Leakage in the 60 Tonne D_2O Tanks

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The specified (Monte Carlo) level for D_2O in the acrylic vessel is 1×10^{-14} gU/g.

It will take at least 7 days to exchange D_2O from a 60 tonne tank into the acrylic vessel. In that time the radon in the 60 tonnes will have decreased by a factor of 1.8 due to decay. Hence the tolerable level of radon initially in a 60 tonne tank is equivalent to 1.8×10^{-14} gU/g.

1. Leak rate of mine air into a 60 tonne tank

We first calculate how many Rn/hr leaking into the tank will give a 1.8×10^{-14} contribution.

L_l (Rn/hr) (3.8 day $\times$ 24/ln2) = 6480 Rn. Therefore L_l = 49.2 Rn/hr

This corresponds to a leak rate L of mine air of

L (cc/sec)(35000Rn/ 1000cc) = 49.2 Rn/hr. Therefore L = 4×10^{-4} cc/sec

This estimate ignores the dilution of the radon concentration when the 60 tonnes is mixed into the 1000 tonnes in the acrylic vessel.

(Note that 10^{-4} cc/sec = 10 cc/day to give you a feel for the size of leak we are after).

The polypropylene layer must not have a leak rate of more than 4×10^{-4} cc/sec.

Techniques such as soap bubbles are good to 10^{-3} to 10^{-4} cc/sec. Dye penetration is good to around 10^{-4} but involves messy dyes that are hard to clean up. Pressurizing the inside of the tank with a sniffer gas and using a sniffer on the outside of the tank is good down to about 10^{-5} cc/sec and maybe lower in some limited situations.

We propose that the manufacturer do a soap bubble test to demonstrate there are no leaks to the level of sensitivity achievable with soap. Scientists would follow up with a more sensitive test and get smaller leaks repaired.

2. Emanation of radon from polypropylene

The total submerged area of a 60 tonnes tank is about 71 m^2. If radon emanation is to contribute no more than 1.8×10^{-14} gU/g then the rate must be

$6480 \text{ Rn} = R(\text{Rn/m}^2 \text{ hr}) \times 71 \text{ m}^2 \times (3.8 \text{ day} \times 24 / \ln 2)$

which gives $R = 0.7 \text{ Rn/(m}^2 \text{ hr)}$

Samples of polypropylene at least 1 m^2 in area has to be supplied to Queen's for radon emanation testing.

3. Emanation of radon from "transitional materials"

Assume that the polypropylene gives an attenuation factor of 10^4 for radon. Then the "transition materials" should not emanate more than 10^4 Rn per square meter per hour (assuming all the radon comes out of the "transitional materials").

The equivalent amount of uranium tolerable scales with thickness. 10 mils (0.010 inches) of transitional material at 0.4 ppm uranium or 100 mil at 0.04 ppm uranium, etc. would give 10^4 Rn per square meter per hour.

Samples of transitional material at least 1 m^2 in area has to be supplied to Queen's for radon emanation testing.

4. Pressure test with nitrogen gas

The volume of an empty 60 tonne tank is 6×10^7 cm^3. If we pressurize it to 1 psi then an extra 4×10^6 cm^3 of nitrogen gas has to be added.

If we observe a drop of 0.5 psi in one week, then the leak rate is

2×10^6 cc/ 1 week = 3.3 cc/sec

Hence a pressure test with nitrogen in an empty 60 tonne tank will only find gross leaks over a week.

5. Pinholes

From Chris Waltham, $C(\ell/\text{sec}) = 0.182 D^4 P/L$ for a pinhole of diameter D (cm), length L (cm) and pressure differential P (microns). If $C = 4 \times 10^{-4}$ cc/sec, D=0.06 mm, P=0.5 inches of water and L=0.5 cm we calculate that we can only tolerate one such pinhole. Note that a pinhole of 0.06 mm (60 microns) is very small.

6. Specifications on individual tanks

H_2O

All tanks before the radon decay tanks and 10 tonne holding tank do not have to meet an air leak tolerance. These tanks are essentially open to room air.

All tanks after and including the radon decay tank and 10 tonne holding tank must be radon tight in inverse proportion of its volume to the requirement of the 60 tonne tank (4×10^{-4} cc/sec max. leak). For example a 10 tonne tank must not have a leak greater than $(60/10) \times (4 \times 10^{-4}) = 2.4 \times 10^{-3}$ cc/sec.

D_2O

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Appendix

Mine air at 2 pCi/liter of ^{222}Rn has 35000 Rn per liter.

60 tonnes of D_2O at 1.8×10^{-14} gU/g has 6480 radon atoms total.

Half-life of ^{222}Rn is 3.8 days.

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