SNO-STR-91-53

Degassing Radon in the Initial Fill

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The acrylic vessel of the Sudbury Neutrino Observatory is to be surrounded by 7300 tonnes of light water (H_2O). At a continuous fill rate of 38 ℓ/min, it will take 133 days to fill the tank. The influent (INCO) water contains ^{222}Rn with an initial activity of 5 pCi/ℓ, and if we were simply to fill the tank with this water, we would have to wait approximately two months for this radon to decay to the equivalent level of 1.5×10^{-14} gU/gH_2O. If, however, we were to degas the water for some or all of the fill, the necessary waiting period would be much shorter.

If the radon from the influent water is assumed to have mixed uniformly at the end of the fill, then from SNO-STR-88-001, we have:

$$\overline{A} = \frac{A_o}{T}\int_0^T e^{-\lambda(T-t)}dt$$
$$\simeq \frac{A_o}{\lambda T} \text{ for } T \gg \frac{\ln 2}{\lambda}$$

where $\overline{A}$ = average activity in tank after T days of fill
A_o = ^{222}Rn activity of influent water
T = fill time
$\lambda = \frac{\ln 2}{3.8\text{ days}} = 0.1824\ \text{d}^{-1}$

One litre of water at the desired level of 1.5×10^{-14} gU/gH_2O has an activity of 2×10^{-7} ^{222}Rn decays/sec. For tank water with an activity of $\overline{A}$, it takes a time $t_{wait} = -\frac{1}{\lambda}\ln\frac{2\times10^{-7}}{\overline{A}}$ to decay to this level.

We consider the following six cases:

Case A: <u>No degassing</u>

$A_o = 5$ pCi/ℓ
$T = 133$ days
Therefore, $\overline{A} = 0.206$ pCi/ℓ
$= 7.63 \times 10^{-3}$ decays/sec, and
$t_{wait} = 57.8$ days

Case B: <u>Degas from day 1 to day 133 with 99% efficiency</u>

$A_o = (1 - 0.99) \times 5$ pCi/$\ell = 0.05$ pCi/ℓ
$T = 133$ days
Therefore, $\overline{A} = 2.06 \times 10^{-3}$ pCi/ℓ
$= 7.63 \times 10^{-5}$ decays/sec, and
$t_{wait} = 32.6$ days

Case C: <u>Degas last 30 days with 99% efficiency</u>

First 103 days: $A_o = 5$ pCi/ℓ
$T = 103$ days
$\overline{A} = 0.265$ pCi/ℓ
$= 1.50 \times 10^6$ pCi in 5660×10^3 ℓ
Last 30 days: $A_o = (1 - 0.99) \times 5$ pCi/$\ell = 0.05$ pCi/ℓ
$T = 30$ days
$\overline{A} = 0.00914$ pCi/ℓ
$= 15000$ pCi in 1640×10^3 ℓ
Total activity: $[(1.50 \times 10^6)(\frac{1}{2})^{\frac{30}{3.8}} + 15000]$ pCi
$= (6303 + 15000)$ pCi $= 21303$ pCi in 7300 tonnes
$= 2.92 \times 10^{-3}$ pCi/ℓ
$= 1.08 \times 10^{-4}$ decays/sec
Therefore, $t_{wait} = 34.5$ days

Case D: <u>Degas last 30 days with 99.99% efficiency</u>

First 103 days: Same as case B

Last 30 days: $A_o = (1 - 0.99)^2 \times 5$ pCi/ℓ = 0.0005 pCi/ℓ

T = 30 days

$\overline{A} = 9.14 \times 10^{-5}$ pCi/ℓ

= 150 pCi in 1640×10^3 ℓ

Total activity: (6303 + 150) pCi = 6453 pCi in 7300 tonnes

= 8.84×10^{-4} pCi/ℓ

= 3.27×10^{-5} decays/sec

Therefore, t_{wait} = 27.9 days

Case E: <u>Degas last 40 days with 99% efficiency</u>

First 93 days: A_o = 5 pCi/ℓ

T = 93 days

$\overline{A}$ = 0.295 pCi/ℓ

= 1.50×10^6 pCi in 5090×10^3 ℓ

Last 40 days: $A_o = (1 - 0.99) \times 5$ pCi/ℓ = 0.05 pCi/ℓ

T = 40 days

$\overline{A}$ = 0.00685 pCi/ℓ

= 15000 pCi in 2210×10^3 ℓ

Total activity: $[(1.50 \times 10^6)(\frac{1}{2})^{\frac{40}{3.8}} + 15000]$ pCi

= (1017 + 15000) pCi = 16017 pCi in 7300 tonnes

= 2.19×10^{-3} pCi/ℓ

= 8.12×10^{-5} decays/sec

Therefore, t_{wait} = 32.9 days

Case F: Degas first 103 days at 99% and last 30 days at 99.99% efficiency

First 103 days: $A_o = (1 - 0.99) \times 5$ pCi/ℓ = 0.05 pCi/ℓ
$T = 103$ days
$\overline{A} = 2.65 \times 10^{-3}$ pCi/ℓ
$= 1.50 \times 10^{4}$ pCi in 5660×10^{3} ℓ

Last 30 days: $A_o = (1 - 0.99)^2 \times 5$ pCi/ℓ = 5×10^{-4} pCi/ℓ
$T = 30$ days
$\overline{A} = 9.14 \times 10^{-5}$ pCi/ℓ
$= 150$ pCi in 1640×10^{3} ℓ

Total activity: $[(1.50 \times 10^{4})(\frac{1}{2})^{\frac{30}{3.8}} + 150]$ pCi
$= (63 + 150)$ pCi = 213 pCi in 7300 tonnes
$= 2.92 \times 10^{-5}$ pCi/ℓ = 1.08×10^{-6} decays/sec

Therefore, $t_{wait} = 9.2$ days

Conclusion:

While it is advantageous to degas the influent water at 99% efficiency for the last 30 days of the fill, degassing twice for this time interval would not reduce the decay time by a significant amount, since the decay time is dominated by the radon put in during the first 103 days of fill. However, degassing at 99% efficiency for the first 103 days and then at 99.99% efficiency for the last 30 days would result in a much shorter waiting period of 9.2 days. Degassing for the last 40 days of fill at 99% would make the waiting time only 2 days shorter than degassing at 99% for the last 30 days.

The above calculations assume complete radon mixing. If the fill can be arranged in such a way that the water does not mix, then after 104.5 days the PMT support structure is under water and with no degassing the radon inside it will decay to 1.7×10^{-3} pCi/ℓ = 6.3×10^{-5} decays/sec by the time the fill is complete. (The D_2O would have decayed to 1×10^{-3} pCi/ℓ in this time.) This radon will decay to 2×10^{-7} decays/sec in 31.5 days.

One additional source of radon is the air above the water. To minimize the exchange of radon, O_2, N_2, etc. during filling, plastic ping-pong balls might be floated on the water surface. It is difficult to estimate how much radon in the air enters the water (and therefore increases the waiting time after finishing the fill). When the fill is complete, an inert cover gas will be put in to blanket the space above the water.