Options for the Makeup Water

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1 Conversion Factors

Water inside the PSUP	1700 tonnes
Water outside the PSUP	5300 tonnes
Recirculation rate	132 liters/min continuous
Turnaround time inside the PSUP	9 days
Turnaround time outside the PSUP	28 days
INCO water	0.4 pCi/liter (=7000 Rn/liter)

Water at 1×10^{-14} gU/g has 60 ^{222}Rn per tonne or 0.06 Rn/liter

Storage time Factor 10	12.6 days
Factor 50	21.4 days
Factor 100	25.2 days

2 Radon Load and Recirculation Degassing

It is estimated that at worse there will be about 0.4 radon per liter inside the PSUP. The biggest uncertainty is the 0.4 μg/cm^2 estimate in the level which dust can be cleaned to.

It is estimated that at best there is 2 Rn/liter outside of the PSUP. The largest uncertainty is how much dust will be left on the surfaces. Refer to SNO-STR-92-016 for more details on the estimates.

The ratio of radon outside to inside is $2/0.4 = 5$ at best. If the radon is a factor of 10 higher in the outside and one-tenth lower inside the PSUP then this ratio is 500. Hence we probably need a 99% degasser in the recirculation loop so that water returning inside the PSUP does not have more radon than is already there.

3 Makeup Water Requirements

Makeup water for the H_2O system is required because of losses. The estimated loss rates are given in the table below.

Recirculation Degasser (132 l/min capacity)	190 liter/day	(water vapor loss of one degasser
	380 liters/day	(two degassers)
Evaporation Loss to cover gas	121 liters/day	maximum
Liner leaks	?? liter/day	
	or about 20 tonnes	if leak fills up liner
Monitoring	0.5 to 2 liter/batch	At most three batch per day
Filter changes, flushes	100 -- 200 liter/change	probably 6 - 12 times a year
Total Loss	310 to 500 liter/day	MAXIMUM during normal operation (i.e. no leaks, no filter changes)

4 Where to Put Back the Makeup Water

4.1 Straight to the outside of PSUP

The 5300 tonnes of water outside the PSUP is at best 2 Rn/ℓ which means a total of 1.1 $\times$ 10^7 radon. Putting in 310 to 500 liters of makeup a day means injecting 2.2 $\times$ 10^6 radon in a localized volume which would then mix gradually into the 5300 tonnes.

The makeup rate to recirculation rate is 1 to 377—600. The Rn per liter of water outside the PSUP to the Rn per liter in the makeup water is 1:7000. Hence a single degas of the makeup water is in all likelihood required.

We will need a holding tank on the makeup water for level control purposes. This leads us to the case below (Section 4.2).

4.2 Store in a holding tank and pump to the outside of the PSUP

Assume the volume of the holding tank is 10 tonnes and the amount of makeup required is 500 liters per day. The makeup water is at 0.4 pCi/ℓ or 7000 Rn/liter. We determine the radon in the holding tank as follows:

If we start with 10 tonnes, then after t days there will be (10,000—500t) liters left and the number of radon in this remainder is

(10000-500t)(7000)$2^{-t/3.8}$

We top the tank with 500t liters of makeup with 7000 Rn/ℓ which has

7000 $\times$ 500t radon.

Therefore the total number of radon in the 10 tonnes of water is

(10000-500t)(7000)$2^{-t/3.8}$ + (7000)(500t).

This function has a minimum at about t=7 days of 3.7 $\times$ 10^7 atoms in 10000 liters. Hence the minimum amount of radon in the just filled holding tank is 3.7 $\times$ 10^7 / 10000 = 3700 Rn per liter.

After another t=7 days, there will be (10,000—500t) liters left and the number of radon in this remainder is

(10000-500t)(3700)$2^{-t/3.8}$

We again top the tank with 500t liters of makeup which has 7000 $\times$ 500t radon.

Therefore the total number of radon in the 10 tonnes of water is

$(10000\text{-}500t)(3700)2^{-t/3.8} + (7000)(500t)$

which works out to 3100 Rn/ℓ.

Continuing this series, it can be shown that the lowest value reached will be ($7000 \times 500 \times 7 / 10000$) = 2500 Rn/$\ell$.

Based on the considerations in the previous case (Secton 4.1), this makeup water in all likelihood needs a single degas before it can be put outside the PSUP. The holding tank only wins us a factor of 7000/2500 = 2.8, but we need it in any case for level control and unexpected level upset conditions.

4.3 Store in a 10 tonne tank and put into the recirculation loop

Based on the case above (Section 4.2), makeup water put into the recirculation loop will have at least 2500 Rn/ℓ. The recirculation 99% degasser would bring the makeup water down to 2500/100 = 25 Rn/ℓ. With a makeup rate of 500 liter/day this gives 1.3×10^4 radon per day.

The recirculation rate is 132 liters/min or 1.9×10^5 liters/day. The radon level of the water put back into the inside of the PSUP would be ([1 – 10 Rn/liter)]/100) $\times$ (1.9×10^5) = 3800 to 38000 Rn. These radon combined with the makeup water radon can be compared to 1700 tonnes of water with at most 0.4 Rn/liter or a total of 6.8×10^5 radon.

We conclude that for this case the 99% recirculation degasser is probably sufficient to allow makeup water to be put into the recirculation loop. Space for a second degasser should be left in should the single degasser not approach 99% efficiency and/or the radon load outside the PSUP be higher than expected.