ANSTO/C-912

LUCAS HEIGHTS SCIENCE AND TECHNOLOGY CENTRE

A report to the

National Oceanic and Atmospheric Administration
Earth System Research Laboratory,
Boulder, Colorado

on the

COMMISSIONING OF A 1500 L RADON DETECTOR AT THE TALL TOWER SITE IN MOODY, TEXAS

by

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1 Introduction

In July 2006, field work was jointly conducted by the Australian Nuclear Science and Technology Organisation (ANSTO) and National Oceanic and Atmospheric Administration's Earth System Research Laboratory (NOAA ESRL) to install a 1500L radon (^{222}Rn) detector at a tall tower site in Moody, Texas. The tower is the property of the US Federal Communications Commission.

The purpose of this report is twofold:

(i) to present the results of on-site tests performed on the detector, and

(ii) to serve as a reference document for designated staff performing routine maintenance on the detector.

In addition, this report concludes with a list of recommendations for continued operation of the detector based on its operational status at the time of commissioning. A companion document (ANSTO Technical Note) will also be provided with this report. The technical note outlines the method to process the raw detector output from ANSTO radon detectors.

1.1 Detector location and setup

The Moody tall tower site is located approximately 25km north of Temple at (31°18'53"N, 97°19'36"E) (see Figure 1). The radon detector is located adjacent to an airconditioned instrument trailer (Figure 2; Figure 3), approximately 40m north-west of the tower base.

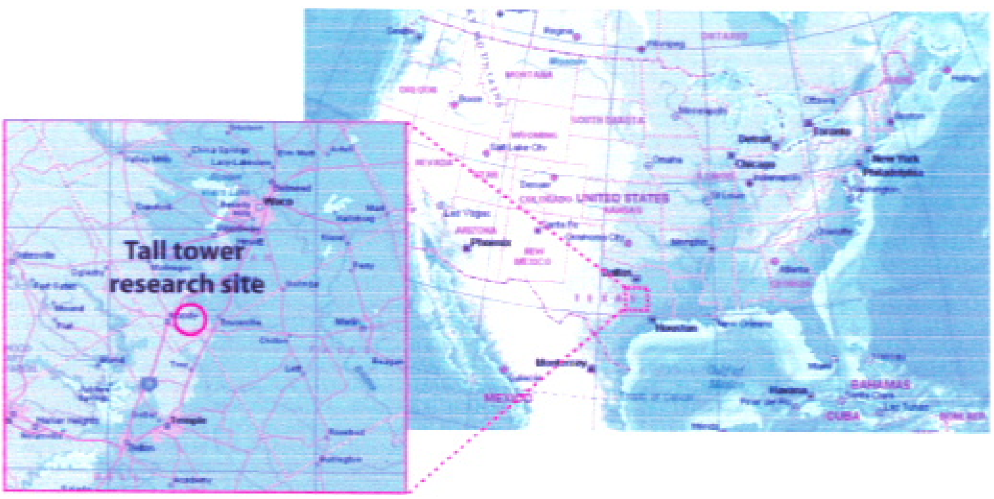

Figure 1: Approximate location of the Moody tall tower site in Texas.

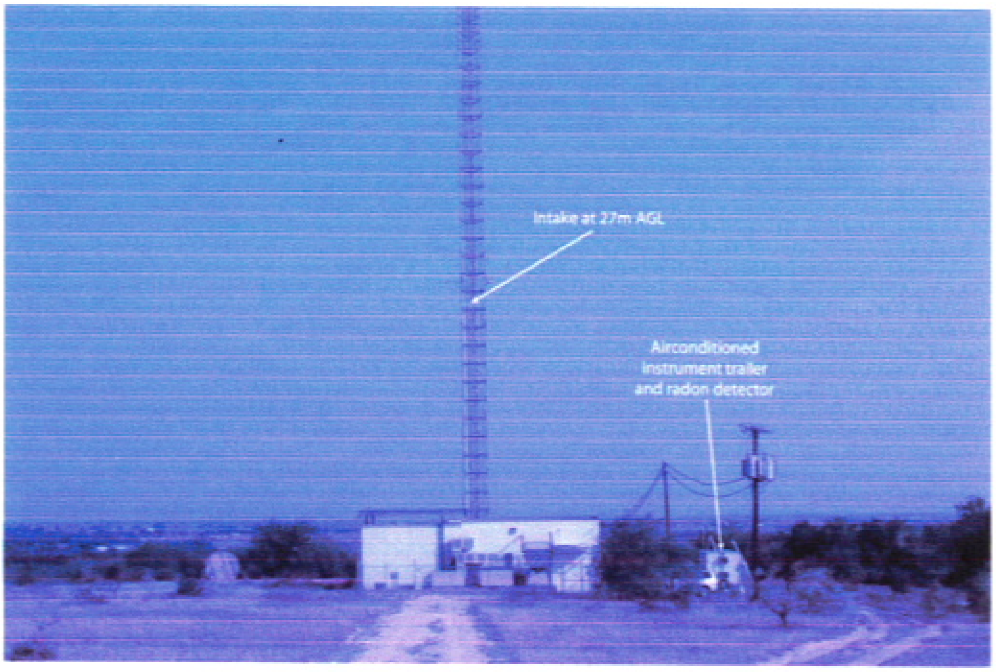

Figure 2: View from the north of the Federal Communication tower site in Moody, Texas.

The communications tower (Figure 2) is approximately 400m tall. Prior to the radon detector being installed, the tower was already equipped to monitor CO_2 and ozone, the instrumentation for which was housed in the trailer. The radon detector was situated outside the southern wall of this trailer (Figure 3).

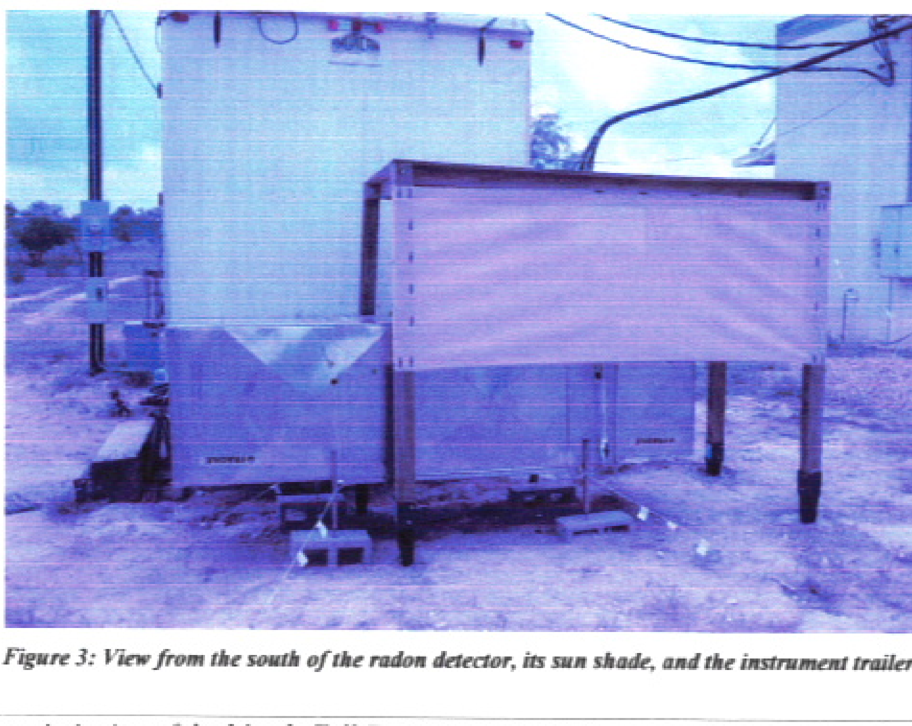

Figure 3: View from the south of the radon detector, its sun shade, and the instrument trailer.

The detector has been designed to require minimal maintenance. Routine tasks include (1) instrumental background checks, (2) detector calibration, (3) data backup/upload, (4) pressure sensor re-calibration, and (5) synchronisation of the logger and PC clocks. Of these necessary tasks, monthly calibration is presently automated.

Descriptions of the above tasks and a suggested schedule are provided in section 5 and the accompanying document **MaintenanceSchedule.xls**. In the event that upgrades of the logger or computer software become available, guidance will be provided to perform the installation.

It is advisable to contact ANSTO before conducting any modification of the installed detector. Any modification or maintenance performed, as well as general comments and results of routine checks, should be recorded, for example, using the electronic log file provided as part of the ***Radon Detector Monitor*** software package, documentation for which has been provided separately.

2 Components

2.1.1 Sample intake

The sampling line for the Moody radon detector is constructed of 4" (100mm) PVC pipe, and has a total length of approximately 75m. From the detector the pipe extends east approximately 14m underground (Figure 4a), then rises approximately 4m before extending approximately 30m south along a catwalk, then up the tower to a height of 27m above ground level (Figure 4b).

The inlet point has been inverted ("gooseneck" style; Figure 4b) to minimise the ingestion of precipitation **(given the dusty nature of the site, it is recommended that a separate aerosol filter also be installed during the next site maintenance visit).**

The intake line is terminated at the detector site by a short section of a reinforced 19mm hose (see Figure 5 and inset).

There have been three water traps installed in the sample line. One at the base of the vertical section of intake line on the tower, another just prior to the intake pipe going beneath the ground, and the final trap just prior to the intake pipe coming back out of the ground near the detector (Figure 6 a-d).

Prior to connecting the detector to the intake line, the maximum flow rate through the unit was 96 L min^{-1}. Once connected to the inlet and with the exhaust valve still fully open the flow rate through the detector was 78 L min^{-1} (due to the impedance offered by the long PVC pipe and length of 19mm hose). When the working overpressure was achieved (described later) by constricting the exhaust valve, the flow rate was 67 L min^{-1}.

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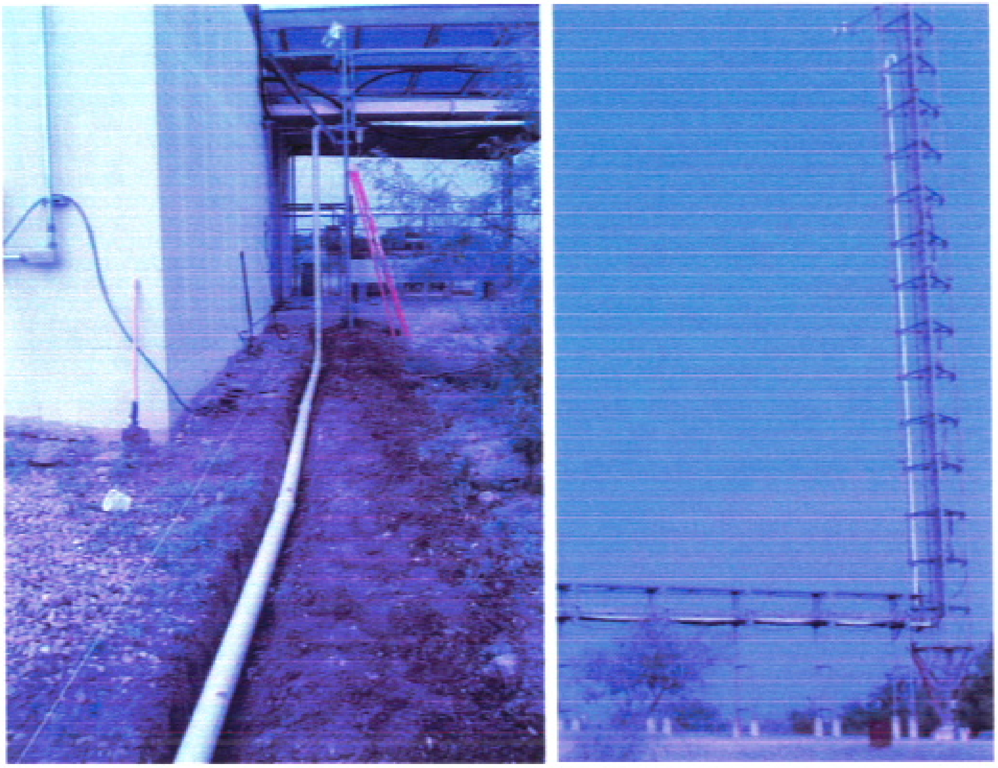

Figure 4: Radon detector's 100mm PVC intake pipe (a) prior to burying and (b) extending up the tower to 27m.

Figure 5: Reinforced clear plastic hose used at the detector end of the intake line. (Inset: shows where it leaves the main 4" PVC sample tube).

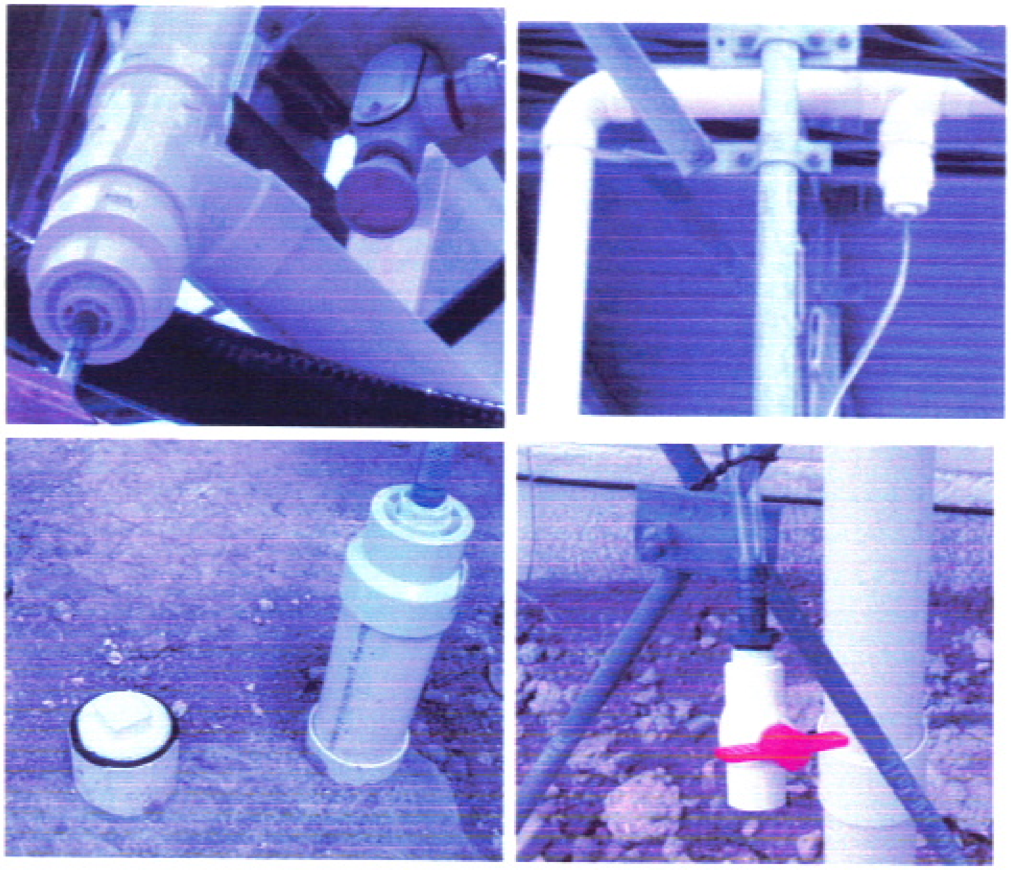

Figure 6: (a) water trap near the tower base, (b) water trap before pipe is directed underground, (c) water trap adjacent where the sample tube emerges from the ground, and (d) example of the termination style of the first two traps.

Significance and removal of thoron (Rn^{220})

It is possible for thoron (an isotope of radon with a shorter half-life) to interfere with the measured radon signal. It is thus desirable to ensure that as little thoron as possible enters the detector tank[1]. Since the half-life of thoron is 55.6 seconds, it is usually sufficient to delay the sampled air before reaching the detector for 5-6 minutes.

For some detector installations, where sample intake heights are lower and tubing lengths shorter, an additional delay volume (of ~400 L) is usually installed to minimise the concentration of thoron in the sampled air.

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[1] Thoron causes an accumulation of ^{212}Pb (half life ~10 hours) on the detectors second filter, the presence of which contributes to the instrumental background of the detector.

However, the total volume of the sample intake line at Moody (75m of 100mm ID tube) is ~580L. Bearing in mind the flow rate measured at the time of commissioning, the delay time for an air sample to reach the detector would be >8 minutes (which is more than nine thoron half lives). Thus, by this delay alone, the concentration of thoron in the air stream would be reduced to negligible amounts. Consequently, provided that the water traps are well sealed, and internal surfaces of the intake pipe are clean, thoron is not expected to significantly contribute to the measured radon signal at this site.

2.1.2 Electronics enclosure

All detector components that need to be accessed for routine maintenance are contained within the electronics enclosure (Figure 7 and Figure 8). Components within the electronics enclosure sit on a platform that is slightly raised from the bottom of the electronics enclosure cover. Exhaust air can escape through a vent in the underside of the electronics enclosure cover.

Important: *The vent on the underside of the electronics enclosure cover is blocked before the detector is shipped. Check underneath the detector to make sure that this cover has been removed for normal operation.*

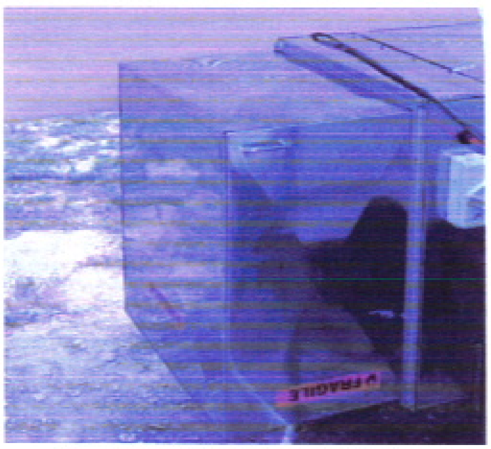

Figure 7: Electronics enclosure closed.

Figure 8: Electronics enclosure open.

A summary of the most clearly visible components within the radon detector's electronics enclosure is shown in Figure 9. It should be noted that the sample inlet valve, data logger and power supply are obscured from view by the gas meter and filter chamber (see instead Figure 12 for inlet valve location).

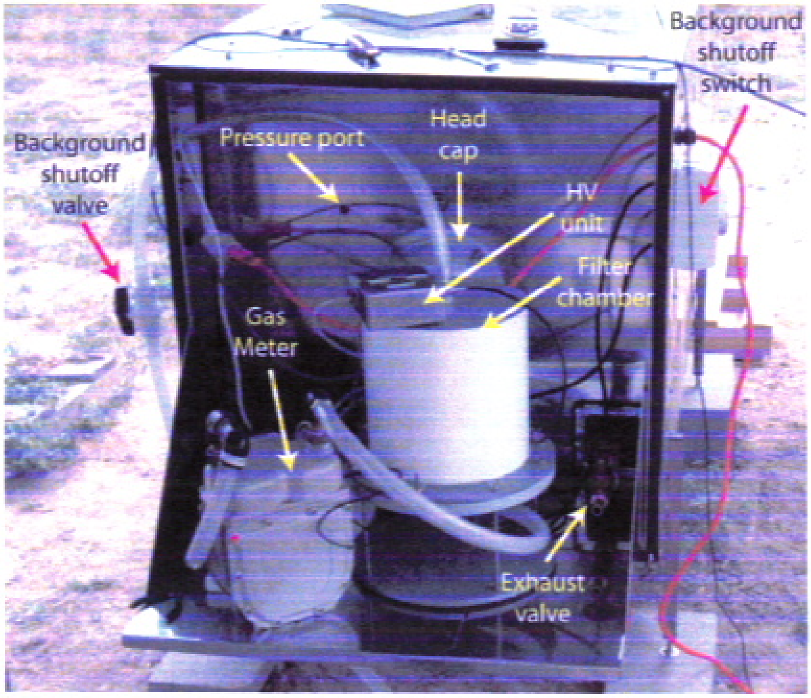

Figure 9: Setup of components within the electronics enclosure.

Sample air enters and leaves the main detector delay volume through inlet and exhaust valves located within the electronics enclosure (Figure 10). These valves provide control over the flow rate through, and pressure within, the main delay tank. By exhausting the sample air back into the electronics enclosure, it is maintained at a positive pressure with respect to ambient conditions. This reduces the chance that external pollutants (which may corrode or otherwise interfere with components of the detector) will enter the electronics enclosure.

The main detector delay tank is also kept at positive pressure with respect to ambient conditions (usually between 80-120 Pa). This is required to minimise the likelihood of ambient radon/thoron progeny at high ground-level concentrations directly entering the detector in the event of a leak developing in the detector's delay volume. The positive pressure is achieved by slightly restricting the exhaust valve (which, in turn, reduces the flow rate through the detector).

To achieve the current overpressure of ~90 Pa in the Moody radon detector (given the length of the intake line), the flow rate through the detector had to be reduced to 67 L min^{-1} (as mentioned previously). **If, for any reason, it is necessary to increase the sampling height at a later date, a stack blower would be required.**

During normal operation, the tank over-pressure is monitored via the tank pressure port (Figure 9, Figure 10) using a micro mass airflow sensor[2] located within the data

[2] Described in the radon detector components report.

logger box. The resulting flow rate is then related to a differential pressure between the tank and ambient atmosphere.

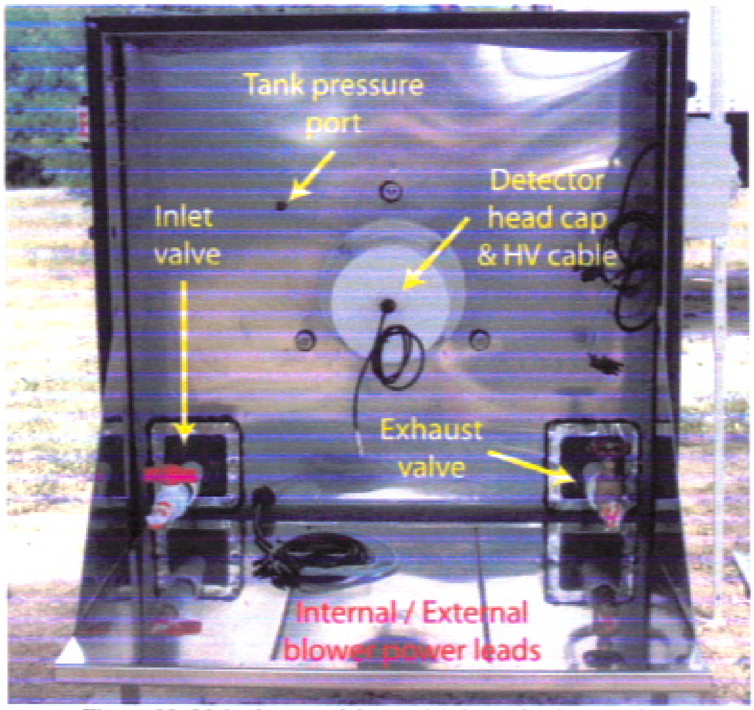

Figure 10: Main detector delay tank inlet and exhaust valves.

2.1.3 Internal/External Blower Enclosure

Two centrifugal blowers are used to move the sample air through an external and an internal flow loop of the detector, and will henceforth be referred to as the external and internal blowers, respectively. The external flow loop refers to the process of drawing sample air *through* the detector delay volume, whereas the internal flow loop refers to the process of circulating the sampled air through the detector's head *within* the detectors main delay volume.

The Moody radon detector has a 1500L delay volume, so at the current flow rate of 67 L min^{-1} the typical residence time for the sample air within the detector delay volume is ~22min.

The blowers are both located at the rear of the detector, inside the main delay volume (see Figure 11). In the event of maintenance being required on the blower units, they can be accessed by removing the cover shown in Figure 12.

<u>IMPORTANT</u>: Before removing the blower cover, switch off the detector power supply – failure to do so will destroy the PMT.

If the rear cover is removed for any reason, the integrity of the foam seal should be checked prior to the cover being replaced. A leak test (see Section 3.1) should then be conducted on the detector prior to restarting.

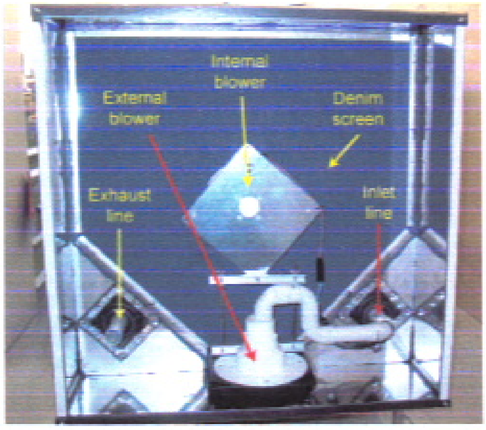

Figure 11: View of the detector with the rear cover removed exposing the mixing chamber where sample air is sucked in and pushed through the denim flow homogeniser to the main delay tank.

Figure 12: Rear cover of an identical radon detector that provides access to the internal and external blowers. The cover is held in place by 4 nuts and bolts at the corners.

Although the two blowers are identical, the flow rate within the internal flow loop is much greater than that in the external flow loop. This is due to different flow impedances of the corresponding flow paths. The internal blower draws air through only the detector head and a short length of 50mm PVC tube, whereas the external blower has to draw air through both parts of the intake line (100mm and 19mm pipes), as well as the internal plumbing of the detector (which is mostly 32mm diameter).

It is necessary to maintain a high circulation rate of the sampled air within the delay volume for improved progeny collection efficiency. For further details regarding the principal of operation of the detector (dual flow loop, two-filter model), the reader is referred to Whittlestone and Zahorowski (1998).

2.1.4 Cap for detector head

Access to the radon detector head is gained via the head cap within the electronics enclosure (Figure 13). The PMT head cap is made from standard PVC components, and is comprised of two pieces, a 150mm bolted trap screw and a 150mm push on cap. A gland is fitted to the push on cap to pass the PMT high voltage cable through.

An O-ring (nitrile rubber type with 6¼" I.D. and 1/8" cross section) is used to make the seal between the head cap and PVC bulkhead fitting.

<u>IMPORTANT</u>: Always disconnect power to the HV unit before removing the head cap, and if the head cap is removed for any reason, always perform a leak test before reconnecting power to the HV unit.

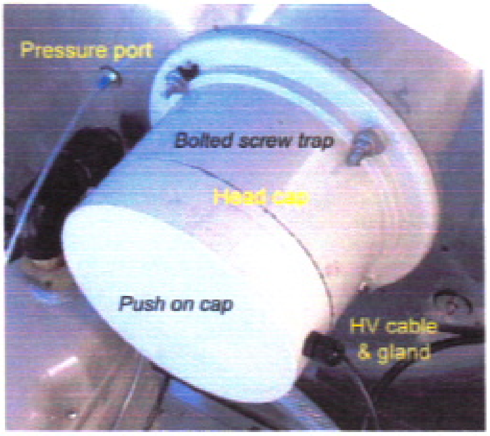

Figure 13: Head cap and components.

2.1.5 The data logger and controlling PC

The data logger and a portable computer (running MS Windows) are used to control the detector sampling protocol and data storage. The computer was supplied by NOAA ESRL.

Figure 14: (a) Radon detector data logger, and (b) controlling computer and calibration unit.

The data logger is situated in the radon detector's electronics enclosure (Figure 14a), and the controlling (Figure 14b) is located in the instrument trailer.

The data logger and computer communicate via a serial connection. The RS-232 communication cable, 120V 60Hz power cable, calibration gas injection line and calibration signal trigger all pass through a bulkhead port in the trailer wall (Figure 15) and into the detectors electronics enclosure.

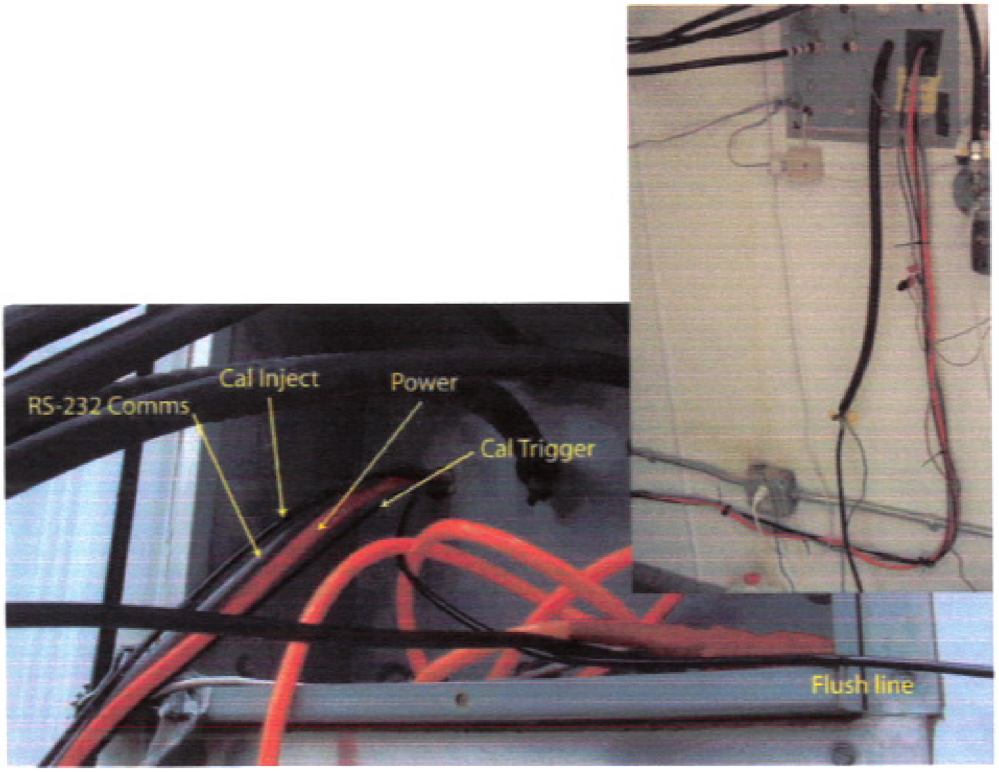

Figure 15:Power, communications and calibration cables inside, and leaving, the trailer.

The logger monitors output from the detector (see Section 8.1 for a channel list). The logger's data file format is comma delimited ASCII (ie. *.csv files). The logger unit is a combination of several components:

1. A Campbell Scientific Inc., CR-510 data logger (http://www.campbellsci.com), SN# 12174;
2. A 12V 2 AH sealed lead acid battery (part no. S3318), Dicksmith Electronics (http://www.dicksmith.com.au);
3. A micro mass-flow controller (Honeywell Microswitch AWM3100 Microbridge mass airflow sensor. 1-800-537-6945. Excitation 10V DC, output 1-5 V DC representing 0-200 sccm, http://www.rswww.com.au/);
4. An electronic interface board, designed and assembled at ANSTO, containing additional circuitry to help the logger power and communicate with components of the detector;
5. Polycarbonate enclosure.

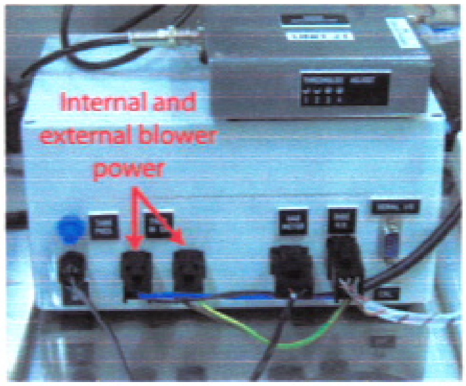

Figure 16: Radon detector data logger in polycarbonate housing.

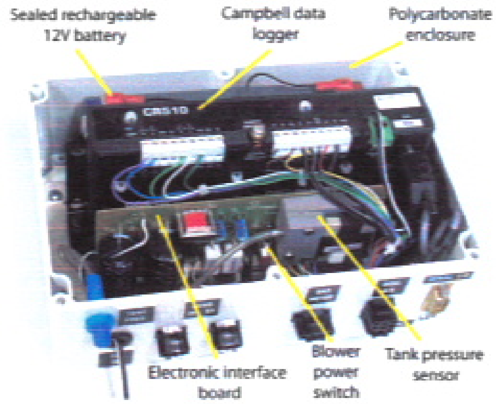

Figure 17: Data logger, housing and additional circuitry for the radon detector.

There are a number of connectors in the logger housing (Figure 16). These include (from left to right, Figure 17): logger power (12V in), a connection for the detector pressure line, blower power supplies (internal and external), flow meter signal, high voltage supply / discriminator power and signal, serial communication port and trigger line for the radon calibration unit.

Power to the internal and external flow loop blowers is distributed via the loggerbox. It is necessary to disconnect power to the blowers for background tests and sometimes for diagnostic purposes. There is an external blower power switch ("background shutoff switch", Figure 9); alternatively, the blower leads can simply be unplugged from the logger housing (Figure 16). If the logger housing is open, a toggle switch mounted on the IC board in the logger enclosure can be used for the purpose as well (bottom, centre Figure 17).

The micro mass flow sensor within the logger housing is used as a differential pressure sensor between the detector tank and ambient air. A calibration was performed on the millivolt output of this sensor at the time the detector was installed. The calibration can be performed by attaching a portable differential pressure sensor to the line between the detector delay volume and the logger micro mass flow sensor (Figure 18). The result of a calibration performed during the commissioning visit is displayed in Figure 19. The PC's Detector Control Program allows for a set of linear calibration coefficients to be entered so that a calibrated real time pressure record can be displayed.

Figure 18: Calibration of the micro mass flow sensor with a hand held differential pressure sensor.

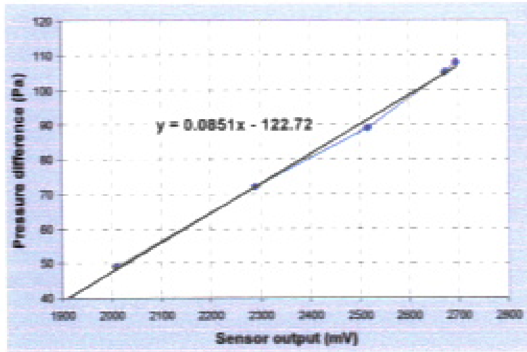

Figure 19: Results of onsite pressure calibration performed on the Moody radon detector and linear approximation of the calibration curve.

3 Detector tests

3.1 Leak Test

3.1.1 Overview

There is a large difference in concentration of short-lived radon and thoron progeny (~2 orders of magnitude) between ambient air and air inside the detector. Consequently, the integrity of the seal around the detector delay chamber is crucial for the detectors operation. A leak test is performed on all newly installed detectors, and may be repeated if deemed necessary by subsequent data quality checks.

As mentioned previously, to counteract inevitable small leaks the detector delay chamber should be kept under a slight positive pressure with respect to ambient (80 to 120 Pa). This ensures that in the presence of a leak air would only flow *from* the detector. The required overpressure can be achieved by slightly constricting the tank exhaust valve (Figure 10).

There are several components of the detector that may cause leakage from the detector delay chamber if not correctly installed. These include: the PVC detector head cap and internal O-ring seal, the gland through which the high voltage supply lead passes, and the pressure port fitting (Figure 13). A satisfactory leak test provides confirmation that these components have been correctly installed. Even a small light leak could damage the sensitive photomultiplier tube in the detector head. Consequently, a leak test should be performed before connecting power to the detector electronics.

Lifting or moving the detector can stress the seams and joints. This may result in small leaks developing. If the detector needs to be lifted or moved, it is recommended that a leak test be performed before it is used again. For the same reasons, do not move the detector with power still connected to the PMT in the case of a light leak developing. A significant light leak would destroy the PMT if power was connected to it at the time.

3.1.2 On site leak test

During the detector installation a leak test was performed in the following manner: the tank exhaust valve was closed and the outlet of the flow meter was connected to tank inlet valve, which was fully opened (Figure 20). Power was then applied to the external blower. Several minutes was allowed for the tank to pressurise before the flow rate was read from the gas meter's analogue readout over a three minute period. The average leak rate per minute was then calculated and was approximately 1.6 L min^{-1}.

Should the result of a leak test ever exceed 3-4 L min^{-1}, the system should be physically inspected for leaks, and the leaks removed.

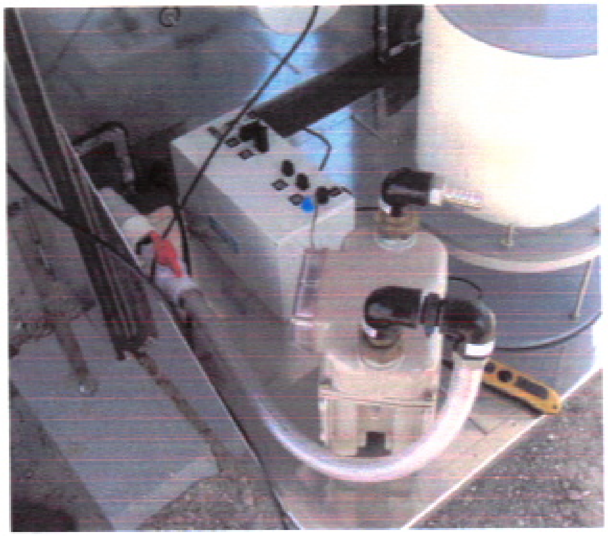

Figure 20: Setup for leak testing of the Moody radon detector.

3.2 Background Test

3.2.1 Overview

Regular determination of the instrumental background of a radon detector is important since this is required to process the raw data and strongly influences the detector's lower limit of detection. The instrumental background rises with time, with a rate that depends on the long-term average of the sampled radon concentration. This is due to accumulation on the second filter of lead -210, a long-lived radon progeny. Cosmic radiation is also a factor contributing to the instrumental background. Consequently, the background varies as a function of geographical location. Furthermore, buildings materials might contain enough radium-226 for the resulting gamma field to affect the background. The scintillation material itself that is used in the head also contributes to the instrumental background.

Since the sensitivity of the detector head to radon as well as the instrumental background increase with high voltage applied to PMT (eg. Figure 28), this necessitates the determination of an "optimum" operating high voltage setting that has a relatively low background whilst also having an acceptable detector head sensitivity to radon progeny decay. Optimisation of the high voltage setting is discussed in section 4.4.

3.2.2 Background tests of the Moody detector

After assembling the detector and performing the leak test power was cut from the blowers. The high voltage unit was then set to 675V and the detector left for five hours (675V was the operational voltage setting chosen for the detector based on pre-deployment tests at ANSTO).

The instrumental background was then measured at half hour intervals, every 25V from 600 to 750V (see Figure 21; Figure 22). At a high voltage setting of 675V the background count was 1.2 counts per minute, a reasonable target for an initial background count. Comparing the field background test to the pre-deployment tests it is evident that the background onsite was larger than observed at ANSTO (at a high voltage setting of 675V in the pre-deployment tests the background count was 0.6 counts per minute).

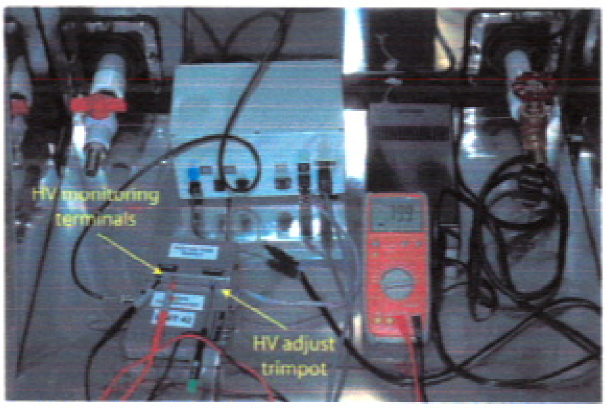

Figure 21: Adjustment of the high voltage setting with a jewellers screwdriver during a background check. Voltmeter leads are connected to the high voltage terminals and the screwdriver is positioned in the trimpot for high voltage adjustment.

After connecting the detector to the intake line and performing the calibration/sensitivity tests (discussed in the next section) another check of the instrumental background was made at 675V. The background count at this high voltage setting had risen to 1.7 counts per minute. Furthermore, the background count at this high voltage setting gradually reduced over a 10 hour period, indicative of thoron contamination in the sample line.

To help identify the source of thoron, a leak test was performed on the intake line. To do this, an end-cap was placed on the sample inlet at 27m (with the rest of the system plumbed normally and both inlet/outlet valves of the detector fully open). Power was applied to the external blower and several minutes were allowed for the flow to stabilise. Over a three minute period, the average flow rate through the blocked intake tube was almost 3 L min^{-1}.

It was later discovered that the sump plug of water trap number 3 (Figure 6c) had not been properly sealed when the pipe was installed, and furthermore, that there was soil within the pipe. The pipe near the sump plug was cleaned and the plug properly sealed. However there was not enough time to perform another intake leak test or background check to see whether the thoron contamination problem had been fixed.

It is recommended that a follow-up background check be made at the earliest convenience. If thoron contamination is found to still be a problem, it will be necessary to check the integrity of each of the joins in the lower portion of the intake line (which would entail digging up the buried line).

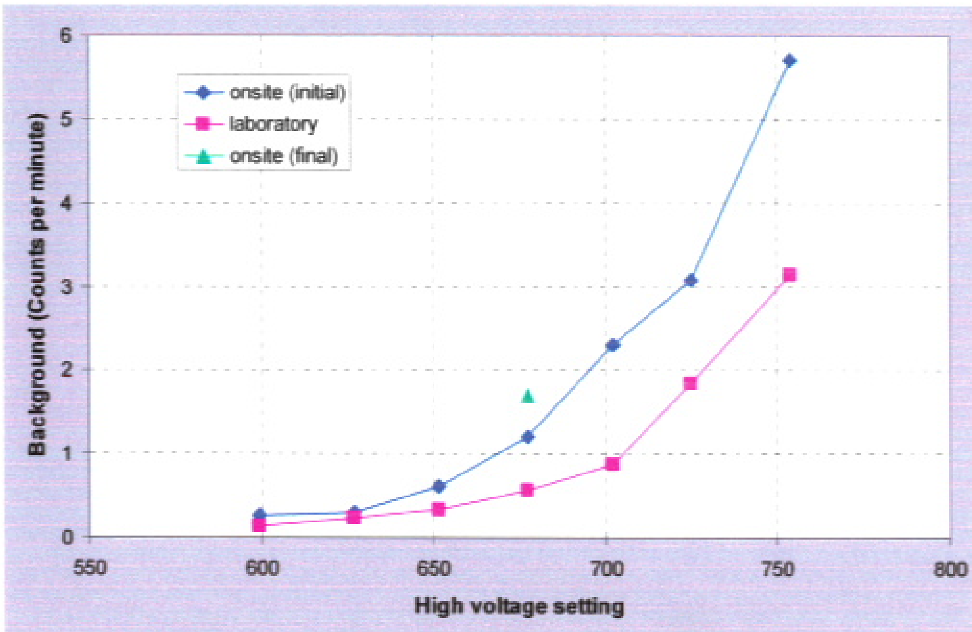

Figure 22: Background tests of the Moody radon detector: pre-deployment in the laboratory, after initial setup in the field and immediately prior to commissioning.

3.2.3 Conducting a background test

Routine background tests (three per year) should be performed, **but only at the preset operating voltage** (see the file **MaintenanceSchedule.xls**). To do this, turn off the detector's blowers (using the switch in Figure 23) and shut off the valve on the intake line (shown in Figure 24). Wait at least 24 hours and then reopen the valve on the intake line and switch the detector's blowers back on. Calculate the half hourly background count as the average of the half hourly counts from the 11th to the 23rd hour of the background check.

If, for any reason, a repeat of the complete background curve is required, this can be measured in the following way: Turn off the detector blowers and shut the tank inlet valve. Wait 4-6 hours, or preferably overnight. Reduce the high voltage setting to

600V. A pair of terminals built into the high voltage supply unit (labelled ± HV/1000) enables a representation of the high voltage setting (value/1000) to be monitored with a voltmeter during adjustment (see Figure 21). At 30 minute intervals, adjust the high voltage setting up in increments of 25V to a setting of 750V (ie. over about 3.5 hours). Plot the measured count rate vs the high voltage setting.

Figure 23: ***Blower shutoff switch in the "ON" position.***

Figure 24: ***Background shutoff valve in the "OPEN" position.***

4 Detector sensitivity and calibration

4.1 Overview

An important part of the commissioning process is characterising the detector's sensitivity to radon as a function of high voltage setting for a defined radon concentration. In conjunction with knowledge of the instrumental background, this information is used to select the optimum high voltage setting that is used for routine operation.

4.2 Completion of detector setup

The detector must be fully operational to characterise its sensitivity to radon. Before conducting a sensitivity test it is necessary to check:

(1) the integrity of the inlet line;
(2) that the intake tubing is connected to the inlet of the filter chamber inside the electronics enclosure;
(3) that the outlet of the filter chamber is connected to the inlet of the flow meter;
(4) that the outlet of the flow meter is connected to the inlet of the detector tank;
(5) that the intake, inlet and exhaust valves are open;
(6) that the tank pressure port is connected to the logger pressure port;
(7) that the radon gas calibration line is connected to the flow meter;
(8) that power is on to the internal, external and stack blowers;

(9) that the position of the exhaust valve has been set to achieve a tank overpressure of 80-120Pa.

4.3 Sensitivity test

A portable calibration unit (Figure 25 and Figure 26) was used to inject radon-rich air into the flow meter inlet (see Figure 27). The air was pumped from the calibration unit to the detector housing through a 3mm internal diameter (ID) injection line. The calibration unit was configured to inject radon-rich air at a rate of ~40-60 cc min^{-1}. A low injection flow rate (compared to the ~70 L min^{-1} sampling rate) ensured that the calibration air stream was not a significant source of ambient air (which might contain thoron), since the source was ventilated with unconditioned ambient air.

The timer in the calibration unit was set for 60 hours and injection initiated mid morning. When the radon concentration in the tank had equilibrated (to approximately 41.1 Bq/m^3; based on the radon source yield of 2.797 Bq min^{-1} ^{222}Rn and a flow rate of 68 L min^{-1}), a quick sensitivity sweep was performed (averages of 10 ten second counts every 25 volts from 550 to 800V; see Figure 28). The system was then left overnight.

The following morning another sensitivity test was performed, with counts totalled every half an hour for 25V increments of high voltage setting starting from 575V. The intention had been to continue to 750V but the test was interrupted by contract tower climbers[3]. The results of this partial test are shown in Figure 28, as well as a comparison with the pre-commissioning tests.

Figure 25: The Moody radon detector calibration unit.

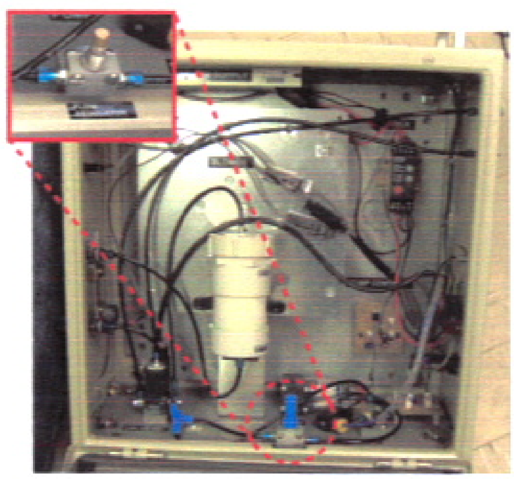

Figure 26: Inside the calibration unit. The NOAA ESRL radon source characteristics are: total Ra-226 activity 22.202 kBq, yield 2.797 Bq min^{-1} Rn-222. Inset shows the internal flow rate regulator for the source injection pump.

[3] The contract climbers needed to help with the pipe leak test and were only available for one day, so interruption of the sensitivity test was unavoidable.

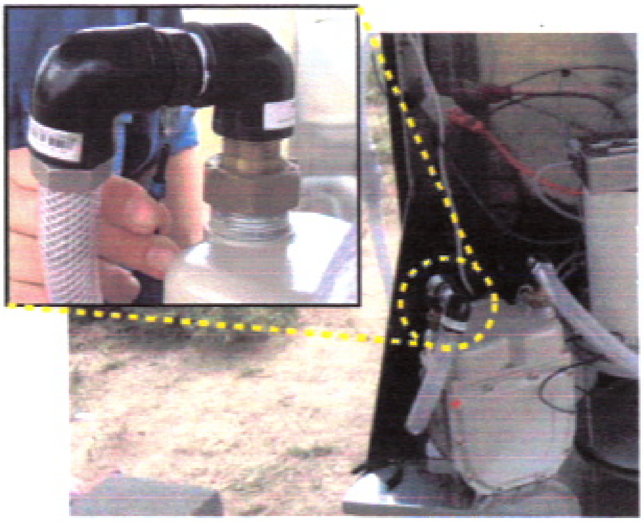

Figure 27: Modified inlet of the gas meter for calibration gas injection.

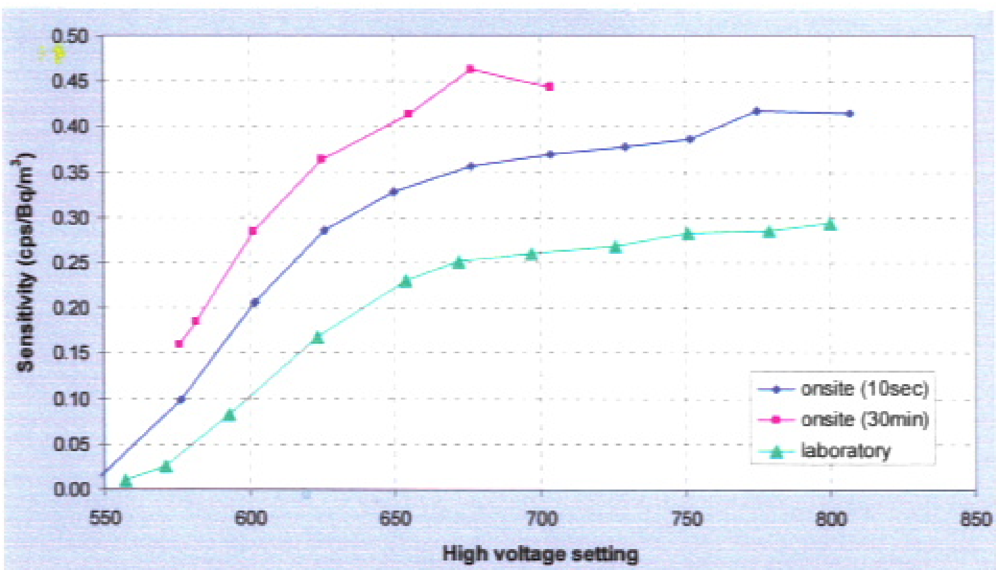

Figure 28: Sensitivity of the 1500L Moody detector to radon as a function of high voltage setting.

A considerable difference was observed in the sensitivity curves recorded in the laboratory and on site. The most likely reason was the different ambient radon levels at the periods the data were collected (Moody is a continental site and ambient radon levels are considerably higher than at ANSTO, near the coast). The irregularity evident in the 30-minute curve is attributable to noise (a large contribution to the on site counts from the high voltage units ULD channel).

4.4 Optimum high voltage setting

Based on the combined results of the background and sensitivity checks both in the laboratory and on site, an optimum high voltage setting (or "working voltage") of

675V is recommended for the Moody tall tower radon detector. At high voltage settings below this value, the slope of the plot is quite steep (ie. there would be a large change in the detectors calibration coefficient for relatively small changes in the high voltage setting). At high voltage settings above 675V the slope of the sensitivity curve reduces markedly.

4.5 Routine Calibration

Having established the optimum high voltage setting, periodic calibration of the detector is recommended. This procedure can be conducted directly on an operating detector without the need to adjust any of the detector components. At present, the installed portable calibration unit is setup to automatically perform a calibration once every 28 days. The unit also has a push-button trigger for manual initiation of a calibration if necessary.

A calibration event involves the injection of radon-rich air from a calibrated source into the sample air stream of the operating detector for a period of 4-6 hours[4] followed by a 5-6 hour flushing period. An example calibration curve taken at ANSTO is shown in Figure 29 (exact values may change depending on source strength, flow rate, background and ambient radon concentrations).

A calibration coefficient is determined from each calibration cycle. Assuming a linear change of the detector sensitivity with time between calibration cycles, 30-60 minute calibration factors can be linearly interpolated for post-processing.

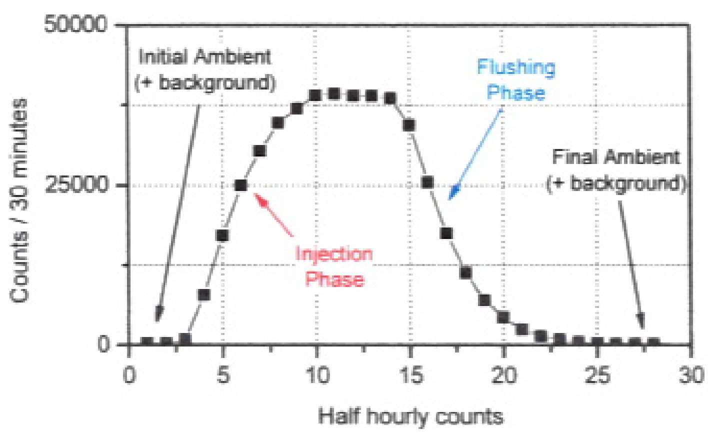

Figure 29: Example calibration cycle for a 1500L radon detector.

Front and rear views of the radon calibration unit are shown in Figure 30 a,b. Features on the front panel include:

1. Two indicator lights. The green light is illuminated when there is power to the unit. The red light is illuminated during the calibration period (when the injection

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[4] Depending on the hardware settings inside the calibration unit.

pump is running), and will only come on when the calibration pushed button is pressed or when initiated by the logger.

2. A calibration push button switch for initiating a calibration cycle. To stop a calibration injection before the preset cut-off time, cycle mains power to the unit.

3. A flow meter with a flow control knob for adjusting the flow rate.

The calibration unit operates in one of two states. The default state is "Flushing Mode" where ambient air is pushed through the source[5] and the radon-rich air is directed via a solenoid valve to the flush line. The flush line vents to the outside atmosphere at a flow rate of approximately 40-60 cc min^{-1}. It should be emphasised that the amount of radon released to the atmosphere (from a source similar to the one used at Moody) is equivalent to that emanating naturally from 2 m^2 of soil. The second mode is the "Injecting Mode" (or calibration mode). In this state, the solenoid valve switches such that the radon rich air is injected into the operating detector for a preset time at 40-60 cc min^{-1}. The flushing flow rate is controlled by the knob at the base of the flow meter on the front of the calibration unit. Once the correct flushing flow rate has been established, the injection flow rate is adjusted using the internal flow control device (see inset to Figure 26). A schematic of the ANSTO-built radon calibration unit is provided as an appendix to this document (see section 8.2).

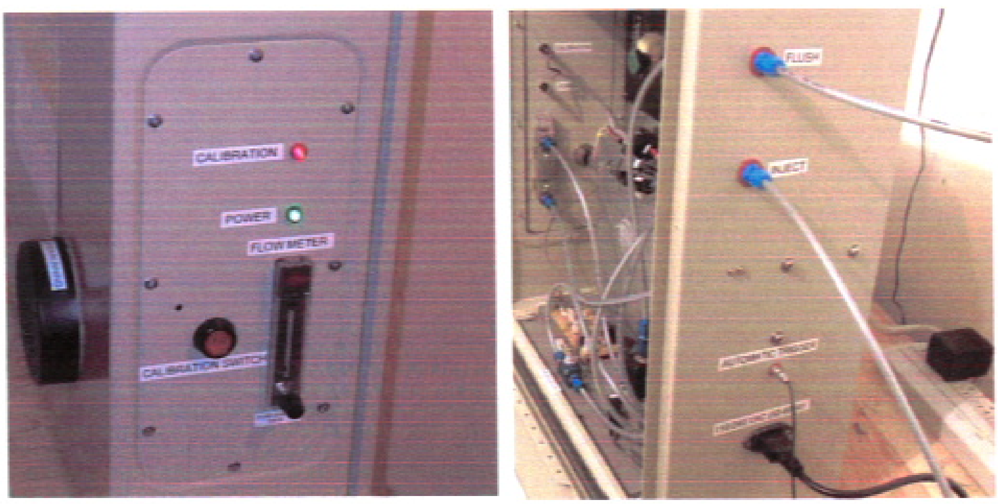


Figure 30: (a) Front and (b) rear views of a calibration unit similar to the one installed at the Moody tall tower site.

It is imperative that the calibration unit is powered at all times with its door closed and the flush line correctly plumbed to outside of the building. Otherwise, the source will not be flushed effectively, resulting in the build-up of radon within the source. If a calibration cycle is initiated without the source having been adequately flushed, the

[5] A blower is used to pressurise the inside of the calibration unit. Consequently, the source will only flush if the door of the calibration unit is shut properly.

raw counts will initially be higher than those corresponding to the calibrated source strength.

4.6 Lower Limit of Detection

The lower limit of detection of the radon detector is defined here in terms of the statistical uncertainty associated with the counting of alpha-emitting radon progeny by the detector head assembly. More precisely, the lower limit of detection is defined here as the equivalent radon concentration (in Bq m^{-3}) at which there is a relative counting error of 30% at a given high voltage setting.

An estimate of the lower limit of detection of the Moody radon detector was made prior to shipping, and was documented in the components report. The result for 675V was ~20 mBq m^{-3}. It was not possible to satisfactorily repeat this test using the onsite data due to the noise that occurred during the sensitivity checks.

5 Routine Tasks

5.1 Overview

The controlling computer at Moody is not fully networked, so it was not possible to configure the detector control software to send an e-mail when any measured parameters stray outside of predefined range. However, the PC has been connected to a nearby computer that is networked, so data may be collected remotely and quality checked regularly.

On longer time-scales (eg. ≥monthly) there are some additional routine maintenance requirements. These include:

(a) **Background evaluation**. A background check should be performed every 4 months in the following manner: Switch off both blowers using the background shutoff switch (Figure 9; Figure 23), close the background shutoff valve on the intake line. After 24 hours, open the shutoff valve, switch the background shutoff switch back on. The hourly background value is then calculated during post processing as twice the average half hourly count over the period 11-23 hours after the detector was shut-down;

(b) **Calibration**. The calibration process is automatic, with an event occurring once every 28 days (Table 1). If for some reason the detector was not operational when a calibration event *should* have occurred, or there is an obvious problem with a recent calibration peak, a calibration can be initiated manually using the red push-button on the calibration unit. The main point to check is that the source flush rate is >20 cc min^{-1} (preferably 40-60 cc min^{-1}), as indicated on the flow meter on the front panel, to prevent a build-up of radon in the source capsule. Occasionally (every 3-4 months) the injection flow rate should be checked manually. To do this, simply press the red button on the calibration unit, and observe the flow rate in the flow meter. This flow should be approximately 40 cc min^{-1}. As soon as the flow rate has been confirmed (or adjusted if necessary, which should take less than a minute), cycle the mains power to the calibration unit (which terminates the injection mode) and make a note of the time and date of the flow rate check in the electronic log file (check to make sure that the red "injection" light is off). Making a note of the time in the log file will be very important because this will cause a small radon pulse that can be removed in post processing;

Julian Day	Normal Date	Leap Year Date
28	28-Jan	28-Jan
56	25-Feb	25-Feb
84	25-Mar	26-Mar
112	22-Apr	23-Apr
140	20-May	21-May
168	17-Jun	18-Jun
196	15-Jul	16-Jul
224	12-Aug	13-Aug
252	9-Sep	10-Sep
280	7-Oct	8-Oct
308	4-Nov	5-Nov
336	2-Dec	3-Dec
364	30-Dec	31-Dec

Table 1: List of scheduled dates for automatic calibration events of the Moody radon detector.

(c) **Data download and backup.** Each month, the radon detector data file, electronic log file, and any matching meteorological data (if available) should be separately archived;

(d) **Pressure sensor calibration check**. Once a year it is advisable to check whether the pressure calibration of the micro mass flow controller in the logger enclosure has changed. To do this, open the electronics enclosure. Connect the positive pressure terminal of a differential pressure sensor to the T-piece provided in the pressure line between the logger and tank pressure port (Figure 18) using a length of 3mm FESTO tubing (or similar). By adjusting the exhaust valve, get a reading of 100Pa on the hand held pressure sensor. Shut down the detector control program, start the stand-alone logger software and enter the real time monitoring mode (see section 5.4). Compare the output of the portable pressure sensor (Pa) to the detector's pressure output signal (mV) using the read-off chart in Figure 19. If there is more than a ±5Pa difference in the readings, a recalibration will be required. Start by completely opening the tank exhaust valve. Compare the output of the portable pressure sensor (Pa) to the detector's pressure output signal (mV), then constrict the exhaust valve a little way. Repeat this process 4-5 times to cover a range of pressures from 70-140 Pa. Plot the curve and replace the existing Figure 19. Next, the calibration coefficients in the Radon Detector Monitor program will need to be updated. To do this, perform a linear regression over the calibration data points in the restricted pressure range 80-120Pa. Shut down the stand alone logger program (making sure to "disconnect" from the logger), then startup the Radon Detector Monitor program, enter the Settings menu, click on the Startup options tab and enter the coefficients; and

(e) **Synchronisation of the logger and PC clocks**. Assuming that the controlling PC clock is synchronised to a reliable time standard (eg. via the network), it is recommended that once a month the data logger and PC clocks are synchronised. Make sure that any **daylight savings option on the PC is TURNED OFF**. Shutdown the detector control program and start the stand alone logger software ("Loggernet"). Connect to the logger and press the set station clock button. Disconnect from the logger then restart the detector control program.

5.2 Detector Control Program

The site computer is running a detector control program called "Radon Detector Monitor" (Figure 31) that downloads the logger data using a Campbell Scientific propriety software tool. The User Manual for the detector control program has been provided separately, but is also available on-line through the program help menu. The stand-alone Campbell LoggerNet software is used for system diagnostics and modifying / uploading the data logger software that dictates the sampling protocol.

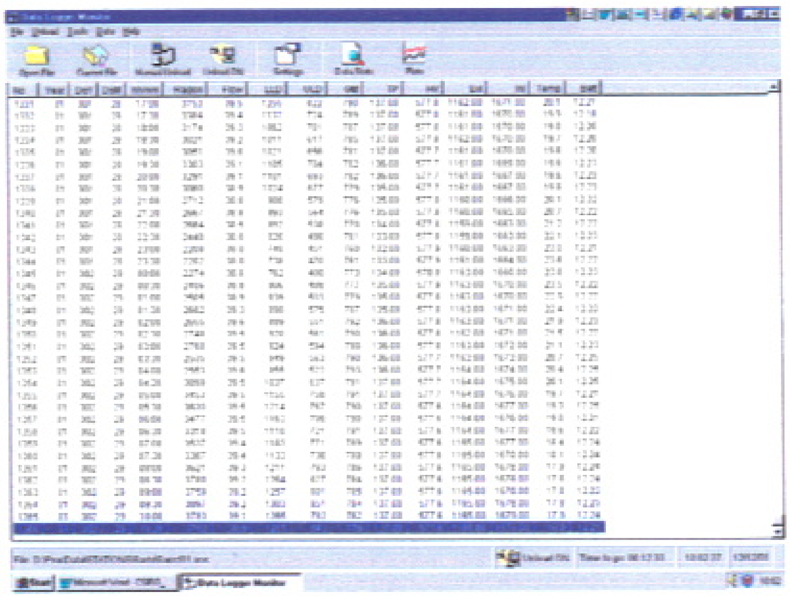


Figure 31: Example screen of the detector control program.

The easiest way to check whether the detector control program is functioning normally is (a) to confirm that the current Day of Month (DoM) and Time (within the past 30 minutes) are displayed in columns 4 and 5, respectively, at the bottom of the screen (Figure 31) and (b) that there no data fields are coloured. The latter might happen as there is provision in the software to set parameter ranges in the settings menu (Figure 32 and Figure 33) so that when a given parameter is outside the set range, the colour of the display is modified (blue if it is below acceptable values, red if it is above acceptable values; Figure 34). When the detector was installed, default values for the bounds were set. It is recommended that after the first month of operation the values set for the bounds should assessed, and reset if necessary.

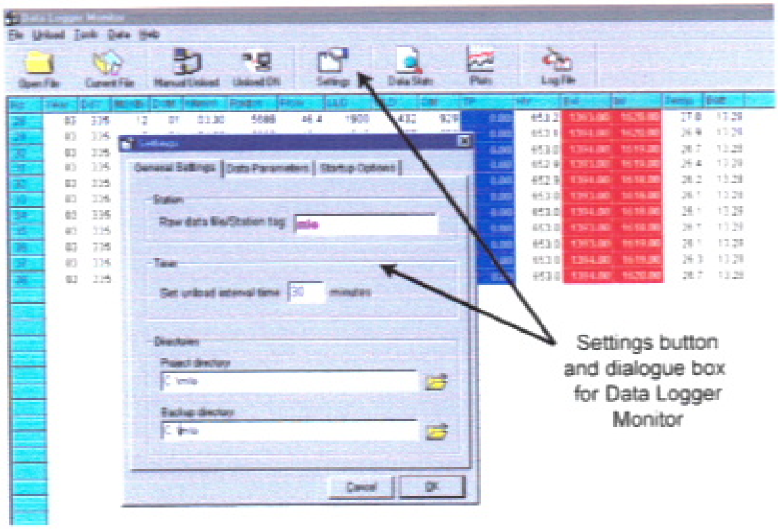


Figure 32: Example of changing the settings in Data Logger Monitor.

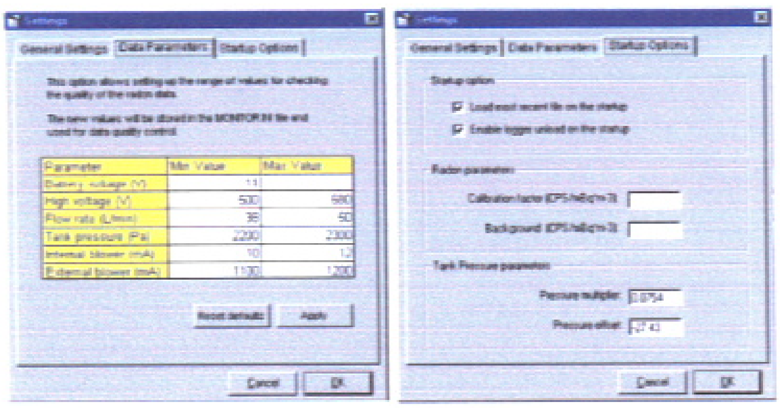


Figure 33: Example of other panels in the settings box.

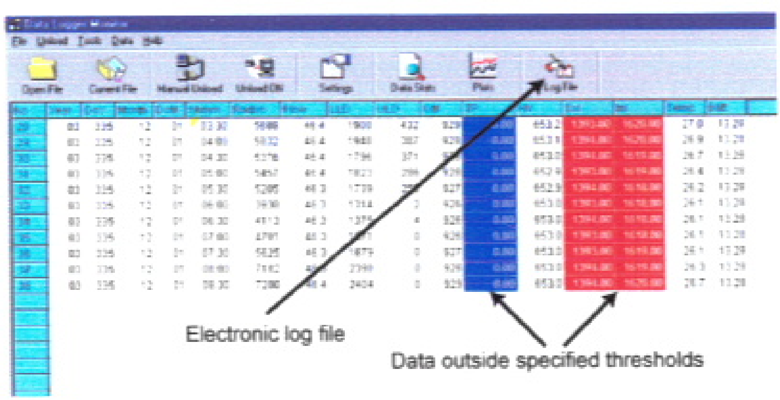


Figure 34: Example of parameter out of bounds auto-flagging.

If parameters are seen to go out of bounds[6], a note to this effect should be entered into the electronic log file (including the date and time that the excursion occurred). If the parameter remains out of bounds for a prolonged period (>12 hours) the problem should be investigated further.

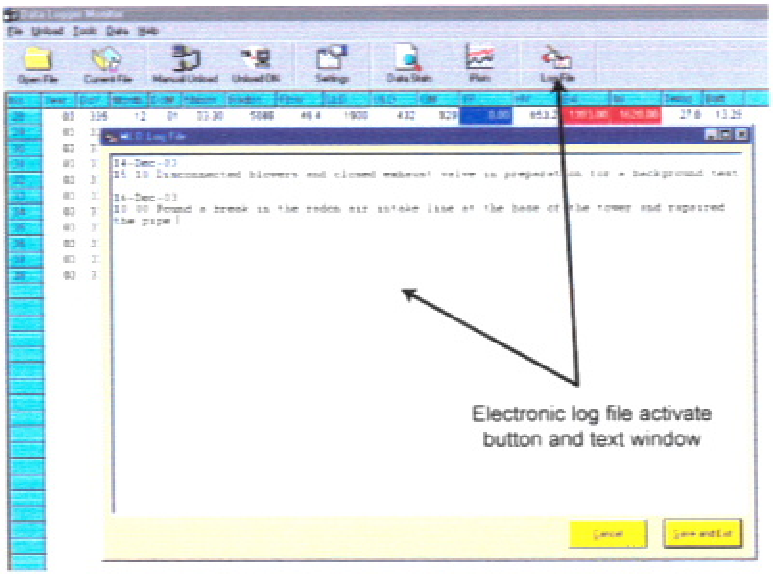


Figure 35: Example screen of the detector control program.

5.3 Data Acquisition

The data logger has been programmed to monitor the detector output and associated signals at 10-second intervals, storing totals/averages every 30-minutes (0 and 30 of every hour). A total of 15 Channels are logged (see section 8.1), including the flow meter signal, two channels of count data from the radon discriminator and an analogue signal representing the high voltage. For display purposes, provision has been made in the detector control software to output approximate real time radon concentrations, but this requires the user to specify calibration and background information in the settings window. More accurate calibration of the radon counts are performed in post processing. The day of month as recorded by the logger is derived from the Julian day (data logger Day of year).

If the computer is connected to the data logger, and the control program is running, the computer will automatically download data from the logger at 30-minute intervals (15 minutes and 45 minutes of every hour). However, the data logger can work in stand-alone mode for prolonged periods (up to one month) if the site computer is damaged or needs to be temporarily disconnected. Once the data logger and computer are reconnected, the first scheduled data transfer updates the computer monthly record. In the event of a power failure, the data logger stores its program and data in non-volatile memory so they will not be lost. Furthermore, the detector control software will start automatically on reboot of the PC if it is enabled in the Windows Startup area.

[6] Providing that the bounds that have been set are realistic

The program creates and updates monthly files in which to store the half-hourly data. The naming convention for data files is SSmmmyy.csv where "SS" is a two letter identifier that represents the detector site name, "mmm" is a three letter month identifier, and "yy" is a two digit year identifier. By default, the data files are stored in the loggers program directory although a separate working directory can be specified. Provision in the software is made for automated backup where a carbon copy of the data is stored in a separate location (a removable storage media or network drive is recommended). The location of both copies of the data can be specified in the program settings, accessed either via the "Settings" button or "Tools" pull-down menu.

Note: The convention for the stored radon data is that the 12:00 saved value represents information collected between 11:30 and 12:00. This should be taken into account when matching the radon data with other data sets (eg. Meteorology).

5.4 Stand alone Campbell Loggernet Software

To use the Loggernet diagnostic software select "Tools/Run Loggernet" from Radon Detector Monitor or from Windows Program Files/ Loggernet / Loggernet if properly installed, or double click the Loggernet icon on the desktop. The Campbell data logger program will start (Figure 36). Click the "connect" button and the inactive station connect screen will appear (Figure 37). To activate this screen, connect to the logger using the "Connect" button in the lower left hand corner of the screen. The program will then attempt to connect to the data logger. Should the connection not be established, an error message will be shown. In this case, check the power to the data logger, and make sure that the communication cable between the PC and data logger is not damaged and correctly plugged in.

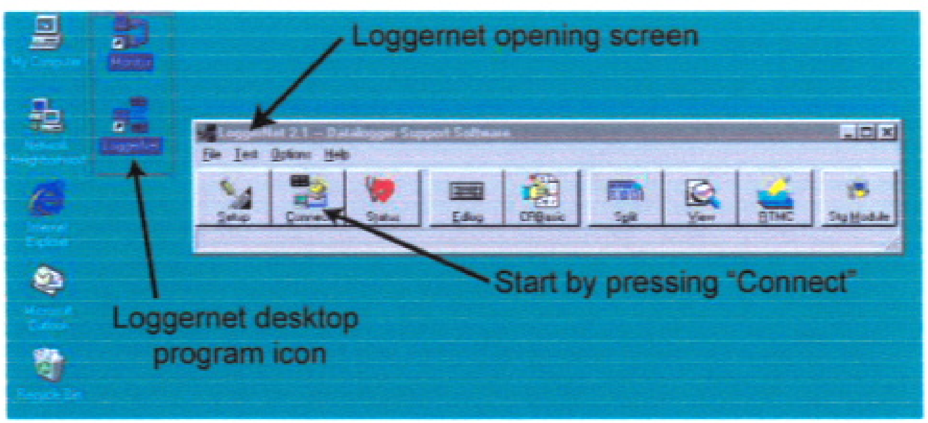


Figure 36: Example of the opening screen of the Campbell diagnostic software Loggernet.

Once the connection is established, the realtime[7] output of sensors can be viewed either graphically or numerically by choosing the appropriate button in the "Display Settings" box (Figure 38).

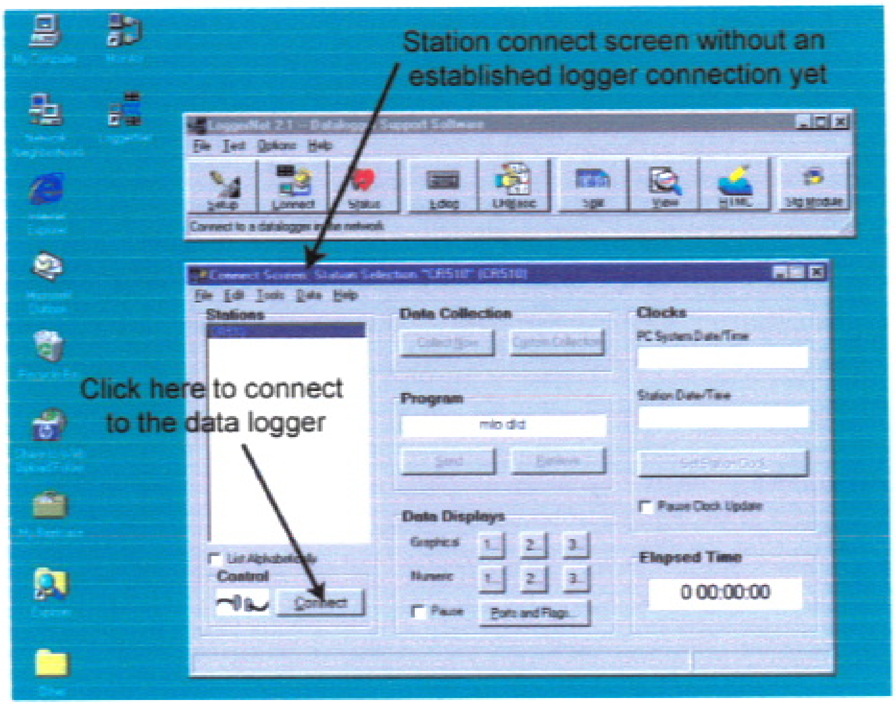


Figure 37: Example of the inactive logger connect screen of "Loggernet".

[7] Updated every 10 seconds

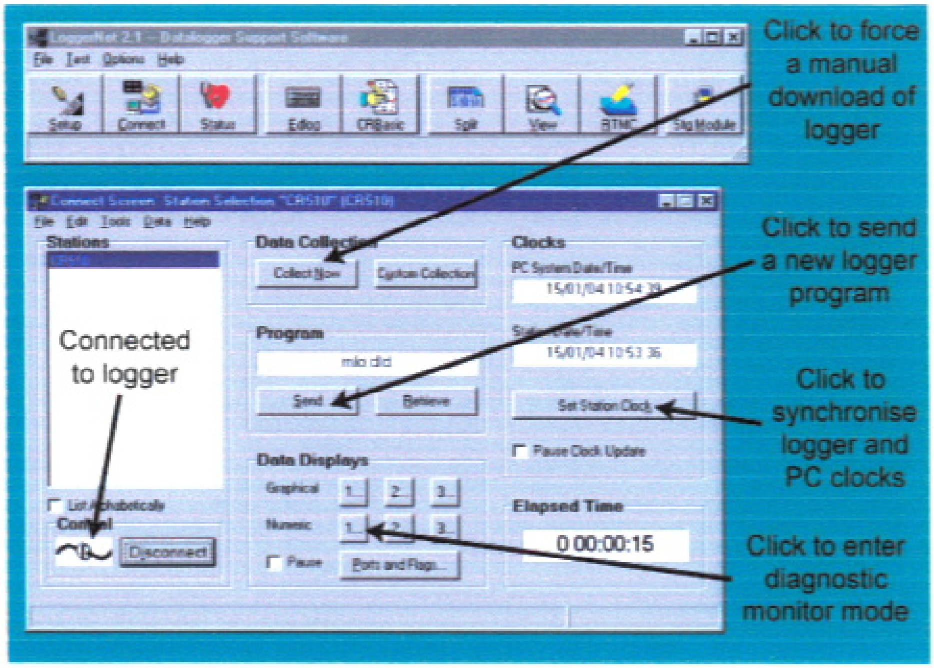


Figure 38: Example of the active logger connect screen of "Loggernet".

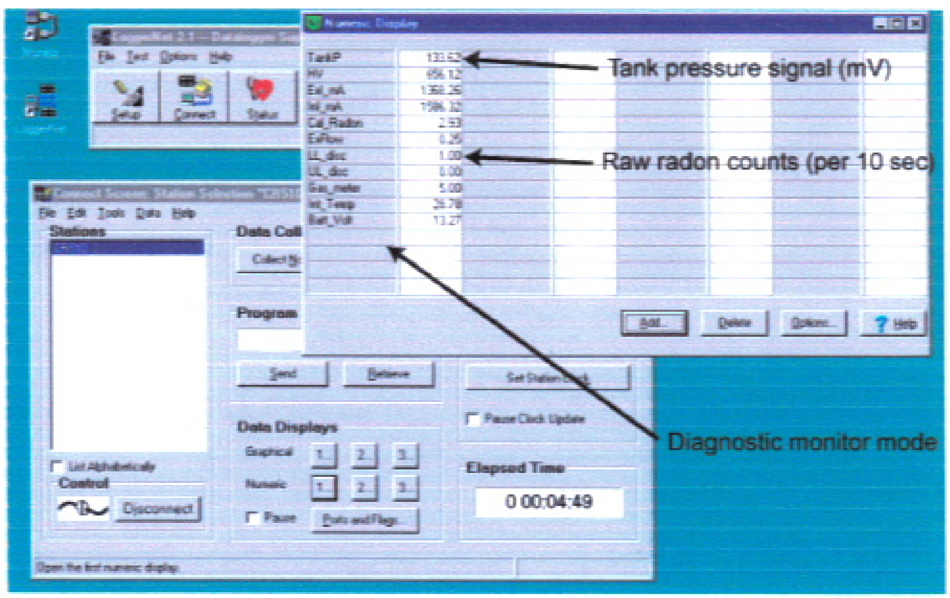


Figure 39: Example of the Loggernet real time numeric display ("monitor" mode).

5.5 Updating the data logger program

The compiled data logger program (*.dld) resides in the working directory. The source code (*.csi) would only be needed if a change needed to be made to the monitoring program. If for any reason there is a necessity to update the current logger program, follow these steps:

1. If the detector control program is running, first manually download the current data from the logger memory to the PC data-file (by pressing "Manual Download" button), and then exit the program;

2. Once the new and old *.csi and *.dld files have been backed up, delete the existing *.csi and *.dld files in the working directory, and then copy the new *.csi and *.dld files into the working directory;

3. Please note, updating the data logger program can affect the data file. To prevent this, rename the current data file (SS*mmmyy*.csv, where SS, *mmm*, and *yy* are abbreviations for the current site, month and year, respectively) to a temporary file (eg. temp.csv). Start Loggernet and connect to the logger. Click the "Send" button in the "Program" box (Figure 38) to upload the program into the logger memory. A warning will be issued that the data currently on the logger will be erased, select OK. From the options presented, select the appropriate *.dld file in the "FileName" box. Then click "OK";

4. Verify that the program is running correctly by accessing the realtime numeric display (Numeric button "1…" in the Data Displays box, Figure 38);

5. Disconnect from the logger and exit both windows of the Loggernet program; and

6. Restart the detector control program.

To clear any spurious data that may have occurred during the program upgrade, perform another manual download of the data logger, and then exit the program. Through Windows Explorer, or at the DOS prompt, delete the current monthly file if one was created (i.e. SS*mmmyy*.csv). Rename the old monthly data file to the correct name (i.e. from temp.csv to SS*mmmyy*.csv). Finally, restart the detector control program. If the program starts with no data on the screen, the old data file has been incorrectly named.

6 Recommendations

Following the installation of the Moody tall tower radon detector there are several recommendations from ANSTO for optimum and continued reliable operation:

1. A background check should be performed at the earliest convenience to determine whether there is still a significant leakage of thoron into the sample line;

2. Filters should be placed within the sample line (a coarse mesh over the inlet to prevent birds entering, and an easily replaceable/economical primary dust filter in an accessible location, eg. near the base of the main tower). A low impedance automobile air filter mounted in a purpose built housing is usually sufficient;

3. Reduce the duration of calibration injection from 6 to 4 hours. This can be done by adjusting the variable time dial in Figure 40 to position "4";

4. When performing the detector sensitivity checks a problem was noted with the logging of the current draw of the detectors internal flow loop blower. The cause of the problem has since been diagnosed as a faulty capacitor within the logger box IC board. A replacement logger box has been dispatched. **The logger boxes should be switched, and the faulty unit returned to ANSTO;**

5. Routine tasks as described in this manual are to be performed according to the schedule outlined in the accompanying document **MaintenanceSchedule.xls**.

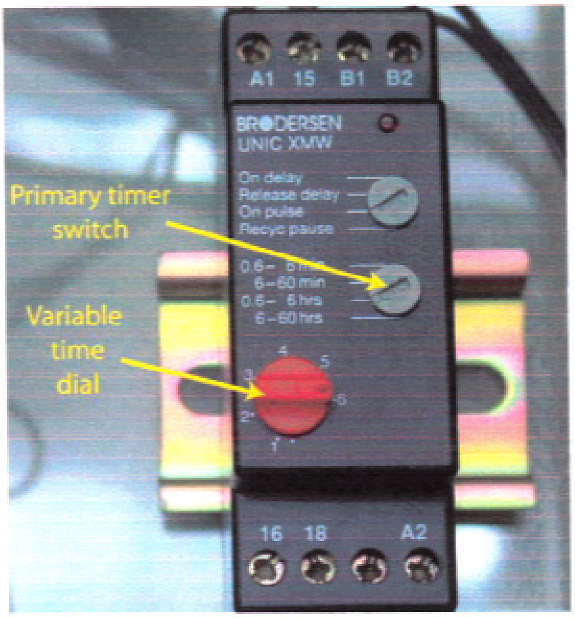


Figure 40: Event timer located within the calibration unit.

7 References

Whittlestone S. and W. Zahorowski, Baseline radon detectors for shipboard use: Development and deployment in the First Aerosol Characterisation experiment (ACE 1), *J. Geophys. Res.,103*, 16,743-16,751, 1998.

8 Appendix

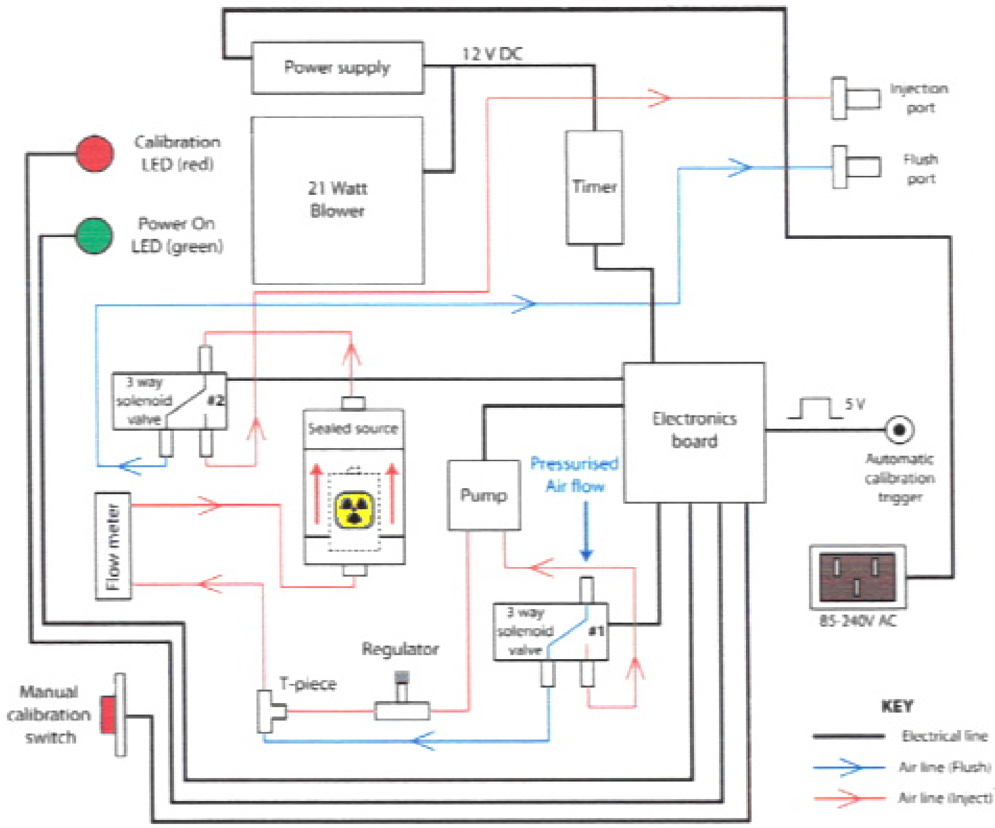
8.1 Logger Channels

The detector control program window displays the following variables:

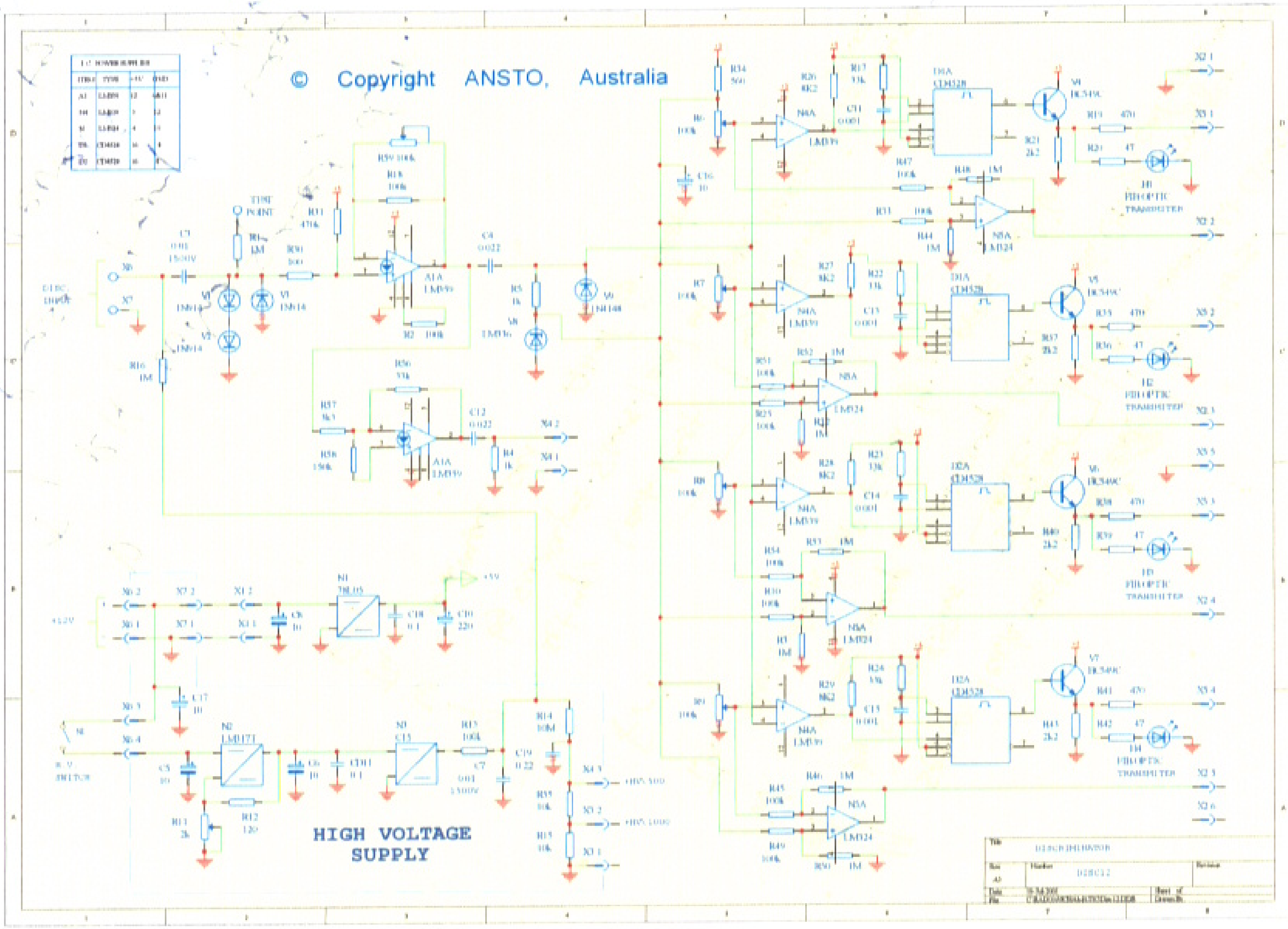
Name	**Comment (format/unit)**
yy	Year (yy)
DoY	Day of year (xxx)
dm	Day of month (dd)
TIME	Time of day (hhmm)

$mBqm^{-3}$	Radon concentration ($mBq\ m^{-3}$)
L/m	Inlet air flow rate ($L\ min^{-1}$)
LLcount	Count per half hour at the lower threshold setting
ULc	Count per half hour at the higher threshold setting
GMc	Gas meter count per half hour
TankP	Average tank pressure (mV/Pa; depending on program setup)
HV	Photomultiplier high voltage (V)
exI	External blower current (mA)
inI	Internal blower current (mA)
Temp	Temperature inside the logger (°C)
Vbat	Logger backup battery voltage (V)

8.2 Calibration Unit Schematic



8.3 Schematic wiring diagrams



Schematic of the High Voltage/discriminator unit.