

Radon Control Options for the Cavity Liner

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Introduction

This report is intended to characterize the expected radon control performance of the proposed cavity liner, using the presently known characteristics of the various components. The design aim for radon is that the 5.2 kilotonnes of light water have an equivalent of 10^{-13} gU/g. This means that the approximately 2000 m² of liner surface should emit no more than 12 atoms \cdot m⁻²·hr⁻¹ (assuming complete mixing of the radon). The required effectiveness of the liner at reducing the flow of radon into the water then depends on the emanation of the material(s) that the liner is placed on. The norite host rock and standard concrete both emanate radon at about 2×10^4 atoms \cdot m⁻²·hr⁻¹, and shotcrete at about ten times that rate [1, 2]. For the purposes of the present calculations it will be assumed that a concrete foundation is used.

Liner Performance

The physical structure of the liner as described in the cavity liner DCD-17-240-02-G is shown in Fig. 1. The geotextile fabric next to the foundation provides both a small gap and presumably a weak emanation source but in the present calculations is assumed to play no role. Its emanation properties are currently being measured. The Miradrain layer (high impact polystyrene core) serves both as a diluting air gap and as a permeation barrier. Miradri layer (a rubberized asphalt) provides a permeation barrier and an emanation source of $110 \text{ atoms} \cdot \text{m}^{-2} \cdot \text{hr}^{-1}$ [2].

The flux of ^{222}Rn atoms that penetrate into the water from the liner/foundation assembly has been estimated using a 1-dimensional diffusion equation (Fick's Law) for each layer of the liner assembly. The ^{222}Rn concentration within the outer Miradrain air gap was taken to be the buildup obtained after one ^{222}Rn lifetime, or 15 pCi/l.

The concentration of ^{222}Rn in the inner Miradrain air gap is controlled by the diffusion through approximately 38 mils of "polymer" (the Miradrain and the high-strength polymeric film) and 60 mils of Miradri. Assuming a diffusion length of 50 mils for the polymer (typical for these plastics) an attenuation of a factor of 2 is obtained. The measured attenuation for the Miradri [3] is approximately 15.

The ^{222}Rn concentration in the inner Miradrain gap is determined by diffusion through the Miradri/polymer composite, emanation from the Miradri and mixing with mine air. If we assume that the inner gap is isolated from the mine air, then a concentration of 1 pCi/l is achieved, of which 0.1 pCi/l is due to the Miradri emanation.

The ^{222}Rn emanating into the water through the innermost Urylon layer (polyurethane) is controlled by diffusion through 26 mils of "polymer" (factor of 1.7 attenuation) and through the 200 mils of polyurethane. The measured diffusion length of 47 mils [3] for the polyurethane give an attenuation factor of 70 and an overall factor of 120 for this section. This information and the diffusion equation can be used to calculate the emanation rate from the water side of the liner (appendix I). This gives a rate of approximately $2.4 \text{ radons} \cdot \text{m}^{-2} \cdot \text{hr}^{-1}$, which is satisfactorily within the design aim.

The radon level can be reduced further by flushing the outer air gap

with mine air. A radon concentration equal to the flush gas concentration plus the initial concentration times the ratio of the replacement time for the gap gas to the radon lifetime (132 h). Therefore a reduction of a factor of 3.6 could be achieved by replacing the outer gap air every 10 hours. This would require an air flow of $2 \text{ m}^3 \cdot \text{h}^{-1}$.

Discussion

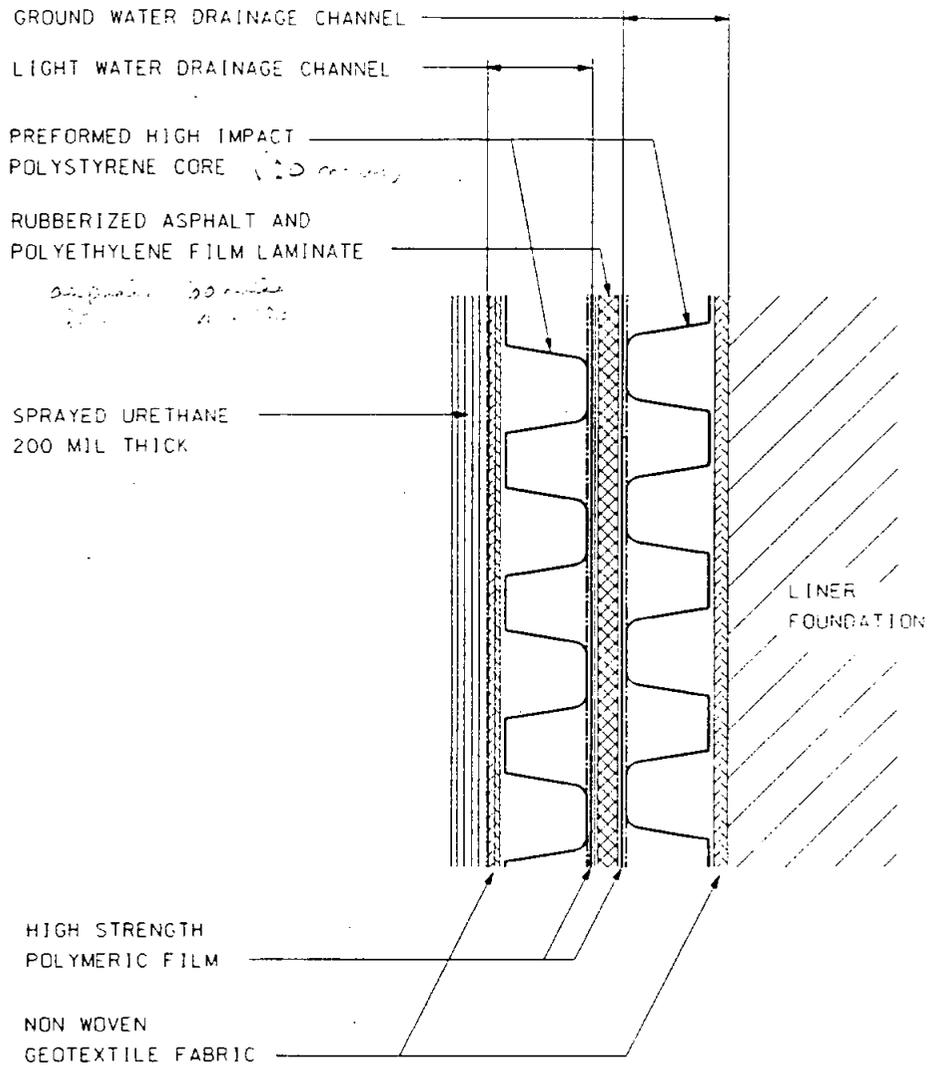
In considering the makeup of the foundation, it appears that the use of shotcrete would result in a factor of approximately 10 increase of the radon leakage rate. This could be recouped by applying a high-build epoxy layer of paint on the foundation slightly in excess of 0.1" thick. The cost of this layer should be taken into consideration when comparing possible foundations. The effect of such a layer is being measured.

The foundation contains weepholes back to the norite rock. This means that some of the underlying shotcrete and norite rock is uncovered and will provide additional emanation into the outer Miradrain air gap. However 0.5" dia. weepholes 6" deep placed on a 1 m rectangular lattice spacing only increases the exposed surface by approximately 0.6%, and so should not cause any significant increase in the radon source.

It is worthwhile to put the design aim of 10^{-13} gU/g equivalent into the context of other operational parameters. The thorium equivalent content is very small compared to that of the uranium because of the short ^{220}Rn half life (56 s compared to 3.8 d for ^{222}Rn) for passing through the liner. Also the water mixing time (assumed to be approximately 10 hours) is compared to the half life of the longest lived daughter below ^{220}Rn (11 hr for ^{212}Pb). The absence of significant contribution from the thorium chain means that the background from the water is roughly half that calculated using white book numbers for the light water contribution to the internal $\beta\gamma$ background, which in turn is about 10% of the total internal $\beta\gamma$ background.

At 10^{-13} gU/g , the liner contribution is comparable to the emanation loading in the outer water of about $1.5 \times 10^{-13} \text{ gU/g}$ [4]. The emanation loading is controlled roughly equally by dust loading (at $4 \mu\text{g}/\text{cm}^2$) and cabling. The radon load of the water outside the PSUP is assumed to be reduced by approximately one hundredfold by the water barrier at the PSUP. This outer water contribution to the inner water radon loading is therefore

very small compared to the inner water emanation load of approximately 0.7×10^{-13} gU/g, (of which approximately 20% is contributed by $0.4 \mu\text{g}/\text{cm}^2$ dust loading). These numbers suggest that there is a very large safety factor on the liner design parameters for radon.



References

- [1] E. D. Hallman, D. L. Cluff and D. Cloutier, **Sudbury Neutrino Observatory Radon Measurements - January 1992 6800 ft Level - Creighton Mine**, SNO-STR-92-005.
- [2] J. Bigu and E. D. Hallman, **Emanation and Permeability Studies at the Elliot Lake Laboratory**, SNO-STR-92-018.
- [3] J. Bigu, E. D. Hallman and L. Kendrick, **Permeability of Different Materials to Radon (^{222}Rn) Gas**, SNO-STR-91-069.
- [4] H. Lee, B. Sur, X. Zhu and A. B. McDonald, **Estimates of Emanated Radon Load**, SNO-STR-92-016.

Appendix 1; Detailed Estimates

How can one estimate the flux of ^{222}Rn atoms that penetrate into the water from the liner?

The easiest way is to assume that we can solve the diffusion equation in one dimension and apply that solution step by step.

Step I. The ^{222}Rn emanated from the rock/ concrete/ shotcrete surface gives rise to an equilibrium concentration of Rn in the air gap [Miradrain core] next to it. We assume that so little Rn is allowed to leak into the next layer (the inner core) that this equilibrium Rn concentration is given simply by the total amount of Rn emanated by the rock/shotcrete/concrete surface in one ^{222}Rn lifetime (5.5 days). Let us call the surface emanation rate (the source term) j_0 , and the Rn concentration in the first air gap C_0 . Then for an air gap of 1 cm. (0.4 inches),

$C_0 = 150$ pCi/liter or 2640 atoms/cc if $j_0 = 2 \times 10^5$ atoms / m^2 / hr [characteristic of a shotcreted surface]

and

$C_0 = 15$ pCi/liter or 264 atoms/cc if $j_0 = 2 \times 10^4$ atoms/ m^2 / hr [characteristic of a concrete or rock surface]

Step II. What is the concentration of Rn in the inner air gap [inner Miradrain core] ? This depends on the attenuation to radon permeation provided by the 60 mil of rubberized asphalt and approx. 38 mils of polymer between these 2 air gaps. This attenuation or permeability depends on the thickness of each material, their sequence, their characteristic Rn diffusion coefficients and their Rn solubility. In a simple calculation, neglecting the attenuation due to the rubberized asphalt, neglecting Rn solubility, and assuming the Rn diffusion length in the polymer to be 50 mils (characteristic of many plastics), one finds that the concentration in the inner gap is a factor of 2 less than the outer gap concentration. However, a direct MEASUREMENT of this concentration ratio by Bigu et. al. [ref. 2] finds it to be around 15 to 20 indicating perhaps that there is a significant Rn solubility in the asphalt.

Let us call this reduction factor R, and the concentration of Rn in the inner gap, C_1 .

There are two other factors that can influence C_1 . The first is Rn

emanation from materials into this gap. This is dominated (presumably) by Rn emanation from the asphalt (Miradri) layer, measured at 110 atoms per m^2 per hour. This would contribute an additional concentration of less than 0.1 pCi/liter — completely negligible. The other factor is mixing of the air in this gap with mine air. If this air gap is not gas tight with respect to mine air, presumably the lowest concentration of Rn that one can achieve here would be equal to mine air Rn concentration which is 3 pCi/liter.

Step III. One can now relate the flux, j_1 of Rn that can migrate across the innermost polyurethane layer whose thickness was 100 mils originally, but has now been upgraded to 200 mils plus additional polymeric layers with total thickness of 26 mils, to the concentration, C_1 of Rn in the inner air gap. Solubility of Rn in the polyurethane is neglected, the diffusion coefficient for Rn measured in polyurethane translated into a diffusion length of 47 mils for Rn in this material [3]. With the approximation of zero Rn concentration in the water (a very good approximation for our purposes), this relationship is:

$$j_1 = 2 \times \sqrt{\frac{D}{\tau}} \left(\frac{C_1}{e^{a/x_s} - e^{-a/x_s}} \right) \quad (1)$$

where $D(cm^2s^{-1})$ is the diffusion constant and $x_s(cm) = \sqrt{D\tau}$ the diffusion length for the polyurethane barrier of thickness a for a radioactive gas (Rn) with a radioactive lifetime τ .

Various scenarios for Rn concentrations and fluxes are listed in the table.

DISCUSSION: In the last column are listed the calculated emanation rate, j_1 into the light water from the liner. The emanation rate from the polyurethane itself is measured at 2 per m^2 per hr and can be neglected. The emanation rate required for the design goal of 10^{-13} g/g eq. U is 12 per m^2 per hr.

It is seen that the most important thing is to achieve a polyurethane thickness of 200 mil as this will achieve the design goal for almost all scenarios. The next thing is to not expose a shotcreted surface to the liner. Even if a concrete layer sits on top of a shotcreted layer, it is not clear what degree of Rn reduction it will achieve. One can reduce the foundation emanation rate by coating it with a high build epoxy paint. However, the reduction achieved in this way is variable and depends on which paint, conditions of application, ambient conditions, etc. (ref. 2 and private communication from J. Bigu). It may be possible to achieve a reduction of a factor of 7 or so with a 100 mil

	j_0 $10^4 \text{atoms}/m^2/\text{hr}$	C_0 (pCi/l)	C_1 (pCi/l)	j_1 (atoms/ m^2 /hr)
I.	2 (concrete surface)	15	7.5 (red. factor, R=2)	149 (100 mil polyurethane)
II.	20 (shotcrete)	150	75 (for R=2)	1490 (100 mil poly)
III.	2 (concrete)	15	1 (for R=15)	20 (100 mil poly)
IV.	20 (shotcrete)	150	10 (for R=15)	200 (100 mil poly)
V.	2 (concrete)	15	3 (mix with mine air)	60 (100 mil poly)
VI.	2 (concrete)	15	7.5 (R=2)	17.7 (200 mil poly)
VII.	2 (concrete)	15	1. (R=15)	2.4 (200 mil poly)
VIII.	2 (concrete)	15	3 (mix with mine air)	7.2 (200 mil poly)
IX.	20 (shotcrete)	150	75. (R=2)	177 (200 mil poly)
X.	20 (shotcrete)	150	10. (R=15)	24 (200 mil poly)

layer of epoxy paint. Weep holes which are spaced at the rate of 1 per m^2 and are 0.5 inch diameter by 6 inches deep contribute an uncovered surface fraction (hence a higher level of Rn emanation) of only 0.6%. Hence they are not a problem. Finally it is seen that if all else fails, one can always flush the air gap(s) with mine air. The lifetime of Rn is 132 hours. Thus flushing with mine air at x pCi/l at a rate such that the gap air is replaced once every y hours brings the total Rn concentration in the cavity to:

$$C_1(\text{new}) = C_1(\text{old}) * y/132 + x \quad (2)$$

Thus flushing with mine air at a rate at which it would replace the gap air once every hour (this rate works out to a air flow of $20 \text{ m}^3 / \text{hr}$) would take care of a situation where C_1 (old) is even as high as 400 pCi/l. [ie. C_1 (new) due to the flushing would in this case become 6 pCi/l.]


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EMANATION AND PERMEABILITY STUDIES AT THE ELLIOT LAKE LABORATORY

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SNO-STR-92-018

The following are data obtained during the months of February and March, 1992.

²²²Rn EMANATION STUDIES

Material	Emanation Rate	
	atoms kg ⁻¹ h ⁻¹	atoms m ⁻² h ⁻¹
Norite	5.03 ± 0.79	248 ± 39*
Shotcrete	52.04 ± 5.35	1968 ± 202*
Boron composite	5.71 ± 0.85	216 ± 32*
Miradri	—	111 ± 2.9
Polyurethane	—	?

+ Only rough estimates (atoms m⁻²h⁻¹) because surface area has not been calculated accurately. Samples still in emanation chambers.

* There have been difficulties in the measurement of this sample because of what seems to be considerable outgasing. It will take another 2-3 weeks, before attempting for the third time.

NOTE: The above values require further verification because calibration factors have to be rechecked, and because changes have been introduced in the emanation chambers and emanation systems.