On Rn Diffusion through Urethane and Polypropylene 1.

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March 4, 1996

SNO-STR-96-013

1. Rn Diffusion/Leaks through Uretane O-rings.

1.1 The experiment

The experiment was performed with O-ring stack made of polypropylene and containing the following urethane O-rings:

- 19 O-rings of 3.3" O.D., 0.139" (0.35cm) of thickness;
- 2 O-rings of 3.5" O.D., 0.125" of thickness;
- 2 O-rings of 1.25" O.D., 0.1" of thickness.

For the sake of simplicity, we'll treat the data assuming that the O-ring stack has 22 O-rings with O.D.=3.2" (8.4 cm), A=0.139" (0.35 cm) of thickness. Total length of O-rings is 580 cm.

Data on Rn rates are presented in Appendix 1. The external origin of Rn inside the stack is clearly seen. As the Rn diffusion through polypropylene was found to be low (see Section 2), we'll assign this effect to Rn diffusion /leaks through urethane O-rings.

1.2 Rn flux into O-ring stack

For estimations of Rn flux we will accept a statement that Rn penetrate through urethane of 0.35 cm of thickness, with a total surface of urethane of S = 3.14xO.D.xAx22 = 200 cm^2. We'll also accept that the equilibrium Rn flux into O-ring stack provides, after extraction and transfer into a Lucas cell, a rate of 200 day-1 in a Lucas cell. The latter corresponds to approx 600 Rn atoms entering O-ring stack in 20 h and, therefore, Rn flux is:

$$j = \frac{600}{S \times 20 \times 3600} = 4.2\times10^{-5}\ cm^{-2}\ s^{-1} \qquad (1.2.1)$$

Rn emanation from urethane contributes approx 2% to the flux j (based on Rn emanation rate of 0.2 Rn/h from 100 cm of urethane O-ring [5]).

1.3 Rn diffusion constant

The following formulae relates Rn flux j with the diffusion constant [1]:

$$j = \frac{2D}{X} \frac{C_{air}}{[\exp(A/X) - \exp(-A/X)]} \qquad (1.3.1)$$

where

- C_{air} - Rn concentration in air which is approx 3 pCi/l underground, or 60 Rn atoms in cm^3;
- $X = \sqrt{Dt}$ - diffusion length; t=4.8x10^5 sec - Rn lifetime.

Equation is satisfied when D = 2.8x10^-7 cm^2 sec^-1.

From (1.3.1) we can find Rn flux through urethane of different thickness:

Table 1.3.1

Thickness	Application	j, cm^-2 sec^-1
0.075" (0.19 cm)	1/2" valve, handle	8.5x10^-5
0.092" (0.23 cm)	1/2" valve	6.8
0.100" (0.25 cm)	1/2" valve	6.2
0.132" (0.34 cm)	1" valve, face	4.3
0.139" (0.35 cm)	2" valve, face	4.2
0.177" (0.45 cm)	FTS	2.9

Smaller the O-ring's thickness (i.e. smaller O-ring's surface), higher the Rn flux "j" per unit surface. Therefore, we can accept an approach that the integral Rn flux through an O-ring is just a MATTER of O-ring's LENGTH.

1.4 Valves as a Rn source

Each polypropylene valve has 6 urethane O-rings:

Table 1.4.1

Valve	O-rings specification				
	Identi-fication	Quan-tity	I.D., inch	Thick, inch	Length, cm
1/2"	handle	2	0.39	0.075	4.3
	face	2	0.65	0.092	6.7
	circumference	2	1.00	0.100	9.8
1"	handle	2	0.62	0.102	6.6
	face	2	1.20	0.132	11.7
	circum	2	1.50	0.132	14.1
2"	handle	2	0.77	0.100	7.7
	face	2	1.86	0.139	17.1
	circum	2	2.41	0.139	21.4

Assume that Rn penetrates through face & circumference O-rings only (there are 2 O-rings in a row in the handle), so, one can estimate background contribution from each valve:

Table 1.4.2

Valve	Total length of face & circum O-rings, cm	Counts/day in a Lucas cell from a valve, 20 h sealed	Rn flux, atoms/h
1/2"	33.0	11.4	1.7
1"	51.6	17.8	2.7
2"	77.0	26.6	4.0

The numbers in the last column are VERY HIGH: for comparison, 1 t of D2O (@ 10^-14 g/g) reproduces 0.45 Rn/h.

1.5 Contribution to the MDG background

Present background of MDG (sealed for 20 h) is 160 counts in a Lucas cell, net [2], with estimated relative contribution from different MDG parts as [3]:

Table 1.5.1

Line between Rn board and FTS	12%
FTS	13%
- Line between FTS and Deg chamber	46%
- Degasser chamber	29%

The measured counting rate of Rn extracted from O-ring stack (sealed for 22 h) is 200 counts/day in a Lucas cell, net. One can compare the measured MDG background with the expected contribution from Rn diffusion through O-rings:

Table 1.5.2

	Estimated length of O-rings, cm	Counting rate in a Lucas cell, day^-1: Expected from diffusion	Counting rate in a Lucas cell, day^-1: Measured (160/day x rel contrib of Table 1.5.1)
1. Line Rn-board/FTS	77	24	19
2. FTS	220	69	21
3. Line FTS/Deg chamber	108	34	74
4. Degasser chamber	150	47	46
- Total	555	191	160

Note that the high expectation of "2" compare to the measured rate could be due to the fact that the assumption accepted in section 1.3 is not correct; high measured rate in case "3" could be due to the fact that high bkg contribution from valve NCV127A (see discussion in [2]) may still exists.

2. Radon diffusion though polypropylene.

To study Rn diffusion through polypropylene, extractions were made from led polypropylene pipe of the following dimensions:

- 183 cm lenght,
- 2.4 cm I.D.,
- 3.3 cm O.D.,
- 1,900 cm^2 surface,
- 0.45 cm thickness.

Rn rate was measured to be 20 counts/day in a Lucas cell (or 60 Rn atoms in Lucas cell), net, after extraction from the pipe sealed for 6 weeks [4]. This rate corresponds to Rn flux through polypropylene:

$$j = \frac{60 \times \ln 2}{3.8 \times 86{,}400 \times 1{,}900} = 6.7 \times 10^{-8} \ \mathrm{cm}^{-2}\ \mathrm{sec}^{-1} \qquad (2.1)$$

Equation (1.3.1) is satisfied when diffusion constant

$$D < 1.2 \times 10^{-8} \quad \mathrm{cm}^{2}\ \mathrm{sec}^{-1} \qquad (2.2)$$

(As there may be a contribution from Rn emanation, we consider it as a lower limit for D). The number obtained is about factor of 2 better than the estimated from the results of the Rn emanation experiment at Queen's (see Appendix 2).

Total Rn load from PP pipes in the MDG (assuming 5 ft x 2" dia x 1/4" thickness) will be < 12 Rn atoms/20 h, or < 4 counts/day in a Lucas cell, net, extraction from the MDG sealed for 20 h. The latter number is far less than the present background of MDG (160 counts/day in a Lucas cell, net, after extraction from MDG sealed for 20 h [2]); therefore, Rn diffusion through polypropelene as a source of MDG the background is ruled out.

In a similar way one can estimate Rn load from all PP of the D2O system: < 350 Rn/h (PP of 3000 ft x 2" dia x 1/4" thick used, taken from [1]).

3. Results and discussion.

- Diffusion/leaks through urethane O-rings is likely to be a source of the present MDG background;

- Diffusion through PP pipes contributes less than 3% to the present MDG background;

- Rn rate measured in O-ring stack can be explained by Rn diffusion through urethane O-rings with diffusion constant

  $$D = 2.8 \times 10^{-7}\ \mathrm{cm}^{2}\ \mathrm{sec}^{-1};$$

- Rn rate measured in PP pipe can be explained by Rn diffusion through polypropylene with diffusion constant

  $$D = 1.2 \times 10^{-8}\ \mathrm{cm}^{2}\ \mathrm{sec}^{-1};$$

- Estimated Rn loads are:

100 cm urethane O-ring, diffusion	- 5.1 Rn/h,
---------//-----------, emanation	- 0.1 Rn/h,
100 cm vitone O-ring, emanation	- 10.0 Rn/h,
---------//-----------, diffusion	- ?
1/2" valve	- 1.7 Rn/h,
1" valve	- 2.7 Rn/h,
2" valve	- 4.0 Rn/h,
all MDG	- 30-60 Rn/h,
PP pipe, 100cm x 2" dia x 1/4" thick	- < 0.4 Rn/h,
all PP in MDG	- < 0.6 Rn/h,
all PP in D_2O system	- < 350 Rn/h,
compared with Rn loads from:	
6000 t H_2O (@15×10^{-14} g/g)	- 40,500 Rn/h,
1000 t D_2O (@10^{-14} g/g)	- 450 Rn/h,
1 t ------//-------	- 0.45 Rn/h

- If vitone O-rings used (instead of urethane), background of the MDG is expected to be at least 2 times higher of the present one;

- Rn load from the MDG alone does not represent relevant background source for the SNO detector if it is in the light water line. However, MDG should be re-designed for the D_2O water system;

- It looks useful to perform an experiment on permeability of valves to Rn under realistic condition, i.e. logged with water: a chain of valves (10 or so) is filled with degassed water, and Rn extraction is done after couple of days of exposure.

References
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[1] B.Sur, SNO-STR-92-056.
[2] H.Lee, V.Novikov, "Progress in the MDG background reduction", Dec11, 1995.
[3] H.Lee, V.Novikov, "Status of the MDG background", Feb 28, 1996.
[4] H.Lee, Nov28,1995 extraction from PP pipe sealed for 6 weeks.
[5] H.Lee et al., SNO-STR-93-045

O-ring Stack

Radon board to top of degasser (**Excluding large FTS O-rings**)	246.5 cm of O-rings
Degasser chamber	184.6 cm of O-rings
O-ring stack	511 cm of O-rings

When the O-ring stack is surrounded by mine air (at about 3 pCurie 222Rn per liter) a 21 hour seal followed by an extraction gives about 200-300 counts per day in the Lucas cell. A seal of 1.5 hours gives about 30-50 counts per day.

The O-ring stack was then covered with two zip-lock bags and nitrogen gas from boil-off liquid nitrogen was flowed into the bags continuously at about 6 liter an hour starting Jan. 9.

The results are:

Jan 10	21 hour seal	307 counts per day
	2 hour seal	27 counts per day
Jan 11	18 hour seal	260
	1.5 hour seal	15
	1.5 hour seal	23
Jan 15	4 DAY seal	113
	1.5 hour seal	21
Jan 16	23 hour	28
	1.7 hour seal	8
Jan. 22	5 DAY seal	30
Jan 23	23.5 hour seal	29
	**** Shut off the nitrogen gas flow on Jan 23 **	
Jan 25	2 DAY seal	98
	1.6 hour seal	8
Jan 26	21 hour seal	78
	1.4 hour seal	19
Jan 30	4 day seal	300
Jan 31	22 hour	140
Feb 5	22 hour seal	130

(Please note that for the numbers 8, 15, 21, 23, 27, 28, ... etc. per day there are very large statistical errors on them)

The extractions on the O-ring rig are now over. NO MORE. Looks like diffusion through O-rings accounts for about 17% of the 5 hour running monitor degasser background.

On Rn Diffusion through Polypropylene

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September 19, 1995

1.ESTIMATION of DIFFUSION CONSTANT in PP.

For 1/4" thick PP emanation rate was found to be <0.14 Rn/(m^2 hr) [1], or 3.9x10^-9 cm^-2 sec^-1. This limit can be considered as well as a limit on Rn flux, j, due to diffusion through polypropylene.

The following formulae [2] relates Rn flux with the diffusion constant D [2]:

$$j = \frac{2D}{x} \frac{C_{air}}{[\exp(a/x) - \exp(-a/x)]}, \qquad (1)$$

where

- C_{air} - Rn concentration in air; for rough estimation, we can take 0.1 pCi/l (2 Rn in c.c. or so),
- $x = \sqrt{Dt}$ - diffusion length,
- t = 5.5 days = 4.8x10^5 sec - Rn lifetime,
- a = 0.635 cm (1/4") - PP thickness.

Equation (1) is satisfied when D = 2.8x10^-8 cm^-2 sec^-1, which represents upper limit on diffusion constant D in PP.

2.DISCUSSION of MDG DATA.

The mall section of PP piping between the Rn board and FTS is a source of relatively high Rn: after 2.8 days of sealing approx. 400 Rn atoms are appearing in this part. Consider if Rn diffusion through PP could be a source of Rn.

Taking D = 2.8x10^-8 cm^-2 sec^-1, a = 0.45 cm, C_air = 3 pCi/l (approx. 50 Rn/c.c.), one can get from equation (1) j = 2.5x10^-7 cm^-2 sec^-1. Taking total surface of PP of 1,500 cm^2, one finds (corrected for decay) 36 Rn atoms to be accumulated after 2.8 d of sealing,- far less than 400 Rn seen.

Since the upper limit on D was used, we conclude that diffusion through 0.45 cm PP is unlikely to be a source of Rn in this part of the MDG.

[1] H.Lee et al., SNO-STR-94-048.
[2] B.Sur, SNO-STR-92-056.

On Rn Diffusion through Urethane and Polypropylene-II

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March 27, 1996

The Rn flux into an O-ring stack filled by nitrogen was found to be similar to the flux when it is under vacuum. This result supports Rn diffusion through urethane O-rings as an explanation for the appearence of Rn inside the stack.

Three extractions were done from the sealed O-ring stack [1] filled by nitrogen @ 1 atm. To ensure effective Rn extraction from N2, extractions were done at a very low flow rate which was controled by the vacuum level at the Alcatel pump.

Extractions identification	Seal time, d	Max P at Alcatel, mtorr	Extraction time	Estimated N2 flow rate, lpm	Counts/day in a Lucas cell, net
1. March 12, 1996					
a) bkg prior to extr.			45min		45/ LC #7
b) extraction from N2	4.9	120	1h37min	0.01	405/ 9
c) bkg after extract.			1h37min		27/ 8
2. March 13, 1996					
a) extraction from N2	1.0	200	45min	0.02	127/ 6
3. March 25, 1996					
a) bkg prior to extr.			45min		0/ 6
b) extraction from N2	10.2	50	2h30min	0.007	390/ 8

The Rn rates obtained are very similar to the ones for the O-ring stack without N2 [1], and the results of the experiments described here can be explained if Rn diffuses through the urethane with a diffusion constant of $D = 2.8 \times 10^{-7}\ cm^2\ sec^{-1}$,- the same as estimated in [1].

[1] E.Bonvin, P.Jagam, H.Lee et al., "On Rn Diffusion...", March 4, 1996.