttings examined = 5%

239 kg x 1.5 x (1 + 4) hours x .05 x .0005 mR/hr = .04 mrem

Driller exposure to radon (high-grade deposit):

In secular equilibrium, 1 kg of 0.1% ore contains 2.8×10^{-7} Ci (curies) of Rn-222 (NUREG-0511). Therefore, 7% ore contains approximately 196×10^{-7} Ci or 1.96×10^{-5} Ci Rn-222 per kilogram of ore. 1.96×10^{-5} Ci x 10^{12} pCi/Ci = 1.96×10^{7} pCi Rn-222/kg of 7% ore.

The amount of material times the percent of radon released equals total specific activity due to radon released by the action of the drill bit, so that (assuming 50% of radon in rock is released)...

382 kg x 1.96×10^{7} pCi/kg x 0.5 (radon released) = 3.7×10^{9} pCi.

Release rate equals amount released per unit of time, so that

3.7×10^9 pCi Rn-222 released over 30 minutes (based on penetration rate of 16 m/hr) = 1.2×10^8 pCi/minute.

Radon concentrations in the vicinity of the driller equals radon released per unit time diluted by compressed air (allowed to expand to atmospheric pressure):

$$\frac{1.2 \times 10^8 \text{ pCi/min}}{420 \frac{\text{ft3}}{\text{min}} \times \frac{250 \text{ psi}}{14.7 \text{ psi}}} = 1.7 \times 10^4 \text{ pCi/ft}^3$$

$$1.7 \times 10^4 \text{ pCi/ft}^3 \times 1 \text{ ft}^3/0.028 \text{ m}^3 = 6.1 \times 10^5 \text{ pCi/m}^3$$

Assuming radon is in equilibrium with its daughters, then 6.1×10^5 pCi/m^3 = 6.1 working levels (WL), since 1×10^5 pCi/m^3 = 1 WL.

Driller exposure, using assumptions noted in a previous section, is 6.1 WL for 30 minutes or about 3 working level-hours or 0.017 WL-months.

Driller exposure to radon (typical deposit):

Amount of material = 239 kg
Percent of radon released = 50%
Total specific activity due to released radon =
239 kg x 8.4×10^5 pCi/kg x 0.5 = 1.0×10^8 pCi
Radon release rate =
1.0×10^8 pCi/19 minutes = 5.3×10^6 pCi/min
Radon concentration in vicinity of driller =

$$\frac{5.3 \times 10^6 \text{ pCi/min}}{420 \frac{\text{ft}^3}{\text{min}} \times \frac{250 \text{ psi}}{14.7 \text{ psi}}} = 7.4 \times 10^2 \text{ pCi/ft}^3$$

$$7.4 \times 10^2 \text{ pCi/ft}^3 \times 1 \text{ ft}^3/0.028 \text{ m}^3 = 2.6 \times 10^4 \text{ pCi/m}^3$$

Driller exposure to radon =
.26 WL for 19 minutes or .082 WL-hours or about
0.0005 WL-months

Exposures of General Public

Radioactivity from settling pit (rotary-mud drilling is used since the pit would contain more radioactive material than would the settling pit associated with diamond-core drilling):

External exposure to an individual from soil (density = 1.8 g/cm^3) containing uranium (plus daughters) is related to the uranium concentration as follows:

1 ppm U in soil yields 4.7 mrad/yr at 1 meter height according to NCRP Report No. 45, p. 61, table 15 (1 mrad = 1 mrem).

Size of settling pit = 5 m x 2 m x 2 m = 20 m^3 (20 x 10^6 cm^3)
Volume of cuttings (high-grade) = 382 x 0.95 = 363 kg
Ore grade (high-grade) = 7% U_3O_8
Volume of cuttings (typical) = 329 x 0.95 = 215 kg
Ore grade (typical) = 0.3% U_3O_8
Percentage of uranium in U_3O_8 = 85%

Uranium concentration in settling pit associated with a high-grade deposit is:

$$363 \text{ kg} \times .07 \times .85 = 21{,}600 \text{ g U into settling pit}$$
$$20 \times 10^6 \text{ cm}^3 \times 1.8 \text{ g/cm}^3 = 3.6 \times 10^7 \text{ g in settling pit}$$

$$\frac{21{,}600 \text{ g U}}{36{,}000{,}000 \text{ g}} \text{ total} = 660 \text{ ppm U}$$

Total exposure at 1 meter height over settling pit is about 600 x 4.7 or 2,820 mrem/yr = <u>0.3 mrem/hr</u>

Uranium concentration in settling pit associated with a typical deposit is:

$$215 \text{ kg} \times 0.003 \times .85 = 548 \text{ g U in settling pit}$$
$$20 \times 10^6 \text{ cm}^3 \times 1.8 \text{ g/cm}^3 = 3.6 \times 10^7 \text{ g in settling pit}$$

$$\frac{548 \text{ g U}}{36 \times 10^6 \text{ g}} \text{ total} = 15 \text{ ppm U}$$

Total exposure at 1 meter height over settling pit is about 15 x 4.7 or 72 mrem/yr = <u>0.008 mrem/hr</u>.

<u>Radon emanation from drill hole</u>:

Since the borehole is not left open for any significant period of time, the general public's exposure potential to radon results from the drilling process itself. Radon would appear to be a problem of concern only for rotary-air holes, since the opportunity for radon release into the atmosphere is significant only for this type of drill hole. Certainly, some aeration of radon entrapped in mud and water associated with coring or rotary-mud drilling would occur at the point of slurry release into the settling pit; however, this aeration would not be 100% and modelling the assumed 100% effective release of radon from rotary-air drilling appears to be the "worst case". Based on the preceding, the general public's exposure to radon would be equal to the total release of radon, diluted by the compressed air, and further diluted and dispersed in the open air about the drill site.

Extreme diurnal, seasonal, and other temperature variations associated with climatic and meteorologic conditions greatly complicate any straight-forward calculation for radon exposure downwind from a drilling area. Several studies of radon dispersion demonstrate that radon concentrations and working level measurements decrease with increasing distance from this source (as well as being a function of climatic and meteorologic factors). For example, data on radon concentration in the vicinity of a uranium mill in New Mexico shows a ten-fold decrease in air radon concentration at distances of 500 to 3000 meters from a uranium tailings pile (Momeni and others, 1979, p. 33, fig. 18). Because radon released from a uranium drill hole is much less to begin with, the phenomenon of dilution and dispersion with distance indicates that general public exposure to radon as a consequence of uranium exploration drilling in remote areas is not a significant problem.

Potential for groundwater contamination:

Concern with the contamination of groundwater aquifers centers around the introduction of natural uranium into aquifers as a result of drilling into uranium-bearing material and subsequently losing drilling fluid into an aquifer. Other concerns that have been expressed, specifically interaquifer communication along the borehole, does not appear to be a significant concern because (1) State of Wisconsin abandonment procedures are designed to eliminate this possibility, and (2) if the abandoned hole does lose its integrity (cement deterioration permits movement of water along the borehole), the amount of uranium introduced from one aquifer to another is within acceptable health standards (see calculations).

Potential contamination of groundwater via introduction of drilling fluid into an aquifer is unlikely, particularly in systems using a mud slurry to cool the drill bit and bring cuttings to the surface. The mud tends to seal the borehole and if fluid loss does nonetheless occur, the driller can detect this loss and drilling stops to permit additional steps, such as cementing the borehole and allowing cement to move a short distance into the porous rock or open fissure that was causing the drilling fluid loss. Besides the sealing of boreholes with mud or cement, exploration boreholes are generally cased (lined with metal pipe that just fits inside the hole) as the hole is drilled. Casing alone eliminates any significant possibility of drilling fluid loss, especially if the casing is adequately cemented into the bedrock below the overburden.

Assuming, however, that drilling fluid loss does occur, the following calculation estimates the impact on the groundwater. Given a nominal 3-inch diameter hole 300 meters in length and the settling pit dimensions noted previously, the volume of drilling fluid involved in approximately 20 cubic meters. Following the assumption that 3 ppm natural uranium is dissolvable into groundwater and 10% of the drilling fluid is lost (see Wells, 1979; note that the solubility of uranium and percent-loss of drilling fluid are very high, "worst case" estimates), the following relationship ensues:

1 g natural uranium = 6.77×10^5 pCi,
2×10^6 cm^3 of drilling fluid loss contains 6 g U-nat,

$$\frac{6 \text{ g U-nat}}{2 \times 10^6 \text{ cm}^3} \times 6.77 \times 10^5 \frac{\text{pCi}}{\text{g U-nat}} = 2 \frac{\text{pCi}}{\text{cm}^3} .$$

The maximum permissible concentration of natural uranium (MPC_w) dissolved in water is 2×10^{-5} microcuries per cubic centimeter or 20 pCi/cm^3. This MPC_w also considers the chemical toxicity of the long-lived uranium nuclides (see Table 1, p. 86 of NCRP Report No. 22 [1959], occupational exposures allowed are divided by 10 to derived permissible non-occupational exposures).

The natural uranium introduced into an aquifer is less by a factor of at least 10 of the maximum permissible concentration. Therefore, the potential for groundwater contamination as a result of uranium exploration is not considered a significant problem, especially in view of the liberal assumptions made for uranium solubility and drilling fluid loss.[1]

SUMMARY

Calculations of potential radiological exposure of exploration workers and members of the general public, as a result of uranium exploration drilling, indicate that such activity does not pose a significant health hazard. These calculations deal specifically with hazards that might be associated with drilling a single exploratory borehole, but multiple borehole exposures, as might be expected in a uranium exploration program over a year's time also do not appear to pose a significant health hazard.

Table 1 lists estimated potential exposure of exploration workers from drilling one hole into a "high-grade" deposit (the richest uranium ore zone currently mined) of 8 meters of 7% U_3O_8 ore and one hole into a "typical" deposit of 5 meters of 0.3% of U_3O_8 ore. For comparative purposes, natural background exposure over a year's time is about 105 mrem and the current permitted exposure to the general public, exclusive of background radiation, is 500 mrem per year. Radon exposure levels currently permitted are 4 WL-months per year and this level has recently been proposed for revision down to 0.7 WL-months per year.

1 The respective radon concentration released by drilling into high-grade and typical deposits both exceed the maximum permissible concentrations of Rn-222 in air, according to NCRP Report No. 22 (1959, table 1). However, this table of MPC_a is for 40 hours per work-week or 168 hours per week of continuous exposure. The MPC's listed insure that maximum permissible body burdens for a particular radionuclide are not exceeded over a 50-year span of continuous exposure. The relatively instantaneous exposure of personnel on a drill rig cannot be compared to recommended levels of continuous exposure over 50-year time spans.

The use of MPC_w is reasonable, however, for natural uranium dissolved in groundwater as a result of drilling fluid loss into an aquifer. The MPC_w for soluble natural uranium used for comparative purposes in this memo is for continuous exposure over a normal 168-hour week for 50 years. The slow movement of groundwater suggests the dilution of uranium released into an aquifer may be so low as to permit the assumption that the uranium concentration in the "contaminated" aquifer remains reasonably constant for a period of time that is commensurate with the assumptions in the MPC_w for soluble natural uranium.

Table 1. Potential Radologic Exposure[1] of Exploration Workers Resulting from Uranium Exploration Drilling.

Drilling Method	Worker	High-grade Deposit	Typical Deposit
Diamond-coring	Driller	0.45	0.01
	Geologist	6.2	0.12
Rotary-mud	Driller	nil	nil
	Geologist	2.3	0.04
Rotary-air	Driller	13.4	0.36
	Geologist	2.3	0.04
	Radon[2] (driller only)	3.0	0.08

[1] Units are mrem per drill hole.

[2] Units are working level-hours.

Potential radiological hazards posed to individual members of the general public as a consequence of uranium exploration appears to result from radioactivity associated with a settling pit, radon in the atmosphere, and potential groundwater contamination. None of these potential hazards appear to be significant sources of radiological exposure to the public. Radiological exposure from a settling pit is about 0.3 mrem/hr in the "worst case" meaning an individual would have to be standing on the settling pit (1 meter distance) for over 1500 hours to absorb a dose approaching the permitted level. Radon released into the atmosphere as a result of drilling is at low enough levels initially and is subsequently diluted and dispersed with greater distance from the drill hole source, so as to pose no apparent hazard to the general public. Even exposures to drillers at the drill site appear to be minor. Groundwater contamination resulting from the introduction of natural uranium into an aquifer results in the "worst case" in a uranium concentration of 2 pCi/cm^3. This is ten times below the maximum permissible concentration in water of 20 pCi/cm^3.

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