Cover Gas Design Criteria (Physics)

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Purpose of this Document

The purpose of this document is to present for discussion and approval the physics considerations that set the operational requirements of the cover gas system during both the fill and operating periods for the SNO detector. In the following the requirements for the fill and operating periods for the light and heavy water volumes of the detector will be discussed separately, as will the requirements for cover gas over the water purification tanks, calibration operations and discrete neutral current detector installation.

Purpose of and Specification for the Cover Gas System

The cover gas will be a *cordon sanitaire* between the radioactivity and biological activity of the outside world and the pure and sterile environment of the water. Therefore the gas should not support life, should not contribute to the radioactivity-induced backgrounds in the detector, and should be a physical, chemical and biological barrier to the mine environment. In satisfying these demands the gas must not adversely affect the performance of the water system, the optical properties of the light or heavy water, or the structural properties of the detector.

During the *fill period* radioactive contamination via the introduction of radon or thoron is unimportant since there will be adequate time for the daughters of these sources to die down to acceptable levels. The important requirement is to suppress biological growth on the surfaces of the detector and in the bulk water.

During the *operating period* radioactivity considerations become the dominant consideration. The requirement to suppress biological growth remains, but is much less demanding than during the fill period, because of the smaller gas volume required to cover the water in the detector.

Choice of Cover Gas

Nitrogen, argon, carbon dioxide and sulfur hexafluoride have been considered for the cover gas. After discussions with potential gas suppliers nitrogen was chosen because it was found that this gas alone could both satisfy the physics requirements and be provided at an acceptably low cost.

Trace Radioactivity

Fill Period

Normal mine air radon and thoron levels [1] are tolerable during this time, [2][3] so nitrogen extracted from mine air would be useable. It will only be necessary to take care with the activity levels in the last thirty or so days of the fill period. At present a membrane system is believed to be capable of providing the fill gas. Depending on the specifications of the membrane units, filtration of mine dust from the air supply might be required.

Operating Period

The heavy-water purity goal of 10^{-14} gU/g [4] implies a cover gas Rn content of 2×10^{-5}pCi/l under equilibrium conditions [5]. If the cover gas is extracted from mine air (3 pCi/l) then a Rn reduction of more than 5 orders of magnitude is required. It is presently planned to achieve this level by fractional distillation of liquid nitrogen (boiloff). Preliminary tests[6] indicate that this should be an achievable level. This technique means that radon would be concentrated in the liquid nitrogen "residue" so that a final small (to be determined) fraction of the liquid nitrogen in each container must be rejected. It also means that low liquid nitrogen level alarms must be employed to ensure that contaminated gas is not used.

There is the possibility that the heavy water may be purified to a level a factor of ten lower than the present goal of 10^{-14} gU/g. It is not clear at present whether the above purification technique can achieve the corresponding level of 2×10^{-6}pCi/l.

The present design goal for the light water is 10^{-13} gU/g [7]. This is a factor of ten less stringent than the present purity goal for the heavy water, and is controlled by the radon coming from the various components of the detector.

In order to assure that adequate levels of radioactivity control have been achieved, it will be necessary to monitor the activity of the cover gas over the light and heavy water. This requirement should be satisfied if tap points are provided at the input and exit to the light and heavy water cover gas volumes so that batch-mode off-line gas analysis can be performed. If flowing the cover gas from heavy to light water were to be used, a monitoring tap would be needed between the heavy water gas exit and the light water input.

Oxygen Content

Fill Period

Normal potable water contains about 10 μg O_2/g for water in equilibrium with air. The reduction factor in biological activity in SNO-like conditions (low nutrient levels, dark, cold) caused by deoxygenation has been reported variously as 10 or 100 from small-scale laboratory tests. Assuming a linear dependence of activity with oxygen level (reasonable if activity is oxygen-limited) we should therefore aim to reduce the oxygen level in the cavity by a factor of 100 on the time-scale of a week. This would mean 0.1 μg/g in the water and 0.2% O_2 content by weight in the gas. The value of one week was chosen on the grounds that it was short on the biological time scale of the detector biota [8] while at the same time achievable.

Biological studies of the effects of cover gas [8] suggest that anaerobic activity occurs at a level about one-twentieth of the normal aerobic levels. This, together with possible practical problems reaching a hundredfold oxygen reduction in a week timescale, might require that a reduced goal of approximately a factor of twenty reduction of oxygen content within a week may have to be accepted.

There is a factor of 1000 in biological activity between D_2O and H_2O in *aerobic* SNO conditions. It may be that the anaerobic lab tests were still oxygen limited due to oxygen stored in the plastics used as nutrient sources. In any case it is clear that the same oxygen requirements for the heavy water as for the light water will be satisfactory.

Operating Period

The goal is the same reduction factor as for the fill period. With low makeup flow rates, this presumably becomes much easier to achieve than during the fill. The oxygen content of the nitrogen obtained by evaporation from liquid nitrogen will have to be measured to confirm that this is so.

Conditions for Light and Heavy Water Purification Tankage

The oxygen, radioactivity and monitoring requirements for the cover gas in the light and heavy water purification system tanks are the same as for the respective water volumes in the detector during the operating period. Accordingly the heavy water system has a factor of ten more stringent radioactivity requirement than the light water system.

Flow Rates

Fill Period

The aim during the fill period is to exclude oxygen from the cavity as quickly as possible to prevent the formation of biofilm on the detector. The growth of a biofilm tends to occur on the order of a few weeks, and once established, it provides its own micro-environment which makes it resistant to attack.

To fill the 7000 m^3 volume with cover gas in one week would require a flow rate of 11.6 $l{\cdot}s^{-1}$. If we assume this flow mixes completely with air already in the cavity then a number of fills will be needed to reduce the oxygen content by a specified amount. For example, if an oxygen reduction of a factor 100 is specified, then $ln100 \approx 4.6$ fills will be needed, *i.e.* a flow rate of about 53 $l{\cdot}s^{-1}$. Details of the fill program will have to be worked out with the gas supplier.

Operating Period

In order to achieve the low radon levels required for the light and heavy water in the close proximity to the mine air it is planned to provide a slight overpressure of cover gas (up to 0.5" water gauge) so that there will be an assured leakage from the cover gas area to the deck area, both for the heavy water and for the light water. This means that all penetrations of the cavity liner must be as leak-tight as practicable and that they must be directly exposed to the cover gas so that the flow of gas from "clean" to "dirty" can be achieved.

The volume of gas above the filled cavity is about 50 m^3 and about 5 m^3 in the neck of the acrylic vessel above the heavy water. The makeup flow rates for the light water will be much lower than during the fill phase; they will be determined by the following losses:

- Solution into the (degassed) water: 0.004 $l{\cdot}s^{-1}$ [9].
- Leaks through the deck structure. Leaks through the cable feed-throughs may be less than 0.001 $l{\cdot}s^{-1}$, but these are not likely to be the dominant factor. PSUP cables and AV ropes are to be pressure sealed.
- Changes in atmospheric pressure: for a 1% pressure change over 24 hours estimated to be around 0.01 $l{\cdot}s^{-1}$.

- Deck leakage contingency budget of about 0.08 $l \cdot s^{-1}$.

Unless the leak situation is out of control, the flow rate necessary to assure a continuous overpressure in the cover gas over the detector will be around 0.1 $l \cdot s^{-1}$ or about 300 $l \cdot hr^{-1}$ in the light water. The flow rate for the cover gas over the heavy water is assumed to be about 10% of that for the light water. It has been assumed that pressure changes from blasting and ventilation surges will happen on a time scale far shorter than the natural period of the cover gas system, so that they will have no effect.

(Assuming that the heavy water is not degassed and that there are negligible leaks, the makeup flow rate into the neck region will be controlled by atmospheric pressure changes. This indicates that a total flow rate of around 1×10^{-3} $l \cdot s^{-1}$ could be required for the heavy water cover. If such a rate is in fact achieved, then the requirement on the gas radiopurity over the heavy water could be relaxed to approximately 2×10^{-4} pCi/l due to the relatively long dwell time of the cover gas. However such a low gas demand would have to be demonstrated before lower quality gas could be used.)

Light and Heavy Water Purification Tankage

The light water purification system will contain tanks totalling about 100 m^3, of which about 30 m^3 would be cover gas. The heavy water system will have about 200 m^3 of tankage, of which about 100 m^3 will be cover gas. The cover gas volume is assumed to be essentially constant except for occasional topping up (5 m^3) of the radon decay tank at a rate of about 1 $l \cdot s^{-1}$. This rate is taken to be the maximum rate that the cover gas system is required to supply clean gas under running conditions, but not under detector fill interchange periods. The latter are discussed separately below. (As for the detector volumes, a slight overpressure of up to 0.5" water gauge is to be maintained at all times in the tanks.)

It is assumed that there will be negligible leakage in the tankage system so that the heavy water tankage cover gas supply will only be required to make up atmospheric pressure swing losses, which should be around 0.02 $l \cdot s^{-1}$. This ignores nitrogen dissolved into a small fraction of the heavy water that is degassed. The light water will have a makeup requirement of about 0.01 $l \cdot s^{-1}$ to account for atmospheric pressure swings. It is assumed that gas used for one tank is not passed on to other tanks. If it were planned to use exhaust heavy water cover gas (after removal of heavy water vapour) to cover light water it would have to be demonstrated that the radioactivity criteria for the gas moving into such a tank was met.

Present experience [10] with the water system indicates that there will be a leakage due to pressure control in the tankage of about 0.01 $l \cdot s^{-1}$ for this purpose.

Total Flows

The total estimated flow for the cover gas demands described above is about 0.11 $l \cdot s^{-1}$. This is equivalent to about 13 l of LN_2 per day. There are also a number of other cover gas demands. If makeup for the water purification system drying gas is estimated at 0.1% then there would be a requirement of about 6×10^{-4} $l \cdot s^{-1}$ for this purpose. (However it should be noted that this would occur as a *surge* of about 1 $l \cdot s^{-1}$ for about 5 minutes.) Degasser use would require about 1.2×10^{-3} $l \cdot s^{-1}$. The H_2O/D_2O level measurement system (bubbler) would use about 2×10^{-3} $l \cdot s^{-1}$. If the calibration system - AV port interlock is vented once a month this would use about 3×10^{-6} $l \cdot s^{-1}$.

These additional uses would give a total estimated demand of about 18 l of LN_2 per day. If a 10% loss is assumed for radon buildup during evaporation, the total would be increased to about 20 l of LN_2 per day. This number assumes that neutral current detector insertion and calibration normal operation does not have any continuing demands on the cover gas supply. At present it is anticipated that the only LN_2 demands for calibration in addition to the ones mentioned above is an initial flush of source holders amounting to about 31 l of LN_2 over the course of about a week.

Flows During Detector Fill Interchanges

The above estimates do not consider times when the detector fill is changed between heavy and light water. To estimate the gas flow required to follow the water level with dexoygenated (and presumably low-radioactivity) nitrogen, we assume that the maximum possible emptying rate is limited by the INCO drain capacity (40 gals/minute). If we take an extreme demand of 200 l/min for nitrogen gas, this would imply that a 250 l LN_2 tank would be emptied in about 15 hours. This seems a manageable timescale for LN_2 tank replacement and would imply that the gas flow piping should be sized to accommodate a maximum gas flow of about $3.3\ \mathrm{l}\cdot s^{-1}$.

Interface with Calibration and Neutral Current Detector Insertion

Any calibration activity is to be such that it maintains the cover gas oxygen and radioactivity levels as outlined above during and after such activities. Similarly, the procedures for neutral current insertion should leave the cover gas properties as outlined above on completion of the insertion process. From preliminary discussions it is believed that the flow estimate of 200 l/min for the detector fill interchange phase should be more than adequate for the neutral current detector insertion. The NC Worst Case Envelope [11] document suggests a maximum flow of $1\ \mathrm{l}/s^{-1}$.

Summary and Conclusions

The cover gas system is to be designed to provide a nitrogen cover at 2×10^{-5}pCi/l radon for the heavy water and 2×10^{-4} pCi/l radon for the light water during the running period and no radon requirement during the fill period. The oxygen content is to be at the 0.2% level or better from a short time after the start of the initial fill (although this may have to be relaxed following further consideration). Nitrogen flow rates should be about 20 l of LN_2 per day during normal running conditions, with provisions for a maximum gas flow rate of about 3.3 l/s (during detector fill interchanges). Total deck penetration leak allowance to each of the PMT, PSUP and AV should individually contribute no more than about 10% of this normal running gas flow. Short term leak increases (due *e.g.* to tension adjustment) should not jeopardize the net outflow condition of the cover gas.

The specifications as given are conservative in that they do not account for decay time of the cover gas. Accordingly the operating requirements should be reassessed after construction of the detector when actual gas flow conditions are known.

The maximum gas flow rates indicated above imply possible loads on the HVAC system and must certainly be dealt with in a way so as not to create a safety hazard. These are outside the scope of this document, but nevertheless must be dealt with.

References

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[3] H. Lee *et al.*, **D_2O Radon Considerations**, SNO-STR-92-040.

[4] G. T. Ewan *et al.*, **Sudbury Neutrino Observatory Proposal**, SNO-STR-87-12.

[5] B. Sur, **Some Elementary Considerations About Cover Gas**, SNO-STR-91-055.

[6] X. Zhu *et al.*, **WET Lab Monthly Report**, July 1992.

[7] B. Sur, H. Lee and B. C. Robertson, **Radon Control Options for the Cavity Liner**, SNO-STR-92-17.

[8] Ramey and Smit, **Effects of Anaerobic Incubation of Plastic on the Development of Populations of Bacteria**, (SNO subproject report) UBC, 29 June 1992.

[9] H. Lee, **Cover Gas Loss in the H_2O**, SNO-STR-92-043.

[10] D. Sinclair, private communication, August 1992.

[11] R.G.H. Robertson **The NC Worst Case Envelope**, 1990

Cover Gas Loss in the H_2O

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The H_2O recirculation will have one or two in-line vacuum degassers. In the process of degassing, a certain amount of water vapor and cover gas will be taken out and vented to the atmosphere.

The following is an estimate of the amount of cover gas (either N_2 or argon) lost by degassing:

- Flow of water through a H_2O degasser 132.5 liter/min
- Water vapour lost by a degasser 132.5 gm/min
  or 16.6 m^3/min of vapor at 8 Torr
- Amount of dissolved cover gas in H_2O under equilibrium conditions:
  1.7 STP c.c./liter for N_2
  3.7 STP c.c./liter for argon

0.22 l/m 0.00375

Hence the amount of cover gas lost by a degasser is

$$\left.\begin{matrix}1.7\\3.7\end{matrix}\right\}\times 132.5\ \text{l/min} = \left\{\begin{matrix}225 & \text{c.c./min}\\ 490 & \end{matrix}\right.$$

~~$= \left\{\begin{matrix}0.02\\0.05\end{matrix}\right.$ m^3/min of gas at 8 Torr~~

(This is about one compressed gas cylinder per 2 weeks)

The amount of cover gas removed is small compared to the volume of water vapor removed (16.6 m^3/min). Note also that if the volume of a degasser is 2.3 m^3, then it takes $(2.3/16.6) \times 60 = 8.3$ seconds for one complete volume change of water vapor. The radon is swept along by the water vapor which at 8 Torr behaves like a normal liquid. We do not have to pump harder (i.e. generate more than 16.6 m^3 vapor/min) to get the radon because 8 seconds is probably fast enough of a turnover time in the degasser.