Radon Considerations for the New Liner

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Purpose: To calculate the required thickness of the polyurethane layer in the new liner design [Ref.1] The thickness is to be such, that the flux of ^{222}Rn atoms into the light water contribute a maximum equivalent of 10^{-13} g $^u/g$ ~~water~~. For a liner with total area of 2000 m^2 and a "outer" water volume of 5800 tonnes, this goal is 13 atoms per m^2 per hour. [Ref 2].

Method: The steady-state one-dimensional diffusion equation with decay and source term is solved for a multilayer system. This equation is:

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} - \frac{C}{\tau} + \phi \left\{ = 0 \text{ for S.S.} \right\} \qquad ①$$

where C is the concentration of Rn at position x, D is the Diffusion constant for a particular medium (layer), τ is the lifetime for ^{222}Rn decay (~ 5.5 days) and ϕ is the production rate or

source term of Rn atoms in the medium (assumed independent of x). ϕ is the unit production rate, or, i.e. say atoms/m^3/sec.

The general solution is :-

$$C(x) = Ae^{x/d} + Be^{-x/d} + \phi\tau \qquad ②$$

where the "diffusion length" $d = \sqrt{D\tau}$ for each medium. The constants A and B must be determined from the boundary conditions.

A computer program has been written whi solves the above system for up to a 3 layer system. A typical geometry is shown below
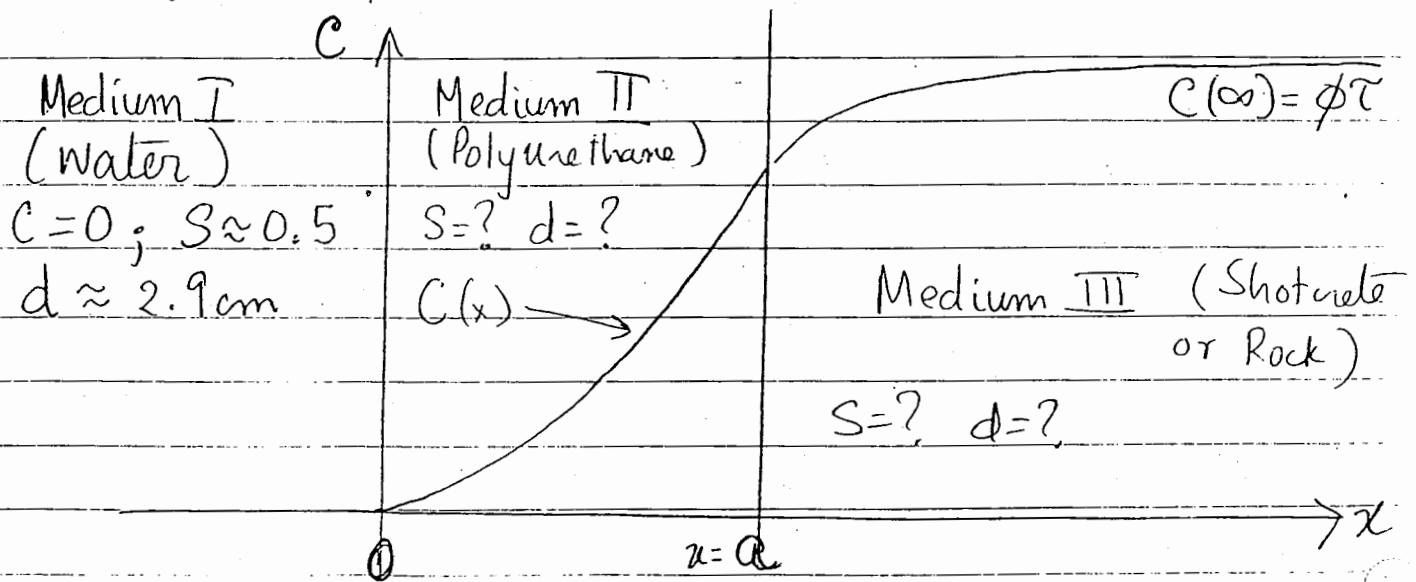

Medium I (water)	Medium II (Polyurethane)	
$C=0$; $S \approx 0.5$	$S=?$ $d=?$	$C(\infty) = \phi\tau$
$d \approx 2.9$ cm	$C(x) \longrightarrow$	Medium III (Shotcrete or Rock)
		$S=?$ $d=?$

$0 \qquad x = a$

Fig 1. 3 layer geometry for Rn flux calculation.

In this geometry, the flux of interest is:

$$\left| j(0) \right| = \left\{ D\frac{\partial C}{\partial x}\Big|_{x=0} \right\}$$

Media I (water) and III (shotcrete/rock) are assumed to extend to infinity. The input parameters are: the diffusion length, d ; the Rn solubility, S^i; ~~for each medium; an~~ and the Rn production rate, ϕ ; for each medium; and the thickness, a, of medium II (the Rn barrier ie polyurethane).

(units)

The time constant for reaching the steady state is dominated by the shortest time of interest; in this case, the Rn lifetime, $\tau = 5.5$ days. This can be complicated during the time the P.U. barrier is absorbing water, since that time to reach saturation can be of order months.

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Input Parameters:

I. Medium I (Water) The Rn concentration in the water is taken to be 0.1 (an excellent approximation). The water is assumed fully mixed since the mixing scale is of order 10 hours ($u << \tau_{Rn}$). Therefore no self-attenuation in the water is achieved. The diffusion length and solubility of Rn in water are of no concern in this formulation.

II Medium II Polyurethane Radon Barrier:

Assuming negligible U content; the parameters of interest are the solubility, S and diffusion length d. For a barrier of thickness, a, the transmitted flux,

$$|j| \propto S \quad \text{and} \quad |j| \propto e^{-a/d}$$

For a thick barrier; the diffusion length is more important because the dependence on it is exponential whereas the solubility is less critical since the dependence is only linear. Unfortunately, the experimental

values of S and d are not clear. Thus

(a) Wojcik [Ref 3] finds $\{S = 5.6$ and $d = 0.14 cm\}$ for P.U. soft and $\{S = 7.9, d = 0.065 cm\}$ for P.U. hard.

(b) Archibald et. al. [Ref 4] find $K \not{D} = 3.48 \times 10^{-9} cm^2 s^{-1}$ for "Mineguard", a hard P.U. spray on barrier which is close to the back up material proposed for S.N.O. However; $k = SD$. Thus if we take $S = 1$, then $d = \sqrt{D\tau} = 0.041 cm$. If $S \cong 5$; $d = 3.31 \times 10^{-4} cm$!!

(c) Bigu et. al [Ref 5] find for "MIROC" again a low-humidity, hard P.U. spray on barrier similar to the SNO backup proposal, $K \cong 3.0 \times 10^{-8} cm^2$. Again for $S = 1$, this gives $d = 0.12 cm$ and for $S = 5$, $d = 0.053 cm$.

(d) The Rn permeability and solubility of the proposed S.N.O. liner formulation, "HH453", a high-humidity spray on P.U., has never been measured. This material is somewhat softer (by feel) than the "MIROC".

(e) The effect on Rn solubility and permeation of water saturation in the P.U. barrier can not be guessed and have not been measured.

<u>Consequently</u> we determine (in following tables) the thickness of barrier required for 3 cases:

$$S = 5.5 \; ; \quad d = 0.14 \, cm \qquad (\text{"soft" P.U.})$$
$$S = 1.0 \; , \quad d = 0.12 \, cm \qquad (\text{naive model})$$
$$S = 8 \; , \quad d = 0.06 \, cm \qquad (\text{"hard" case})$$

The issue of Rn emanation from the P.U. barrier itself is dealt with later.

<u>III</u>. Medium <u>III</u> Rock and Shotcrete.

The latest report of Rn flux density measurements from a shotcreted surface at the 6600 ft level from Bigu & Hallman [Ref 6] indicate a flux of 5.29×10^3 Rn atoms /m^2/s or 1.9×10^7 atoms /m^2/hr from such a surface.

Previous reports indicate that the flux from a bare rock or concreted surface is less by a factor of 10.

Thus a reduction factor of $\sim 10^5$ is
to be provided by the P.U. barrier!!
For such a large reduction, it is
emphasized that uncertainties in
the calculated barrier thickness are
bound to be uncertain by a few
diffusion lengths.

   The parameters required are
the Rn production rate, ϕ, the
solubility, S and the diffusion length,
d.

   We assume (based on experience)
that $S = 1$. Then for emanation into
a low conc. medium ($C = 0$); the
flux density $j = \phi d$. ϕ depends
on the U conc. of the rock/shotcrete
and the "free" fraction of this production.
If the "free" fraction is 100%;

$$\phi = 3.75 \times 10^2 \, Bg/cc. \left| \frac{\rho}{3g/cc} \right| \left| \frac{\cancel{1ppm}}{\cancel{[U]}} \right| \left(\frac{[U]}{1ppm} \right)$$

$$= 1000 \, pCi \, \ell^{-1} \left(\frac{\rho}{3g/cc} \right) \left(\frac{\cancel{1ppm}}{\cancel{[U]}} \right) \left(\frac{[U]}{1ppm} \right)$$

$$\cancel{= 7.75 \times 10^4 \, Rn \, atoms \, cc \, (\quad)(\quad)}$$

The authors recommend $[U] = 2 \, ppm$;
giving $\phi = 2000 \, pCi/liter$ and
$d = 7.0 \, cm$. We take these numbers

at face value. (Note: the authors actually quote d = 10cm).

Calculations :-

Table 1 : This shows in the last column, the required barrier thickness to reach $j(0) \doteq 13$ atoms/m²/hr for a shotcrete source term of $\phi = 2000$ pCi/liter. i.e. 2 ppm U and d = 7 cm (for shotcrete)

S (solubility)	for polyurethane barrier ℓ (diff. length) (cm)	thickness, a (cm)	(in)
5.5	0.14	1.75	0.689
1.0	0.12	1.3	0.512
8.0	0.06	0.725	0.285

Table 2 : The emanation rate from rock/concrete may be factor of 10 less than shotcrete, but the [U] conc. is only a factor of ~ 2 lower. [Refs 7 and 6]

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This would indicate $\phi \approx 1000$ pCi/l and $d = 1.4$ cm to give a flux density of of 5.29×10^2 atoms $cm^2 m^{-2} s^{-1}$. In this case, the required thickness of barrier is:-

for P.U. barrier

S (solubility)	d (diff. length) (cm)	thickness a (cm)	(inch)
5.5	0.14	1.6	0.630
1.0	0.12	1.2	0.472
8.0	0.06	0.66	0.260

Conclusions The increased flux density estimate from the shot crete surface has considerably tightened the requirements for the P.U. as a Rn barrier.

① The presently proposed $0.250''$ to $0.300''$ thick P.U. barrier is barely suitable (no margin of error) in case the Rn diffusion parameters are similar to a "hard" P.U. film. However neither is the S and d known for the presently proposed "softer" P.U. [H.H. 453] nor is the effect of water saturation and hydrostatic head known.

②. Putting a concrete surface with a factor of ~2 less U content but ~5 less diffusion length does not help matters. A concrete formulation with considerably less [U] needs to be found.

Emanation from P.U. material itself:

We require that the P.U. barrier itself contribute no more than the equivalent of 10^{-13} g/g U in the form of ^{222}Rn to the light water outer region. 3 sources of such contribution are outlined below:

① Dust on the surface: If dust has (a density of 3 g/cc and) a U conc. of 2.5 ppm, and if all the Rn in a dust film on the surface comes out, then to reach a flux density of 13 Rn atoms /m²/hr (which gives 10^{-13} g/g eq U in 5800 t of H_2O), we need to limit the dust loading to < 11.5 µg of dust cm^{-2}.

② The emanation rate of the P.U. layer itself must be measured to be less than 13 atoms m^{-2} hr^{-1} due to its

intrinsic content of U. For the "MIROC"
type material, this intrinsic emanation
rate was found to be ~ 2 atoms $m^{-2} hr^{-1}$.
The intrinsic emanation rate of HH453 material
is being measured (at this very moment) in
the W.E.T. Lab.

③ Mine dust can get trapped in the P.U.
as it is being sprayed on the cavity walls.
Certainly if the condition for ① is adhered
to. ie. deposited dust is kept $< 11.5 \mu g \, cm^{-2}$,
the emanation rate should be O.K. Improved
estimates are in progress.

References: *Say something re measurement of S.D. on things at W.E.T Lab?*

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