ANSTO/C-DRAFT

LUCAS HEIGHTS SCIENCE AND TECHNOLOGY CENTRE

A report to the

University of Melbourne

on the

COMMISSIONING OF A 1500 L RADON DETECTOR AT AIR-BOX

by

S. WERCZYNSKI, V. SISOUTHAM, A. WILLIAMS, S. CHAMBERS

Prepared within ANSTO ITNS

Australian Nuclear Science and Technology Organisation

October 2016

TABLE OF CONTENTS

1 Introduction

In May 2016 a 1500 L dual-flow-loop two-filter radon detector, designed and built by the Australian Nuclear Science and Technology Organisation (ANSTO), was installed and commissioned at the AIR-BOX container in collaboration with the University of Melbourne.

The purpose of this report is twofold: (a) to summarise the results of commissioning tests performed on the detector, and (b) to serve as a reference document for designated staff performing routine maintenance on the detector. It concludes with a list of recommendations to facilitate continued operation of the detector based on its operational status at the time of commissioning.

1.1 Detector setup

The AIR-BOX facility consists of an instrumented and environmentally controlled shipping container capable of remote deployment and autonomous operation. It has capability ready for deployment from Antarctica to the tropics and on mobile platforms such as ships or trains or at fixed sites. AIR-BOX provides a capability unique in the southern hemisphere observing the Australian, the Southern Ocean and the Antarctic atmosphere. ANSTO's involvement was to build and commission the radon detector as a permanent member of the suite of atmospheric instrumentation aboard the facility. The radon detector can provide hourly information on air mass origins and the vertical mixing state of the lower atmosphere, invaluable to the interpretation of all measured atmospheric constituents.

The detector has been designed to require minimal maintenance. The only routine tasks that need to be performed are: (1) synchronisation of the logger and PC clocks, and (2) pressure sensor re-calibration. Descriptions of these tasks are provided in Section 4 with a suggested schedule for their completion. Calibration and background checks are scheduled to occur automatically or manually.

Figure 1 shows the location of the radon detector inside the AIR-BOX container.

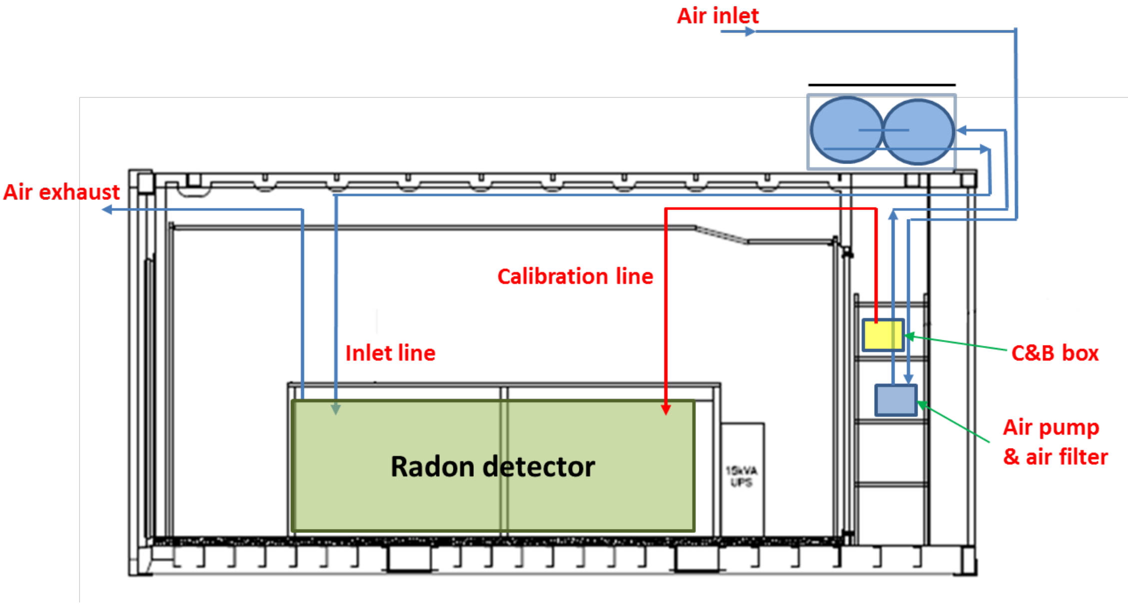


Figure 1: Location of radon detector in AIR-BOX container

It is advisable to contact ANSTO before modifying the detector or installation setup in any way. All maintenance, modifications, and pertinent operational comments should be recorded in the electronic log file, which is accessible via the main menu bar of the ***Radon Detector Monitor*** program. In the event that upgrades of the logger or computer software become available, comprehensive written instructions will be provided on how to perform the required installations.

A detailed schematic of a typical radon detector setup is provided in Fig. 2 below.

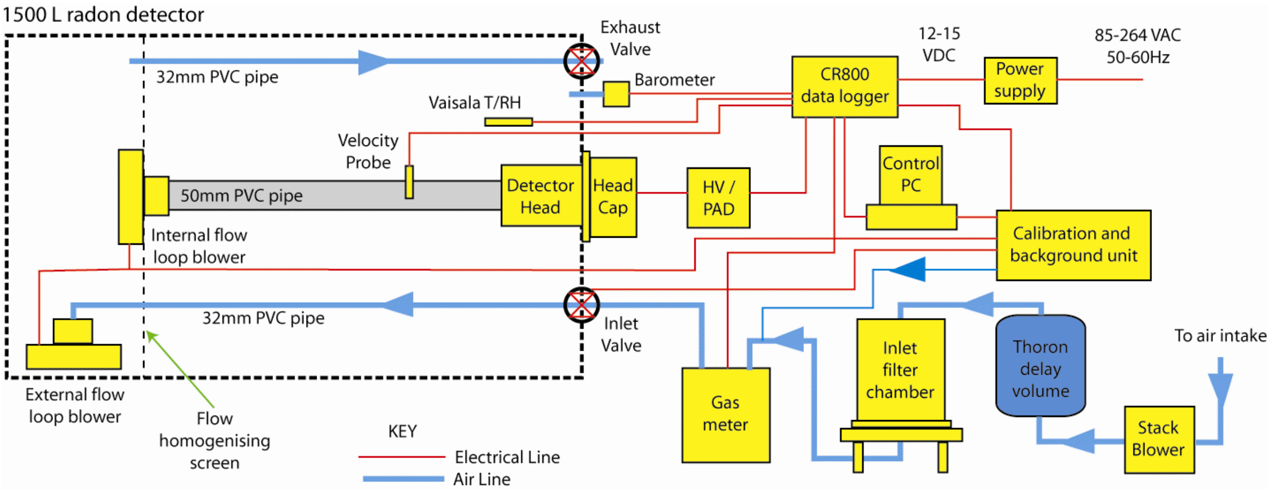


Figure 2: Schematic of an ANSTO two-filter detector setup similar to that installed at AIR-BOX.

2 Components

2.1 Sample inlet system

The radon sampling line was constructed from a combination of continuous 1” HDPE pipe and 19 mm reinforced flexible plastic hose (Fig. 3). The sampling inlet point was approximately 1 m above the roof of the container, about 5 m above ground level (agl.). At the intake point the sampling line was inverted (“gooseneck” style) to minimise the ingestion of precipitation and screened against insects.

Figure 3: Penetration through the wall of the container for detector plumbing and connection to the main inlet line (left) and exhaust line (right).

A stack blower unit (Fig. 4) was located in the specially designed pump enclosure inside the container, behind the electronics rack. The 1” HDPE section of the detector’s intake line connects to the inlet of the stack blower through the air filter.

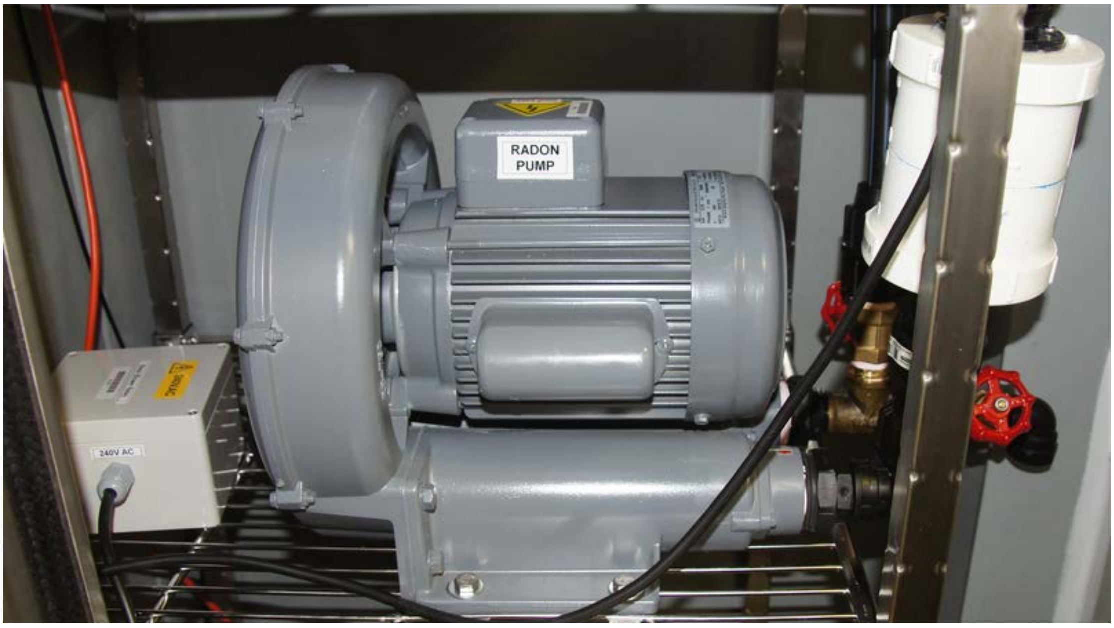


Figure 4: Radon detector stack blower (240V;5A) and coarse air filter.

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

Thoron (^{220}Rn; an isotope of radon, ^{222}Rn) can interfere with the measured radon signal. Consequently, as little thoron as possible should be allowed to enter the detector tank[1]. Since the half-life of thoron is short (55.6 seconds), near-complete removal of thoron can be achieved by delaying the sampled air by around 5 minutes before it reaches the detector. This is achieved using a thoron delay volume (Fig. 5). Progeny of thoron that has decayed within the sample line / delay volume will be captured, and removed from the air stream, by the detector's primary filter (located on the electronics rack, see Fig. 6 and Section 2.4).

It should be noted, however, that thoron concentrations decrease rapidly with height above the ground (due to the short half-life and atmospheric mixing times). So if sampling from heights more than several 10s of metres, the thoron concentration will already be quite small under most atmospheric conditions, and a delay volume may not be necessary (sample flow rate, length and diameter of intake line also need to be considered).

At commissioning, the detector's sampling flow rate was ~83 L min^{-1} when the operating overpressure in the main delay volume was ~100 Pa (as sampled from the t-piece in the pressure line). At this flow rate, a combined volume (inlet line plus delay tanks) of 400 L would delay the sampled air ~5 minutes. The initial background test after a day of normal operation of the detector showed no signs of thoron contamination, so it appears that ambient thoron concentrations are sufficiently low that a 5 minute delay is enough to reduce thoron below detectable levels.

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

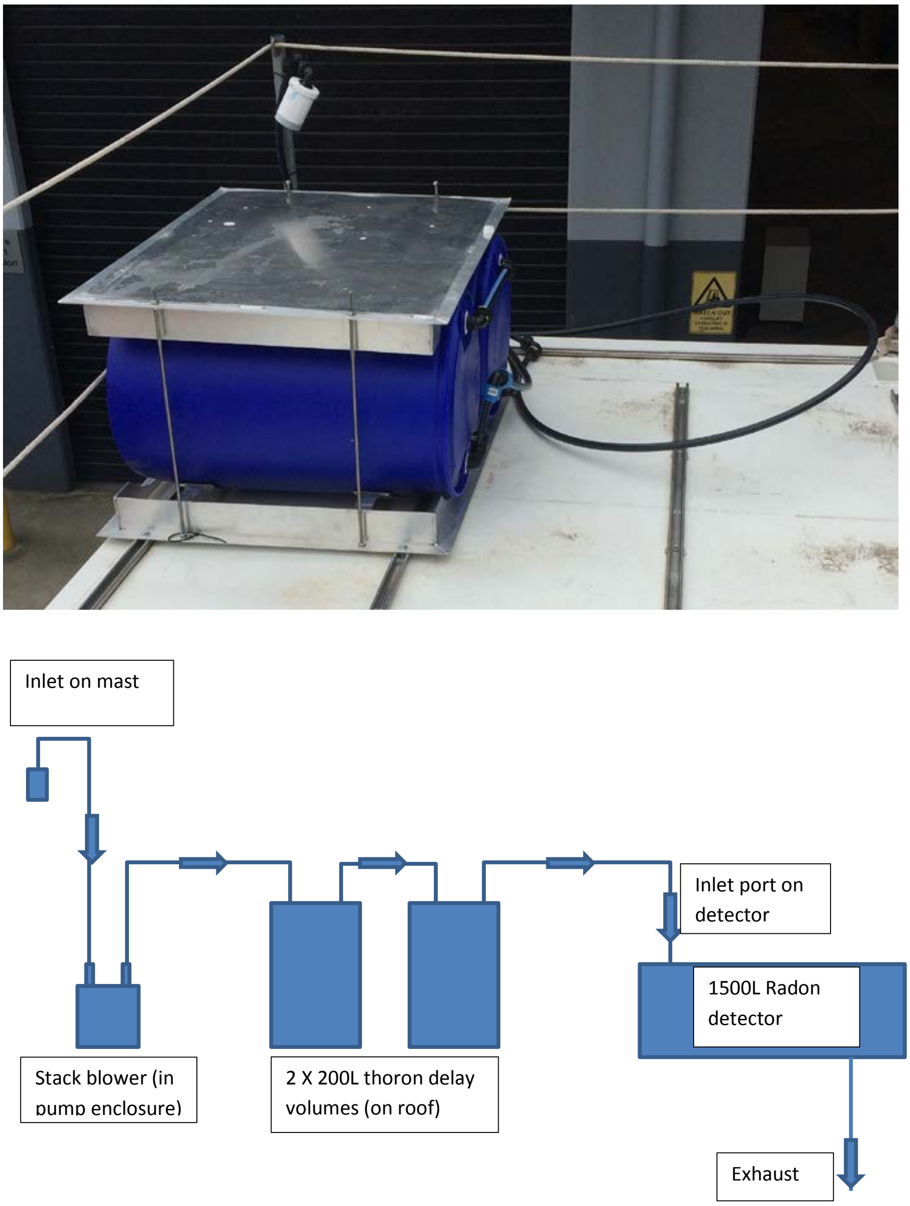


Figure 5: (top) Thoron delay volumes of the 1500 L AIR-BOX radon detector located on the roof of the container; (bottom) flow schematic of radon detector inlet lines and thoron delay volumes

Important: *Do not connect power to the blowers of the radon detector without having first connected an appropriate thoron delay volume. Passing thoron laden air through the detector head will elevate the detector's background count for several days.*

2.2 Electronics rack

Most detector components that may need to be accessed for maintenance purposes are contained on the electronics rack. An overview of the most clearly visible components on the electronics rack is presented in Fig. 6.

Components within the electronics enclosure sit on a platform that is slightly raised from the bottom of the electronics enclosure cover.

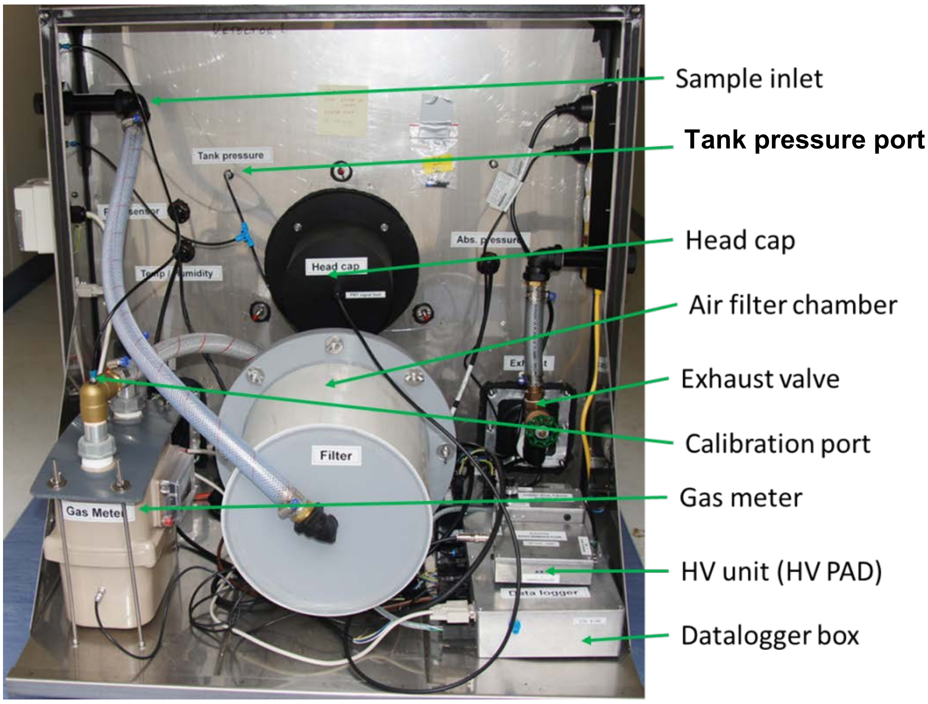


Figure 6: View of electronics enclosure and main components.

Sample air enters and leaves the main detector delay volume through the inlet and exhaust valves located within the electronics enclosure (Fig. 6).

Under normal operating conditions the exhaust valve provides control over the flow rate through, and pressure within, the main delay volume. The inlet solenoid valve is used to stop the flow of any air through the detector during background checks.

Figure 7: (a) The inlet solenoid cut-off valve, and (b) exhaust line gate valve. These valves are located near the bottom of the electronics enclosure.

The main detector delay volume (and entire inlet line downstream of the stack blower) is also kept at positive pressure with respect to ambient conditions (usually between 80-120 Pa). This overpressure minimises the likelihood that ambient radon/thoron progeny at high ground-level concentrations will directly enter the detector in the event of a leak developing in the detector's delay volume or inlet line.

The overpressure is achieved by constricting the exhaust valve (which, in turn, reduces the flow rate through the detector).

During normal operation the detector's overpressure is monitored using a micro mass airflow sensor located within the data logger box (via the tank pressure port in the detector bulkhead; Fig. 6). At the time of commissioning a hand-held differential pressure sensor was used to relate flow rate reported by the micro mass flow sensor to a differential pressure between the tank and ambient atmosphere for 6 overpressure values between 80 and 120 Pa. A linear regression was determined for this relationship and the calibration coefficients entered into the logging software.

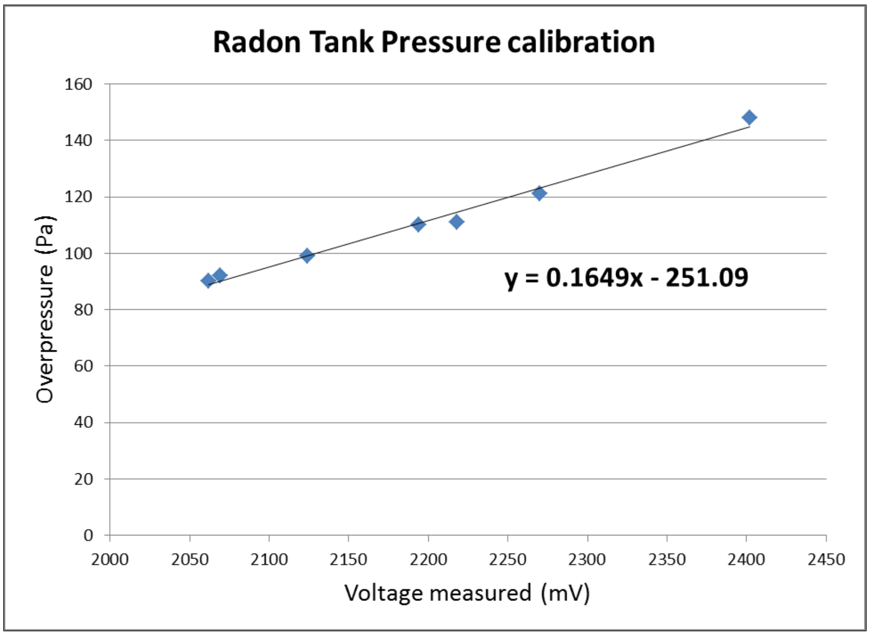


Figure 8: Onsite tank pressure calibration

At the time of commissioning the working overpressure of the detector was ~110 Pa.

Since the sampling flow rate is relatively high and the exhaust air sometimes also contains the radon calibration gas, the exhaust from the detector is vented outside the container in 1" tubing (see Fig. 3-right). The calibration flush line is also ducted separately outside of the container in a 4mm Festo tube.

2.3 Internal/External Blowers

The detector was initially configured with two centrifugal blowers (Figs 9, 10 & 13) to move sampled air through an external and an internal flow loop of the detector. These will henceforth be referred to as the external and internal blowers, respectively.

The external flow loop relates to the process of moving sample air through the detector delay volume; from intake point, through the inlet pipe, thoron delay, primary filter, into the detector delay volume and out of the exhaust valve. It is possible to achieve this using the external blower but, for the AIR-BOX detector installation, movement of air through the external flow loop is controlled by a stack blower in the pump's enclosure. The existing external blower is, however, still useful for some maintenance purposes (e.g. leak testing, see Section 3.1). At commissioning the power lead of the external blower was labelled "no connect" and disconnected from its socket on the front panel of the data logger. It should remain disconnected for normal operation.

The internal flow loop relates to the circulation of sampled air *within* the detector's main delay volume; from the enclosure containing both blowers, through the flow homogenising denim screen, down the length of the delay volume, through the detector head and secondary filter, along the central pipe, and back to the blower enclosure.

Both blowers are identical. They are manufactured by ***PAPST*** (series RG160-28/12N; see http://www.papst.com/). Their specifications are as follows:

- DC radial blowers with an electronically commutated external rotor motor and electronic protection against reverse polarity and overloading. Blower wheels are made of fibreglass reinforced plastic, the housing base of galvanised steel plate.
- Electrical connection via 2 leads AWG 22, TR 64; Voltage range: 7.5-14 VDC; Power: 21.0 W; Mass 1.4 kg; Operating temperature: -20 to 70^{o}C.

Figure 9: External flow loop blower with 32mm PVC fittings.

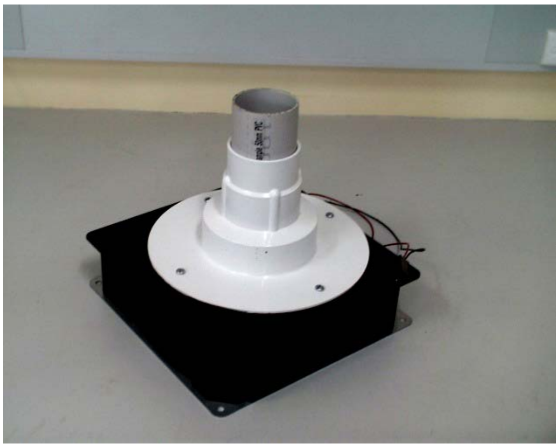


Figure 10: Internal flow loop blower with 50mm PVC fittings.

The detector's blowers are not accessible via the electronics enclosure, they are both located at the rear of the detector inside the main delay volume (see Figs 15 & 16).

IMPORTANT: Before removing the detector's rear cover, switch off the detector power supply (or disconnect the high voltage cable between the HV/PAD unit and the detector head cap) – failure to do so will destroy the photomultiplier tube.

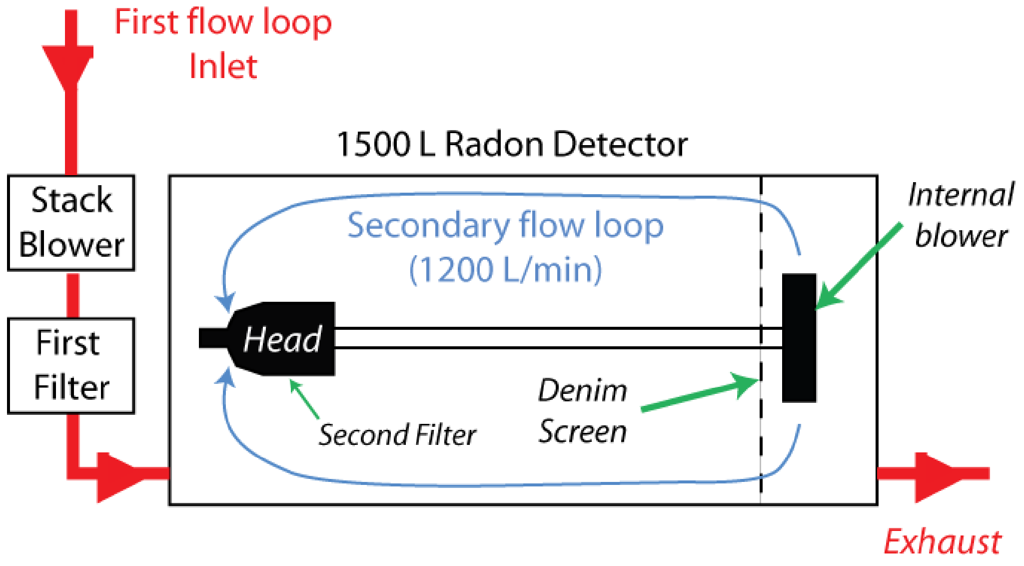


Figure 11: Schematic of the internal and external flow loops of a 1500 L radon detector.

Figure 12: Rear cover of the radon detector that provides access to the internal and external blowers.

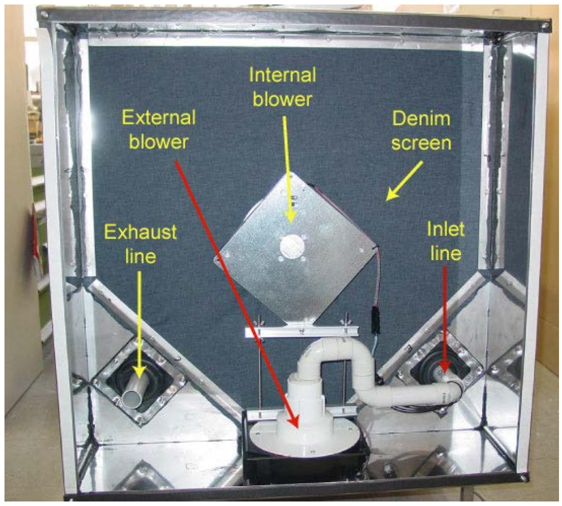


Figure 13: View of a blower enclosure for a similar model detector.

In the event of maintenance being required on the blower units they can be accessed by removing the cover shown in Figure 12. Please note that to facilitate blower replacement (should the need arise) plumbing to the external flow loop blower has not been glued. Consequently, moving the detector may cause one or more of the fittings to come loose (or disconnect totally). If this occurs, the problem will manifest itself as a reduction, or cessation, of the flow rate through the detector if the external blower is being used. However, with the stack blower in operation, no change would be evident in the detectors operational status.

There is a soft foam seal around the edge of the detector where the rear cover sits. If the rear cover is removed for any reason the integrity of the foam seal around the edge 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. It may be necessary to replace the foam seal after removing this cover.

The flow rate of the internal flow loop is much greater than that of the external flow loop (despite the stack blower being more powerful; 1.2 KW compared to 21 W). This difference in flow rate is due to the different flow impedances of the corresponding flow paths. The internal blower draws air through only the detector head and a short length of 50 mm PVC tube, whereas the external blower has to draw air through both parts of the intake line (25 mm HDPE and 19 mm pipes), as well as the internal plumbing of the detector (which is mostly 32 mm diameter PVC). When the stack blower is being used to aspirate the detector, a bypass valve (located on the blower), in conjunction with the detector's exhaust valve, is used to regulate the flow rate through the external flow loop (which is still maintained a factor of 2-3 lower than the flow rate within the internal flow loop).

Since the volume of the radon detector is 1500 L, at the sampling rate of 83 L min^{-1} the typical residence time of air within the detector is ~18 minutes. During this time, some of the sampled radon will decay. Since the half-life of the radon decay products is much shorter than that of radon, it is important that air inside the tank (containing the newly formed radon decay products) is circulated through the detector's second filter (in the measurement head) very quickly, so that the decay products can be captured and observed before they decay. For further details regarding the principal of operation of the detector (dual flow loop, two-filter model), the reader is referred to Chambers et al., (2011, 2014), or Whittlestone and Zahorowski, (1998).

2.4 Inlet Filter and Filter Chamber

For sites where there might be a high loading of salt-spray, dust or other aerosol pollution (generator or furnace exhaust), a coarse filter (e.g. a 4-wheel drive air filter, part #WA5113 or equivalent), is usually installed early in the inlet line. These coarse filters are usually inexpensive and easy to replace compared with the detector's primary filter. Using a coarse filter will significantly extend the life of the detector's primary filter.

Not counting the coarse filter, the radon detector has two filters: one at the tank inlet (called the first, or primary filter), and one within the detector's measurement head (called the second filter).

The main purpose of the radon detector's primary filter (Figs. 14 & 15) is to remove ambient radon and thoron progeny (as well as other aerosols if no coarse filter is installed). The filter used is a LUWA JK Ultafilter (PN# 422202090; http://www.luwa.com/luwa/juice/).

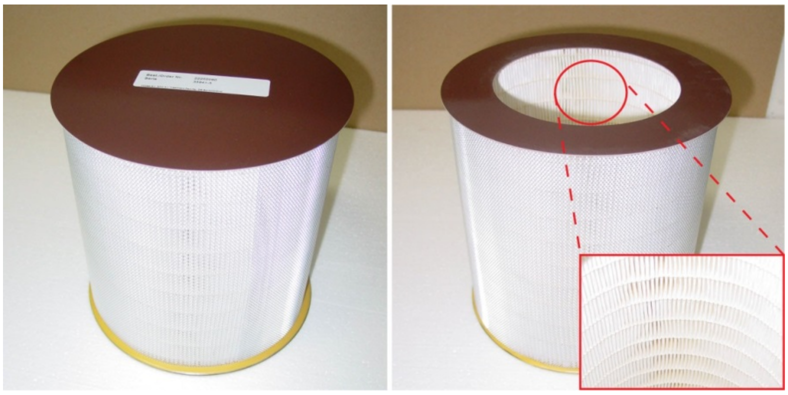


Figure 14: Views of the inlet filter from above and below.

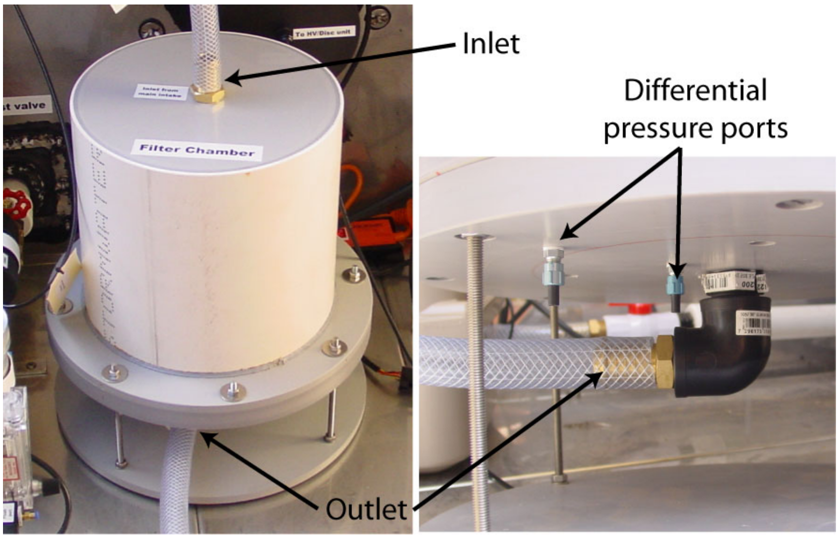


Figure 15: Inlet filter chamber showing inlet, outlet and the differential pressure ports for monitoring the filter status.

The detector's primary filter is housed within a purpose-built, sealed, PVC housing, which is mounted at 180 degrees to provide access to the outlet hose-barb and differential pressure ports, and allow clearer access to the detector head cap.

As the filter becomes dirty (clogged), the differential pressure across the filter will increase. The primary filter should be replaced if the differential pressure measured across the ports shown in Figure 15b reaches 200 Pa. At commissioning, the pressure difference was <10 Pa

2.5 Gas Meter (External flow loop)

A domestic-style gas meter is used to monitor the flow rate of the external flow loop (model 750 *Http://www.Landisgyr.com. /*). A modification has been made to the unit which allows an optical counter to monitor the revolutions of the gas meter's impeller. A flow rate in litres per minute is then obtained by scaling the total revolutions over a 30 minute period based on the cyclic volume of the gas meter (which in this case is 2 L per revolution).

A calibration gas injection port has been incorporated in the up-stream 19 mm hose fitting of the gas meter as shown in Fig. 16.

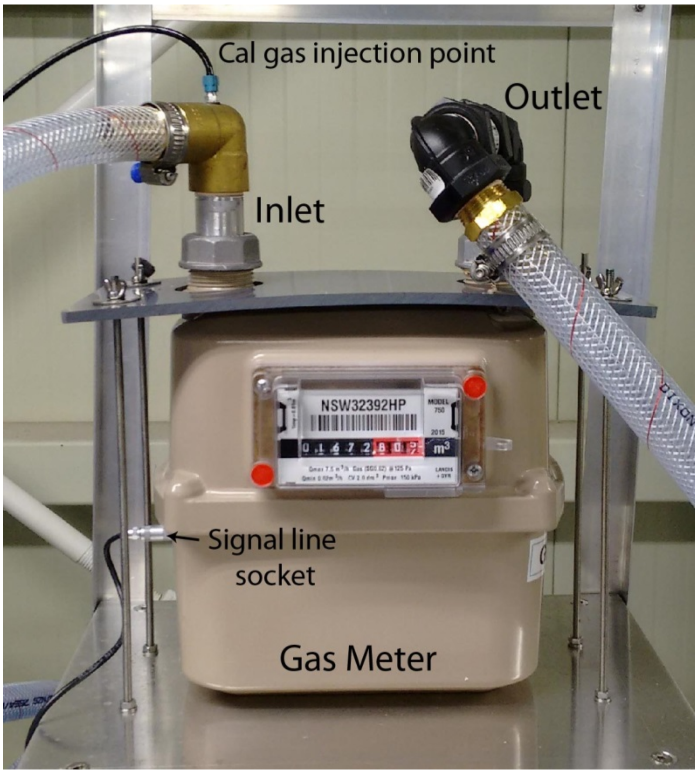


Figure 16: Modified domestic gas meter used for monitoring the flow rate of the external flow loop; the leads from the internal optical counting device and the calibration gas injection port are shown.

2.6 Air velocity sensor (Internal flow loop)

An air velocity probe (insertion type; Fig. 17) has been mounted within the central pipe of the detector (Fig. 18). The probe is positioned to measure the peak velocity of sample air through the detector's 50 mm internal pipe, from which an estimate of the internal-flow-loop flow rate can be made based on the characteristics of turbulent flow in a pipe. The probe is a vent-captor (type 3202.30) manufactured by Weber (www.captor.com).

Specifications
Flow range: 0-20 ms^{-1}; power supply: 24 VDC; power consumption: 0.8-1.3 W; output current: 4-20 mA; operating temperature: -20 to 70ºC; mass: 130 g.

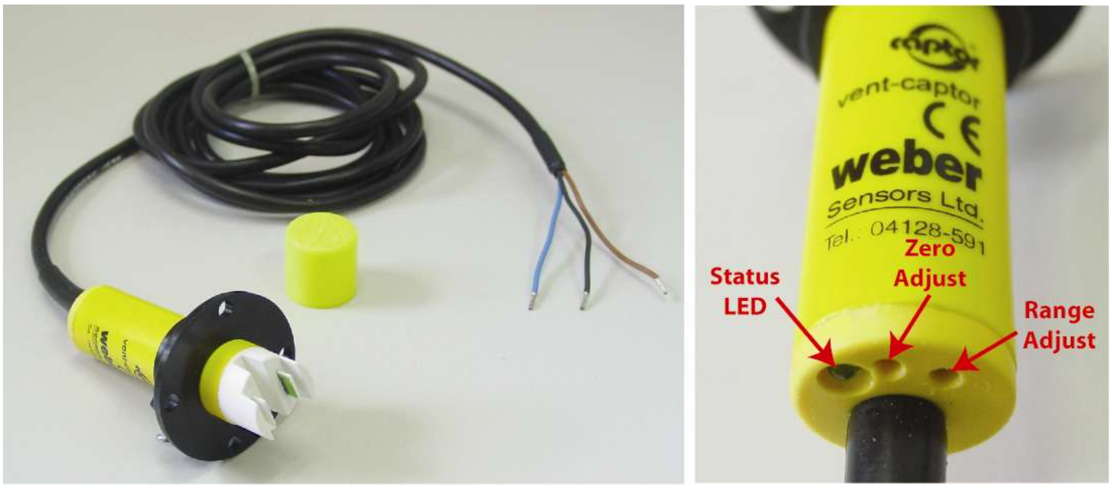


Figure 17: Vent-captor air velocity insertion probe.

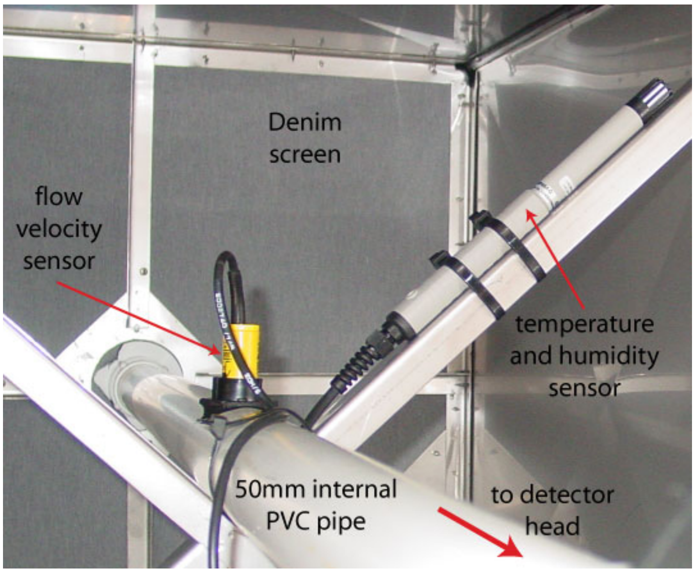


Figure 18: Air velocity probe installed in the central pipe of the detector.

A separate 24 VDC power supply is required to operate the vent-captor probe (Figure 22). The AC adapter used for this purpose was manufactured by Cincon Electronics (model TR36A-24) and sourced from Powerbox (http://www.powerbox.com.au/).

Specifications

- Input: 100-240 V ~1 A, 50-60 Hz;
- Output: 24 V, 1.5 A.

Figure 19: Vent-captor 24 VDC power supply.

2.7 Radon detector head

The radon detector head is comprised of the following components (Figure 20):

1. 5" Photomultiplier tube (PMT) shielded with aluminium foil, earthed and wrapped in black electrical tape (Electron Tubes Products (ETP) model 9330B, http://www.electrontubes.co.uk);
2. PMT socket (ETP part# B15) and resistor cascade with PMT shield earth connection;
3. Aluminium PMT head casing loaded with fine (635 mesh) stainless steel mesh screen (TWP Inc., http://www.twpinc.com/);
4. Scintillation material, ZnS(Ag) coated clear polyester sheet (Saint-Gobain Crystals, http://www.bicron.com/);
5. Aluminium PMT collar anchoring brackets;
6. PVC collar for PMT and anchoring springs;
7. PMT high voltage/signal cable; and
8. 50 mm PVC adaptor.

It is important to store the photomultiplier tube and detector head in a clean, dark environment when not in the detector.

If it is necessary to relocate the detector after it is initially commissioned, the head and other components should first be removed and packed for transport.

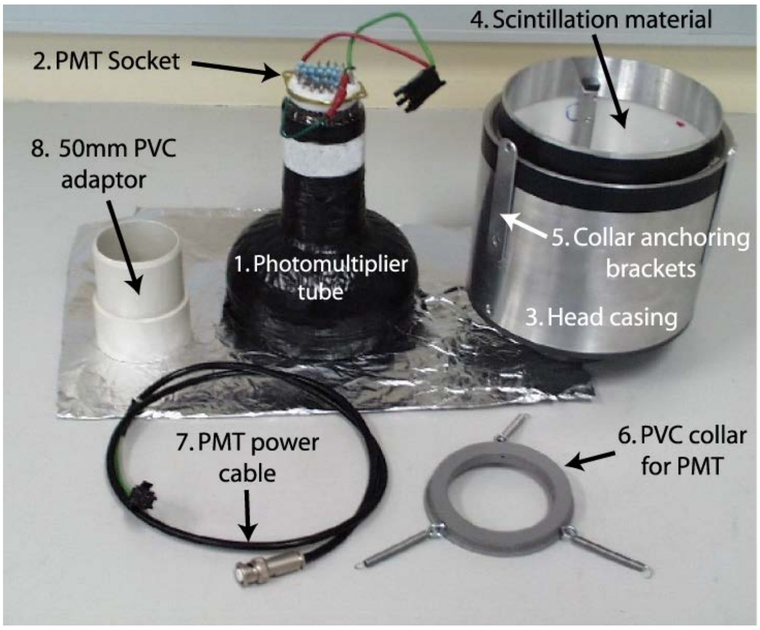


Figure 20: Components of a radon detector head prior to assembly.

Figure 21: Example of an assembled detector head ready for installation.

<u>Replacement / Assembly of a detector head</u>

When a detector is first commissioned the instrumental background is usually ~1 count per minute (although this value is very site specific, see Section 3.2.1). However, build-up of the α-emitting radon progeny ^{210}Pb (half-life 22.3 years) on the mesh screen of the detector head will gradually increase the background count rate. The rate of accumulation will depend on the long term average radon concentration at the site. Under normal operating conditions at an inland or coastal site the mesh screen and scintillation material of the head should be replaced every 3-5 years.

Should a new (or re-lined) detector head be required, they are always shipped disassembled. To reassemble a radon detector head from its constituent components, follow these instructions:

Attention: the assembly of a radon detector head should be performed in a clean environment.

1. The head casing will be wrapped in aluminium foil. Carefully remove this wrapping (Figure 22a).
2. Stand the head casing upright with the large opening facing upwards (Figure 22b).
3. Check inside. If there is any obvious dirt or dust on the scintillation material, **carefully** remove it with a clean tissue (do not apply pressure to the scintillation material since the surface is very brittle).
4. Carefully remove the PMT from the foam padding in its box (Figure 22c). If it has been wrapped in foil for additional protection, carefully remove this wrapping but DO NOT REMOVE THE BLACK ELECTRICAL TAPE (this is part of the electrical shielding of the PMT).
5. Check the face of the PMT. **Remove the protective black film if it is still in place** (Figure 22d). Dirt on the face of the tube can be carefully removed with a lint-free cloth made damp with isopropyl alcohol (if the cloth is too wet the alcohol may soak into the electrical tape and cause the shielding layer to come loose). Take care not to scratch the surface.
6. If the collar anchoring brackets are not already attached to the head do so by removing the three middle screws from the body of the head and using them to attach the collar brackets (the screws should go into the countersunk holes of the anchoring brackets).
7. Insert the PMT face down into the large opening of the head (Figure 22e). Ensure that the tube is firmly seated on the padded mounts in the head. If the fit of the PMT into the head casing is not snug add more layers of electrical tape around the outside of the PMT.
8. Slide the PMT collar over the narrow end of the PMT (Figure 22f).
9. Anchor the springs to the collar brackets using long nosed pliers (Figure 22g).
10. Attach the PMT socket to the tube (Figure 22h), taking careful note of the correct orientation. There is one pin missing on the base of the PMT and one blank hole in the socket; these should be aligned. Press down firmly to seat the socket, but avoid bending the pins on the PMT (check that the soldering of the wires to the socket is still secure).
11. Connect the socket's Earth wire to the PMT's shield wire (Figure 22i).
12. Push the 50mm PVC adaptor into the smaller opening on the bottom of the head. If the fit is not snug, Teflon tape or a non-permanent caulking compound should be used to improve the seal of this joint. Any air that leaks through this joint is not being sampled because it is bypassing the mesh filter. This would reduce the sensitivity of the detector.

Figure 22: Some key steps in the assembly of a radon detector head.

When all components of the detector head have been assembled, the final product should look like the example in Figure 21.

2.8 Detector head cap

Considerable effort goes into making sure that the detector's delay volume is well sealed. However, it is occasionally necessary to gain access to the inside of the delay volume for cleaning, checks, or maintenance purposes. For this reason a removable head cap has been fitted (Fig. 23).

The head cap provides access to most internal components of the radon detector, such as the measurement head, temperature/humidity, absolute pressure, and internal flow loop velocity sensors. To minimise the risk of leaks the head cap has been machined from a single piece of HDPE. It is also completely opaque. A gland has been mounted through the end of the head cap to accommodate the photomultiplier tube's signal and high voltage cable.

Between the head cap flange and detector bulkhead mount an O-ring is used to make an air-tight seal (nitrile rubber type O-ring with 6¼" I.D. and 1/8" cross section). It is important that the base of the flange sits flush with the detector bulkhead to maintain this seal. Take care not to misplace or damage the O-ring and check each time the head cap is removed that the O-ring is not cracked or perished.

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

Figure 23: Detector head cap and central high voltage cable that connects to the High Voltage / Discriminator unit.

The head cap should be removed as infrequently, and for as short a time, as possible, otherwise dust containing ^{226}Ra may enter the delay volume and generate radon internally. The inside of the detector delay volume was thoroughly cleaned prior to sealing it for shipment. When the head cap is removed, ambient thoron (^{220}Rn) will enter the main tank. When the detector is sealed again, the detector should be flushed of thoron for about 30 minutes by operating the "external" and/or CF stack blower WITHOUT the "internal" blower turned on.

2.9 External Power Supply

Most components of the radon detector nominally run on 12 VDC. A 240 VAC to 15 VDC power adapter (Fig. 24) is used to supply the data logger box. The data logger (and auxiliary circuitry) distributes this power as required to the other components. The power adapter is manufactured by ***Powerbox*** Australia (model TRG150A150-21E11). It is enclosed in a polycarbonate case with an IEC320 input connector. It has a wide AC input voltage and single to multi output combinations, Http://www.powerbox.com.au/.

Figure 24: Powerbox Model: TRG150A150-21E11 Power supply for the radon detector.

Specifications

- Input Voltage: 90-264 VAC (47 Hz – 63 Hz)
- Inrush Current: 120A max @ 264 VAC
- Output Voltage: 15 V (10 A; ~150 W)
- Operating Temperature: 0^{o}C to 47^{o}C
- Dimensions: 180 x 74 x 41 mm

2.10 High-voltage supply / PAD Unit

The high-voltage power supply for the PMT, and counting unit that discriminates between the voltage of pulses received from the PMT (to determine whether they are legitimate counts or noise spikes), are combined into a single unit called the High-Voltage / Pre-Amplifier Amplifier Discriminator (HV/PAD) unit (Fig. 25). Discrimination thresholds are usually set to 0.5 and 1.0 V (see Section 8.2 for a wiring schematic).

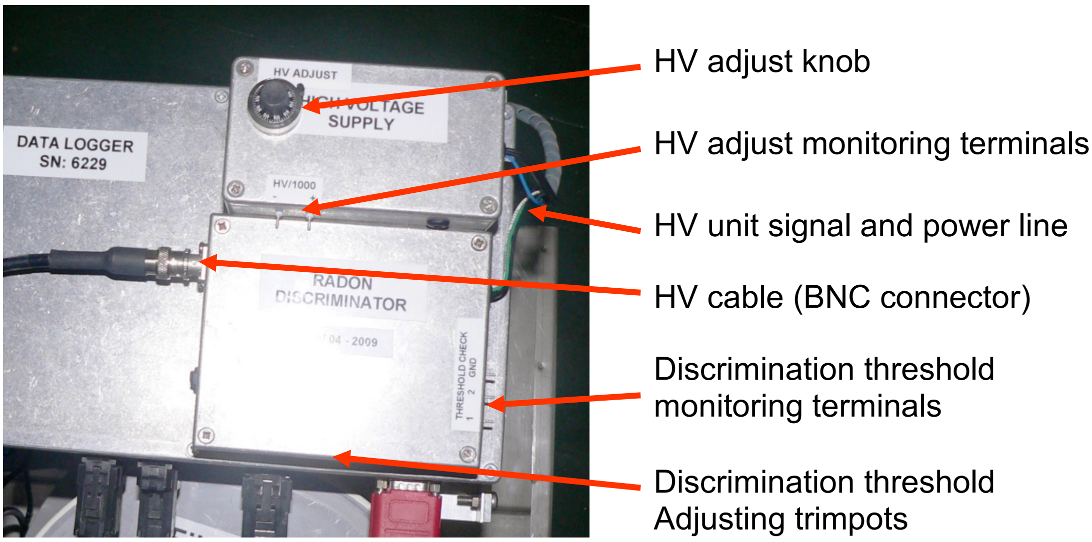


Figure 25: High voltage / pre-amplifier, amplifier discriminator unit.

2.11 The data logger and controlling PC

A commercial data logger (CR800; SN:4146 Fig. 26) and Windows based PC are used to control detector operation and schedule calibrations. The data logger records the output and status of the major detector components. A complete list of channels recorded by the logger is provided in Section 8.1 and a wiring schematic of the logger in Section 8.2. The logger's data file format is comma delimited ASCII (i.e. *.csv files). The CR800 data logger was sourced from Campbell Scientific Inc., (http://www.campbellsci.com/).

The logger is enclosed in a die-cast aluminium box, which also contains an integrated circuit board and differential pressure sensor. This sensor is actually a micro mass-flow controller (Honeywell Microswitch AWM3100 Microbridge mass airflow sensor; excitation 10 VDC, output 1-5 VDC, representing 0-200 sccm (http://www.rswww.com.au/).

The logger program is stored in non-volatile memory so that, in the event of an interruption to the mains supply, the logger will automatically recommence operation as soon as power is restored. Additional circuitry (including the IC board and external connectors) operates the differential pressure sensor, redirects DC power to detector components, and provides ports to which components of the detector can be easily connected for continuous monitoring.

There are a number of connectors on the face of the logger housing (Fig. 26). These include (from left to right, top to bottom): logger power (12 VDC in), differential pressure inlet port, calibration box communication line, internal flow loop blower power, temperature/humidity signal/power line, external flow loop blower power, absolute pressure signal/power line, gas meter signal line (external flow loop), velocity probe signal line (internal flow loop), RS-232 communication line and high voltage supply / discriminator power and signal. If it is necessary to disconnect power to the internal and external flow loop blowers for diagnostic purposes simply unplug the blower leads from the logger housing.

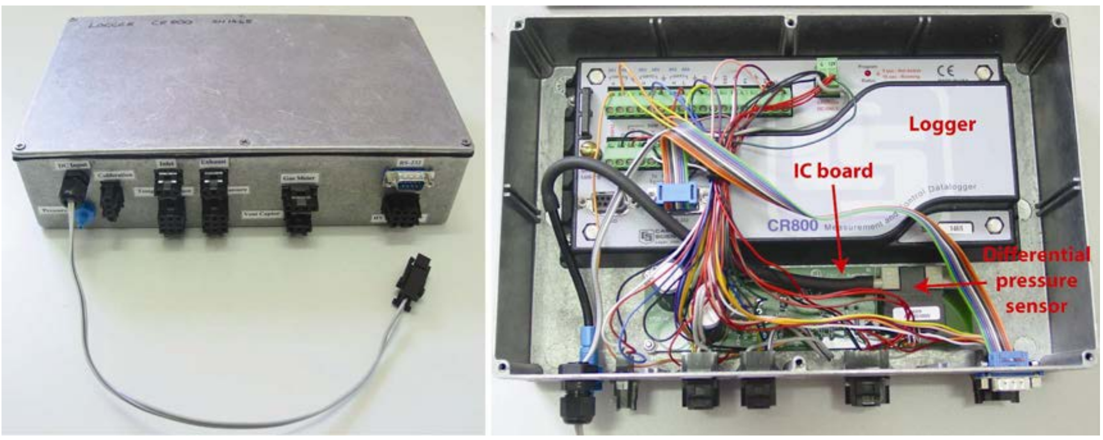


Figure 26: CR800 data logger and auxiliary circuitry in a die-cast aluminium box.

Logger specifications

Voltage Requirements: 9.6 to 16 VDC; Quiescent Current: 1 mA typical; Processing Current: 13 mA; Measurement Current: 46 mA; Operating Temperature: -25 to 50 ^{o}C

The data logger is situated on the radon detector's electronics rack (Fig. 6). The controlling computer is located on the computer rack in the container. The data logger and computer communicate via a serial connection. The computer and calibration unit (Fig. 30) communicate via a USB link.

A micro mass flow sensor within the logger housing serves as a differential pressure sensor between the detector tank and ambient air (Figure 26). A calibration was performed on the millivolt output of this sensor at the time the detector was installed. To do this, a portable differential pressure sensor was attached to a T-piece in the pressure line running from the differential pressure port to the logger (see Fig. 27). The tank overpressure was changed five times by constricting the exhaust valve (Fig. 7b) and a record was made of the mV output of the micro mass flow sensor as a function of the portable differential pressure sensor output. The results of this calibration are displayed in Figure 28.

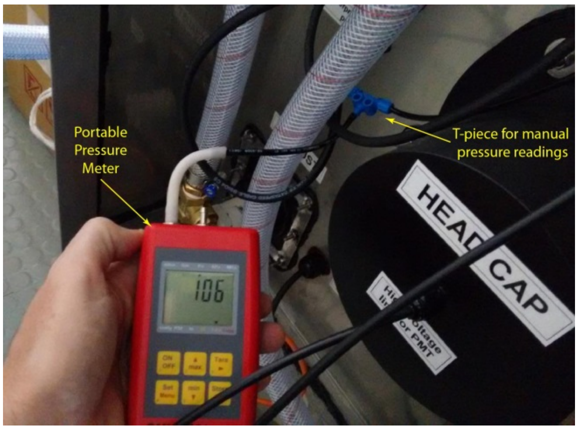


Figure 27: Calibration of the micro mass flow sensor with a hand held differential pressure sensor.

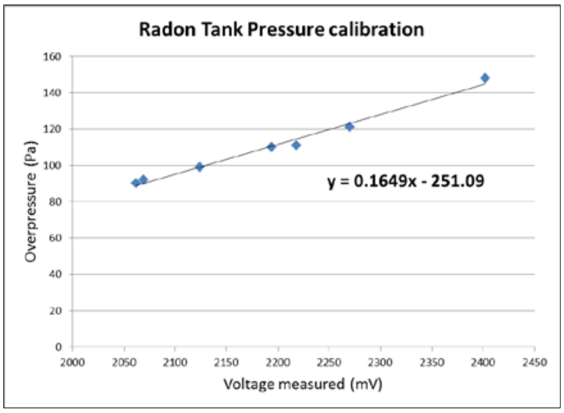


Figure 28: Results of onsite pressure calibration performed and the linear approximation of the calibration curve.

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. Based on the results above, the calibration factors for this unit at the time of commissioning were: **slope (0.1649) and offset (-251)**.

2.12 Absolute Pressure Sensor

Absolute pressure within the main detector delay volume is recorded using a Vaisala analogue barometer (model PTB110,SN:K385000 ; Fig. 29). These sensors are sourced from Campbell Scientific (http://www.campbellsci.com.au/index.cfm).

Specifications

- Range: 600-1060 hPa (resolution 0.1 hPa)
- Output: 0-2.5 VDC
- Supply: 10-30 VDC

- Temperature range: -40 to 60ºC

Figure 29: Vaisala absolute pressure sensor. The sensor is mounted inside the main delay volume, so is not usually visible within the electronics enclosure.

2.13 Internal temperature and relative humidity

The temperature and relative humidity of air within the detector's delay volume is recorded using a Vaisala temperature and relative humidity probe (model HMP155, SN . K5150063; Fig. 30). These sensors are sourced from Campbell Scientific (http://www.campbellsci.com.au/index.cfm or http://www.vaisala.com).

<u>Specifications</u>

- Operating temperature: -40 to 60ºC
- Dimensions: 25.4 cm (length); 2.5 cm (diameter)
- Filter: 0.2 µm Teflon membrane
- Supply voltage: 7-35 VDC
- Power consumption: <4 mA @12 V

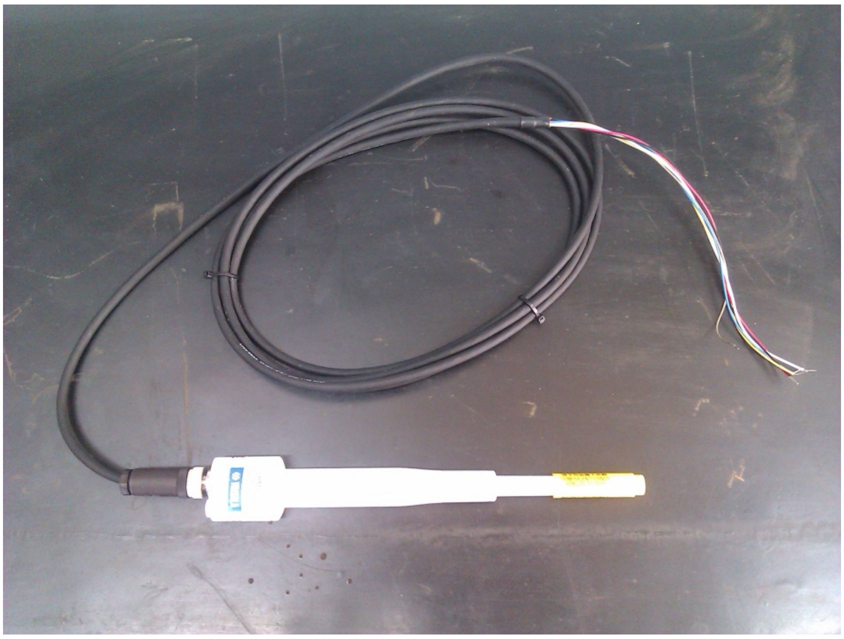


Figure 30: Vaisala temperature and relative humidity sensor.

3 Detector tests

3.1 Leak Test

3.1.1 Overview

There is a large difference (~2 orders of magnitude) in concentration of short-lived radon and thoron progeny between ambient air and air inside the detector. Consequently, the integrity of the seal around the detector's delay volume is crucial for the detector's operation. To counteract inevitable small leaks within the sampling line and detector's delay volume, both should be kept under a slight positive pressure with respect to ambient (between 80 to 120 Pa). If this is the case, when small leaks develop air will only flow *from* the delay volume, not *into* it.

A leak test is performed on all newly commissioned detectors and may be repeated if deemed necessary by subsequent data quality checks. There are several components of the detector that may cause leaks if not correctly installed. These include: the detector head cap and O-ring seal, the glands through which the high voltage supply lead, blower power supply lead, T/RH lead, vent captor lead, pass, the glands through which the inlet and exhaust lines pass, and the pressure port fittings (differential and absolute). A satisfactory leak test provides confirmation that these components have been correctly installed and sealed. Apart from air leaks, 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 HV unit and PMT.

Lifting or moving the detector can stress the seams and joints and result in leaks developing. If the detector needs to be lifted or moved it is recommended that a leak test be performed before it is restarted in its new location. For the same reasons, do not move the detector with power still connected to the PMT in the case of a light leak developing. Even a relatively small light leak could destroy the PMT if power was connected to it at the time.

3.1.2 On site leak test

As part of the detector commissioning process a leak test was performed in the following manner: the tank exhaust valve was closed and portable differential pressure sensor was then attached to the tank pressure port situated on the bulkhead of the tank (Figure 6). Power was then connected to the external flow loop blower via the data logger. After allowing a few minutes for the air pressure inside the detector's delay volume to stabilise, the differential pressure was repeatedly measured; the average of these readings was 550 Pa. This value corresponds to a leak rate not higher than 2L/min, which was established before the detector was shipped to Hobart for commissioning. A leak rate of 2 L/min is considered to be acceptable for 1500L radon detectors. The field leak test was initially performed without the PM tube inside and was then repeated with the PM tube installed, and both tests gave similar results.

3.2 Background Test

3.2.1 Overview of the instrumental background

Even when there is no flow through the detector[2], it will register a small but quantifiable count rate. This is referred to as the instrumental background. Regular determination of a radon detector's instrumental background at the working voltage (Section 3.2.2) is necessary in order to correctly process the raw data. Furthermore, the instrumental background strongly influences the detector's lower limit of detection.

Many factors contribute to a detector's instrumental background, including:

1. The gamma radiation field of building materials containing significant activities of Ra-226 (e.g. dense concrete);
2. Cosmic radiation;
3. Properties of the scintillation material used in construction of the detector head;
4. Accumulation of Pb-210 (α-emitting progeny of radon with a 22.3 year half-life) on the detector's second filter (fine mesh filter inside the detector head); and
5. The instrumental background also changes with the high voltage setting applied to the PMT.

The instrumental background of a detector at any given time is site specific (see points 1 and 2 above), and needs to be determined afresh upon commissioning. Furthermore, the background of a detector gradually rises from the commissioning value (approximately linearly with time), at a rate that depends on the long-term average of the sampled radon concentration. For instance, the background of a detector sampling primarily continental air will increase more rapidly than if it were

[2] And there has been no flow through the detector for the past 6 hours so that the short lived progeny on the measurement head would have decayed.

sampling primarily marine air. This increase in background is due to the accumulation of Pb-210 on the mesh filter of the head (point 4 above).

Background checks at the working voltage should be performed regularly (every 3-4 months) after the detector is commissioned (see Section 4.1).

Background characterisation as a function of PMT bias voltage is performed less frequently (usually pre-shipping and during commissioning only). The purpose of such a measurement is to assist in the determination of the most suitable working voltage setting for the detector's counting system.

3.2.2 Automatic Background Measurements

A calibration and background (C&B) unit is located in the pumps enclosure (Fig. 31). This unit has been designed to perform automated calibration and background measurements on a working detector at a pre-set frequency, although calibration and background events can also be triggered manually via the RDM software interface.

Figure 31: View of the CB unit in pump's enclosure.

A background measurement is conducted by scheduling a time and duration for power to be disconnected from both the inlet stack blower, internal and external blowers. When power is shutdown to these units the inlet solenoid valve will also be closed.

Please refer to Section 5.4 for details regarding the scheduling of background event times via the ***Cal&Back*** toolbar button in the ***Radon Detector Monitor*** program's main screen. After the designated time period for the background event has elapsed, the inlet solenoid valve is opened automatically, stack and internal blowers are then turned back on, and the detector resumes normal operation.

Occasionally it might be necessary to start a background event immediately, rather than scheduling a future event. For this purpose a ***Background NOW*** button has been incorporated within the control window. Pressing this button puts the detector into background mode immediately for the pre-selected time period displayed on the ***Background Settings*** window (see Section 5.4).

Background events are typically scheduled over a 24-hour period. As such, it is most convenient to schedule them to begin at midnight. Please note that it can take up to 6 hours for short-lived progeny on the detector head to decay after the background measurement has commenced. After this time period has elapsed, the result of the automatic background is calculated as twice the average half-hourly background count from hour 7 to hour 24 of the 24-hour background period.

3.2.3 Commissioning background test

After assembling the detector and performing the leak test, power was disconnected from the detector's blowers overnight to make sure short-lived radon progeny on the detector head had decayed. The instrumental background was then measured over half hourly intervals, over the high-voltage range 500 to 650V in increments of 25V. In order to get a more representative background count at each voltage setting, multiple counts were made at each voltage.

The procedure to conduct the commissioning background test was as follows:

- Connect a voltmeter to the HV monitoring terminals of the HV unit (Fig. 32).
- Reduce the HV setting ~75 V below the working voltage with the adjusting knob.
- At 30 minute intervals (on the hour and half hour), adjust the high voltage setting upwards in increments of 25 V. Continue with adjustments to a setting of ~75 V above the working voltage.
- Plot the measured count rate vs the high voltage setting.
- Check the background count rate per minute at the working voltage.

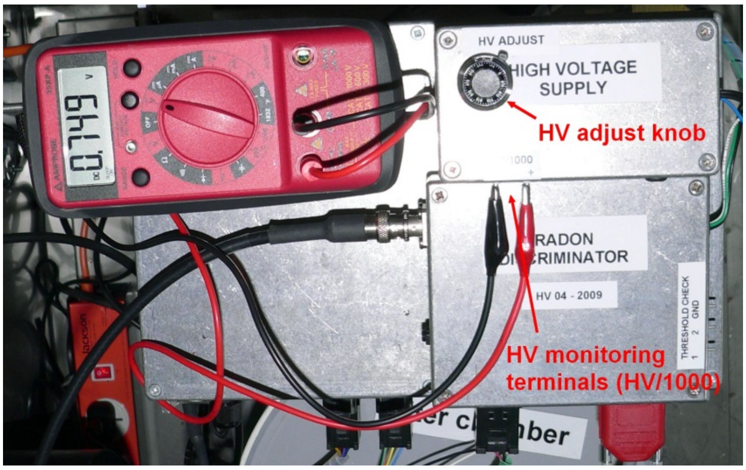


Figure 32: Adjusting and monitoring the high voltage setting during a background check. Here the voltmeter leads are connected to terminals provided to monitor the high voltage signal (output HV/1000).

The results of both the onsite commissioning background test and pre-deployment (at ANSTO) background test of the AIR-BOX radon detector are presented in Figure 33. At ANSTO the detector was located in a building basement for construction / testing, and the higher background values observe most likely reflect radiation emanation from the building materials (dense concrete).

At the end of the commissioning process, a working voltage of 575 V was decided upon, for which the instrumental background count was 1.2 counts per minute. A reasonable target background for a detector commissioning is 1 count per minute.

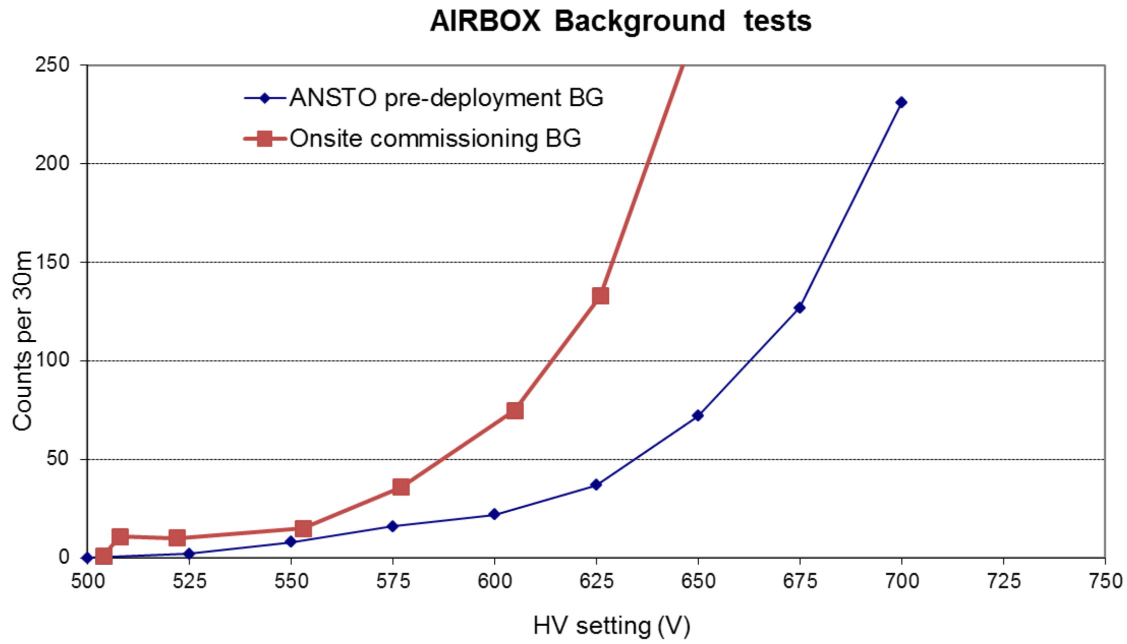


Figure 33: Results of pre-deployment and commissioning background tests.

3.3 Detector calibration and sensitivity tests

3.3.1 Overview

Small changes in the radon detector's sensitivity with time are to be expected. It is therefore recommended to perform routine calibrations on a regular (e.g. monthly) basis as described in Section 3.3.4.

The sensitivity of a radon detector's counting system also varies as a function of high voltage setting. Consequently, an important part of the commissioning process is characterising the detector's sensitivity to radon as a function of high voltage setting when there is a known concentration of radon in the tank. In conjunction with knowledge of the instrumental background, this information is used to select the optimum high voltage setting for routine operation (i.e. the "working voltage").

3.3.2 Automatic Calibration

As the name suggests, the **Calibration & Background** unit in the pump enclosure (Fig. 31) has also been designed to routinely perform automatic calibrations on the detector during normal operation (see Section 5.4 for details). These routine calibrations simply involve injection of radon from the calibrated source for a pre-set time at the working high voltage setting.

Inside the **Calibration & Background** unit is a passive Pylon ^{226}Ra source (Serial Number 234) with an activity of 82.717 kBq ^{226}Ra, which corresponds to a ^{222}Rn delivery rate of 10.422 Bq min^{-1}. The **Calibration & Background** unit injects radon-rich air into the detector's gas meter inlet via a 3mm internal diameter (ID) injection line.

Figure 34: Pylon "passive" calibration source for the AIR-BOX radon detector.

3.3.3 Sensitivity test

A sensitivity test differs from a routine calibration in that a known concentration of radon is achieved, and then maintained, within the detector for an extended period as the detector's sensitivity to radon is monitored as a function of high voltage setting. It is necessary to inject a constant stream of radon into the detector for at least 4 hours in order for the radon concentration within the detector to reach equilibrium, after which time the sensitivity test can commence.

Figure 35: Radon source inside the C&B unit.

For the commissioning sensitivity test the calibration unit was configured to inject radon-rich air at a rate of 80-100 cc/min[3] (see **Flowmeter Test** tab, Section 5.4.3). At a flow rate of ~83 L min^{-1}, and radon delivery rate of 10.422 Bq min^{-1}, the equilibrium concentration of radon within the detector was approximately 125.5 Bq m^{-3}.

When the concentration of radon in the detector had reached equilibrium, the detector's sensitivity was measured for PMT bias voltages varying from 475V to 800V, in 25V increments. The count rate at each point was determined as the average of ten 10-second counts (Fig. 36).

[3] A low injection flow rate (compared to the ~83 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.

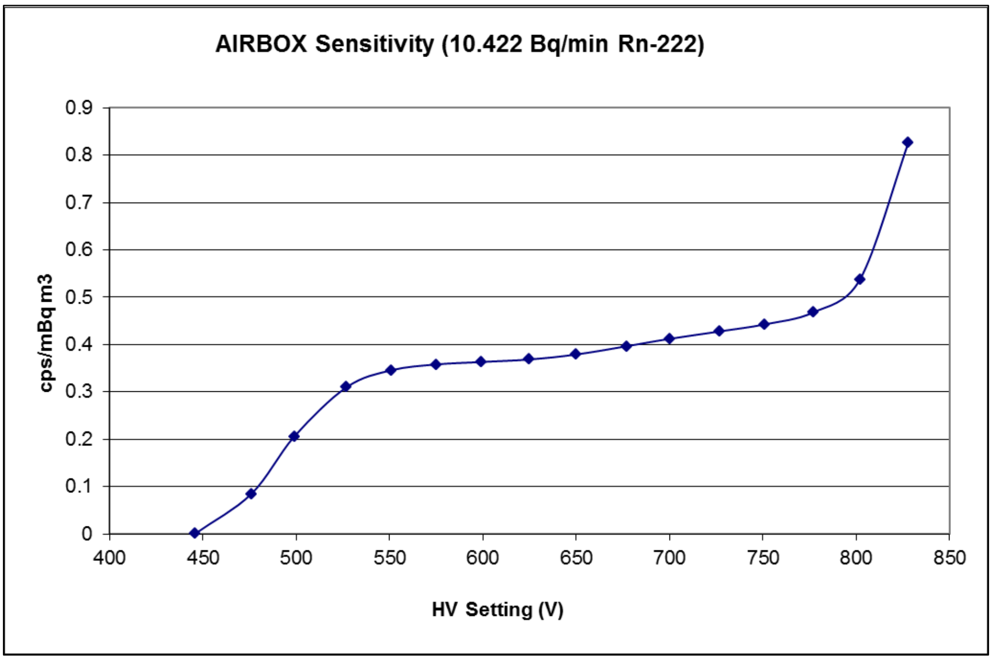


Figure 36: Detector sensitivity as a function of high voltage setting onsite at AIR-BOX

According to the two tests shown above, the "knee" (main break in slope) in the sensitivity curve happens at a voltage setting between 525 and 600V. Based on the results of the background test (see Fig. 33), the chosen working voltage for the AIR-BOX detector was 575V (i.e. a compromise between characteristics of the background and sensitivity curves). Ideally, the working voltage should be low enough to constrain the instrumental background to approximately 1 CPM on commissioning, but high enough that the rate of change in sensitivity with increasing high voltage is low (Fig. 36).

Sensitivity curves, such as the one above, cannot be used for calibration purposes since ambient radon concentrations are not taken into account. This leads to an overestimation of the sensitivity and, depending on changes in ambient radon levels, some irregularities in the shape of the sensitivity curve.

Routine (monthly) calibration of the detector is performed using a different procedure, described in the following section.

3.3.4 Routine Calibration

Periodic calibration of the detector is strongly recommended. The Calibration & Background (C&B) unit has been designed such that a calibration can be performed on an operating detector without the need for user intervention. By default, the Calibration & Background unit is setup to automatically perform calibrations on a monthly basis.

A routine calibration (or "calibration event") involves the injection of radon-rich air to the sample air stream of the operating detector for at least 5 hours, followed by a 4-6 hour detector flushing period to return to ambient concentrations. This process will result in a clearly defined peak in the signal. One such peak measured at ANSTO is shown in Figure 37 (note: exact values for the peak may change depending on source strength, flow rate, background and ambient radon concentrations).

A separate calibration coefficient is determined from each calibration event. Assuming a gradual linear change of the detector's sensitivity to radon with time, for each year of data to be processed, a linear regression is performed through all valid monthly calibration coefficients to derive the 60 minute calibration factor used for post-processing. Some of the individual monthly calibrations may need to be rejected due to rapidly changing ambient radon concentrations (e.g. during "radonic storm" events) or due to malfunction of the injection process. Typically, only a slight (1-3%) reduction in detector sensitivity is expected per year at inland sites (when the rate of accumulation of ^{210}Pb on the detector's head is high), the rate of deterioration for coastal, island or Antarctic sites is expected to be considerably less.

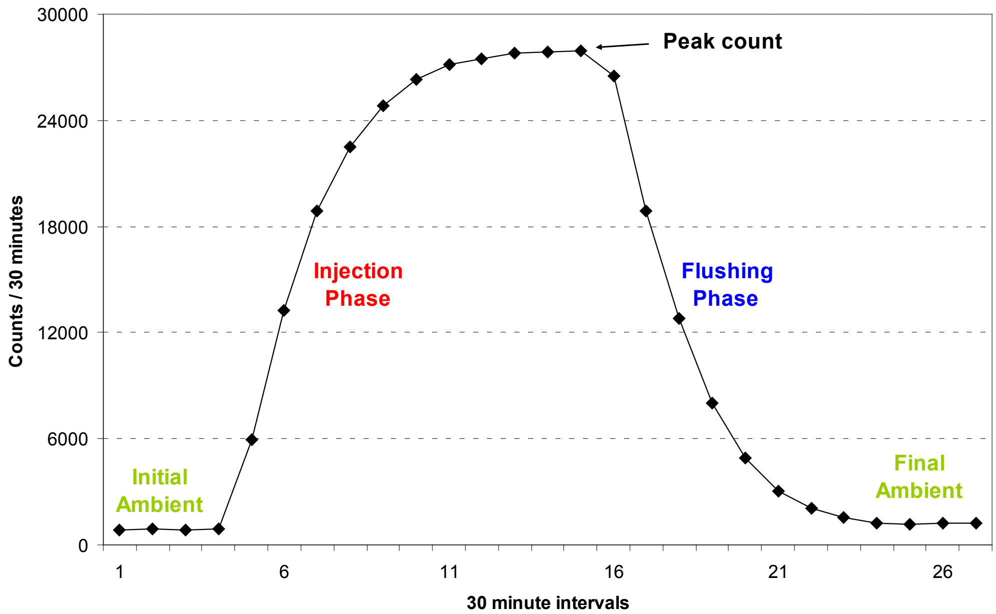


Figure 37: Example calibration event for a 1500L radon detector.

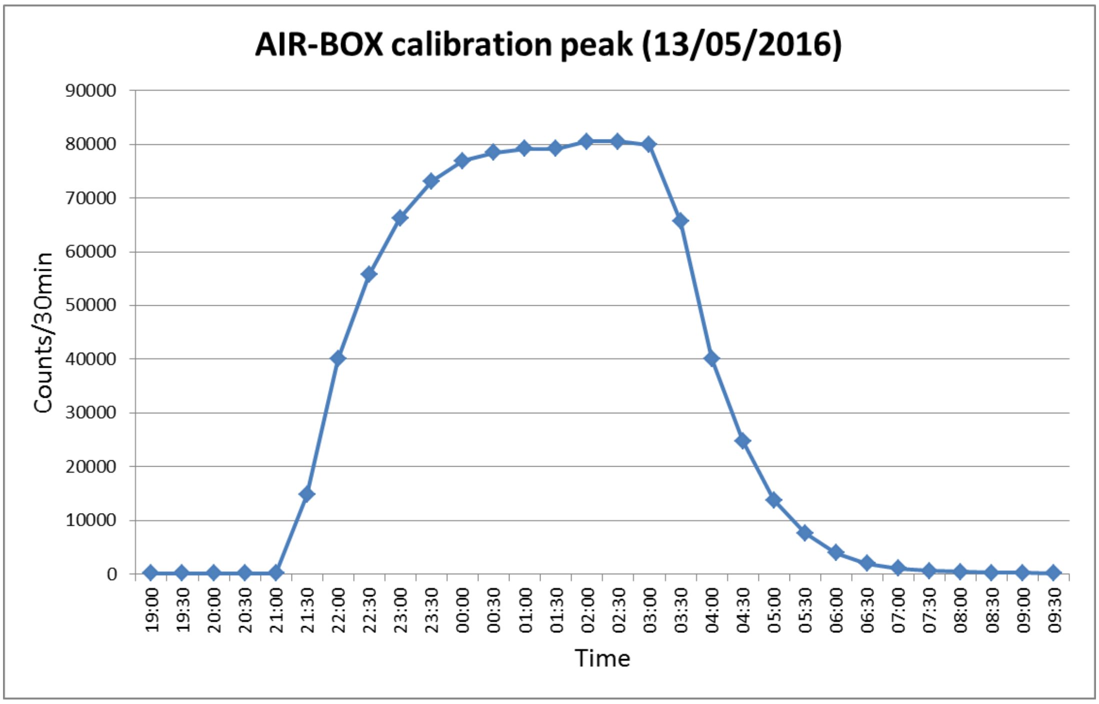


Figure 38: The first calibration curve for the AIR-BOX radon detector.

3.3.5 Lower Limit of Detection

The radon detector's lower limit of detection (LLD) is defined here in terms of the statistical uncertainty associated with the counting of alpha-emitting radon progeny by the detector's counting system. More precisely, the LLD is the equivalent radon concentration (in Bq m^{-3}) at which there is a relative counting error of 30% at the detector's "working voltage".

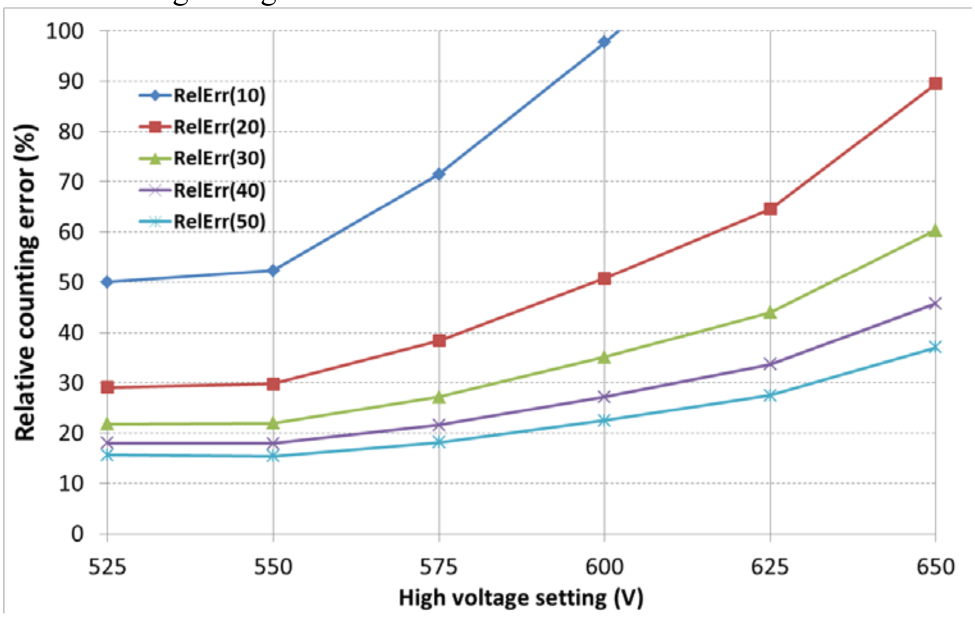


Figure 39: Relative error as a function of high voltage settings for a range of radon concentrations between 10 and 50 mBq m^{-3} based on 2016 commissioning tests.

The lower limit of detection for the AIR-BOX detector was determined using data gathered during the commissioning sensitivity and background tests. Throughout the sensitivity tests a radon concentration of 125.6 Bq m^{-3} was maintained in the detector delay chamber using a 10.422 Bq/min radon source and constant flow rate of ~83 L min^{-1}.

The first step in the determination of the detectors lower limit of detection was to calculate the relative counting error over a range of high voltage settings (500-650V) for a number of proposed lower limits of detection (0.010-0.050 Bq m^{-3}). These results were then plotted (Fig. 39). From Figure 39 it is evident that, at a high voltage of 575V, a counting error of 30% occurs at a radon concentration of ~27 mBq m^{-3}. Thus the lower limit of detection of the AIR-BOX radon detector is 27 mBq m^{-3} in the commissioning configuration, and at a working voltage of 575V.

4 Routine Tasks and Recommendations

4.1 Overview

Please note that since the controlling computer for the AIR-BOX radon detector is NOT connected to the local network, it cannot be accessed for data downloading and performance checks. The regular physical checks of the system are possible (and recommended) every time the AIR-BOX is deployed at the new site or after completion of the project.

On longer time-scales (e.g. ≥monthly), routine requirements for continued operation of the AIR-BOX radon detector include:

(a) **Background evaluation**. (Automatic). Ensure that a 24-hour background event is scheduled in the ***Background Settings*** window of the RDM software to occur every 3 months (after each scheduled background check manually that the system has returned to normal operation).

(b) **Calibration**. (Automatic). Ensure that a 5-6 hour calibration injection is scheduled in the ***Calibration Settings*** window of the RDM software to occur every month. 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 ***Calibrate Now*** button (after each scheduled calibration check manually that the system has returned to normal operation).

Occasionally (every 3-4 months) the calibration injection flow rate should be checked manually. To do this, either look at the graphical display on the ***Flowmeter*** tab of the ***Calibration and Background*** window when a calibration is underway, or use the ***Calibrate Now*** and ***Reset Calbox*** options to briefly check the flow rate. Note the result of the check in the electronic log file available through the ***Data Logger Monitor*** toolbar.

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

(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: connect a differential pressure sensor to the T-piece of the pressure line (e.g. Fig. 31); by adjusting the exhaust valve, get a reading of 100 Pa on the hand held pressure sensor; enter the "Real Time" monitoring mode (through **Settings > Data Logger > Connect** in Radon Detector Monitor) and look at the differential pressure sensor output. Compare the output of the portable pressure sensor (Pa) to the detector's pressure output signal (mV) using the curve in Figure 32. If there is more than a ±5 Pa difference in the readings, a recalibration will be required.

Start the recalibration 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 70-150 Pa. Plot the curve and replace the existing Figure 32. 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 90-120Pa. Go to **Settings > Startup** and enter the new coefficients at the bottom of the screen. Return to the data window and reload the current file (or restart Radon Detector Monitor) for the changes to take effect.

(e) **Synchronisation of the logger and PC clocks**. Assuming that the controlling PC clock is synchronised to a reliable time standard (e.g. 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**. In ***Radon Detector Monitor*** go to **Settings > Data Logger > Connect > Synchronise Clocks**. Then return to the data screen.

4.2 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 20 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 only, 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 few years) 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.

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. A separate working directory can be specified to store the data files. 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.

<u>Note:</u> **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 (e.g. Meteorology).**

5 Radon Detector Monitor software

5.1 RDM overview

The AIR-BOX radon detector is controlled by a program called "Radon Detector Monitor" or RDM (version 7.5). This program downloads the logger and manages the logger's data files. It also allows preliminary data quality control and plotting of selected parameters. An on-line user manual can be accessed through the program's help menu. The main interface screen offers pull-down menus that access all commands as well as a toolbar with icons for quick access to the main features. The status bar at the bottom of the screen provides information about the parameters and actions.

The main functions of the program are:

- Downloading the most recent data from the logger every 30 minutes (at 15 and 45 minutes of the hour);
- Creating and update monthly data files which are stored both in the project directory of the host PC, as well as a second destination of the users choice (as a backup facility);
- Displaying the contents of a monthly data file, and plotting selected parameters over user-defined ranges;
- Displaying 10-second averages of selected parameters in real-time;
- Alerting the user whenever select radon detector parameters are outside pre-defined limits,
- Initiating and controlling calibration and background measurements.

5.2 RDM installation

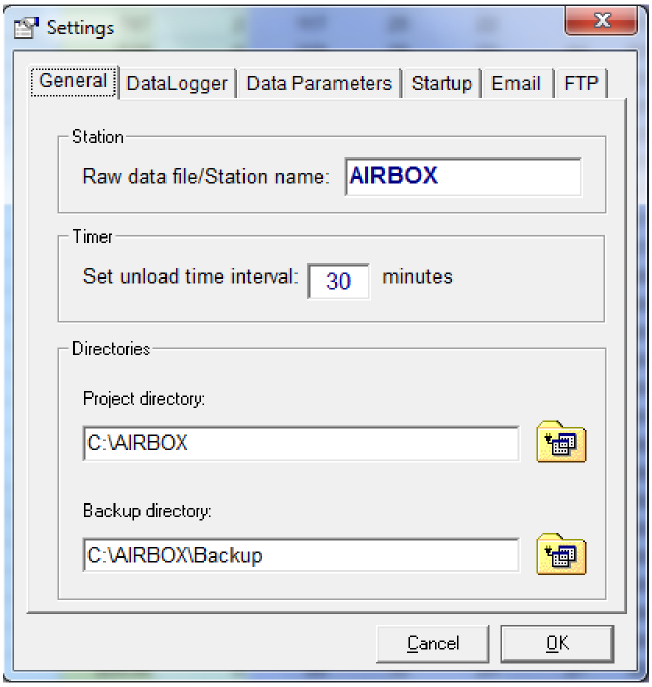
The RDM installation package contains a complete set of drivers and executables, as well as an example logger program; everything that is necessary to run the software and radon detector hardware, including the data logger and C&B unit. The program was designed to run on a PC with a Windows operating system. RDM Version 7.5 has been tested for Windows XP (SP3) and Windows 7. During the installation the user may be prompted to replace some existing files with those supplied. This should only be done if the supplied files are more recent than the corresponding existing files.

The PC should have one free RS232 communication port for the data logger and one free USB port for communication with the C&B module.

5.3 Setting parameters

When **Radon Detector Monitor** is started for the first time the **Settings** dialog window appears. Before RDM starts recording data properly, some initial setup information is required. If the required parameters are not set before logging commences for the new project, the program will either use the previously available settings, or default values. All program parameters are highly customizable, and are stored in the file MONITOR.INI in the program directory. To set or change program parameters after logging has commenced, click on the **Settings** button on the main screen of RDM.

5.3.1 RDM: "General" options tab



<u>Station</u>
Enter a station name that identifies the measurement site (e.g. "AIRBOX" - maximum 8 characters). The naming convention for monthly data file names is XXmmmYY.csv, where XX are the first two letters of the station name, mmm - the first three letters of the current month and YY- the last two digits of the current year. Thus, if data is being collected from multiple stations, the first two letters of each station name should be unique.

<u>Timer</u>
This is where the user specifies the data download interval (in minutes). That is, the interval at which RDM interrogates the data logger to check for, and collect, recently stored data. To minimise the loss of data should a problem arise somewhere in the system, the default (and recommended) interval is 30 minutes, to match the logger averaging time.

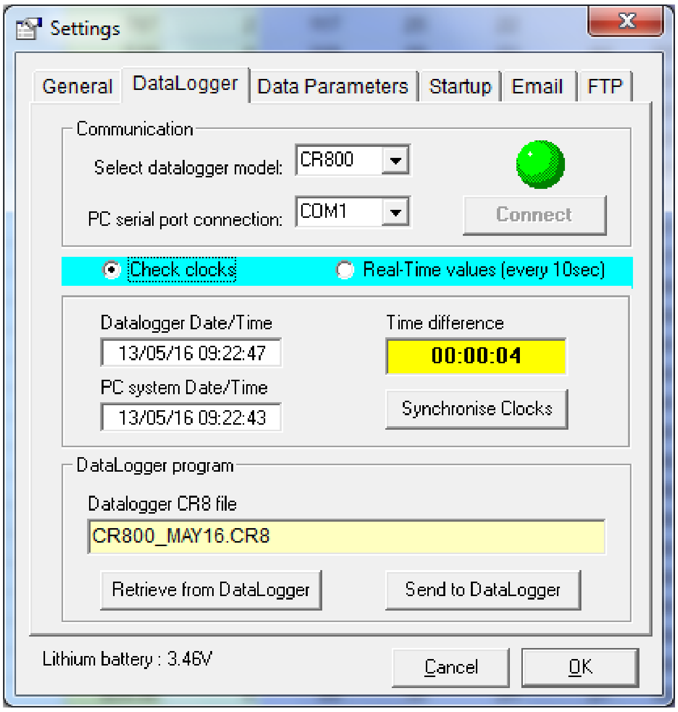
Please note that any change of the current default value should be accompanied by a corresponding change of logger averaging time.

Directories
Project directory defines the working project directory (i.e. where the current monthly data file, and all previous monthly files, are stored).

Backup directory defines the backup directory, to which the current data file, initialisation and project log files are copied. File names for backup data are the same as the original data with an "e" appended to the end of the name. If this field is left blank, no backup data is created. Note that the backup directory can be set to a removable or network drive.

When completing the project or backup directory fields it is possible to browse for an existing directory by pressing the folder button next to the directory text box. If you need to create a new directory, just type the full path in the text box and confirm this after pressing OK.

5.3.2 RDM: "Datalogger" tab



Communication
Here it is necessary to specify the model of data logger operating within the radon detector, as well as the number of the serial communication port to be used to communicate with the data logger. RDM will scan the computer for all available physical serial ports and list them in a drop down combo box. After selecting the appropriate data logger model and communication port, click **Connect** to test the connection between the PC and logger (the AIR-BOX detector operates a model CR800 Campbell data logger).

When communication is established the red light will turn green and all fields of the Clocks panel will become enabled.

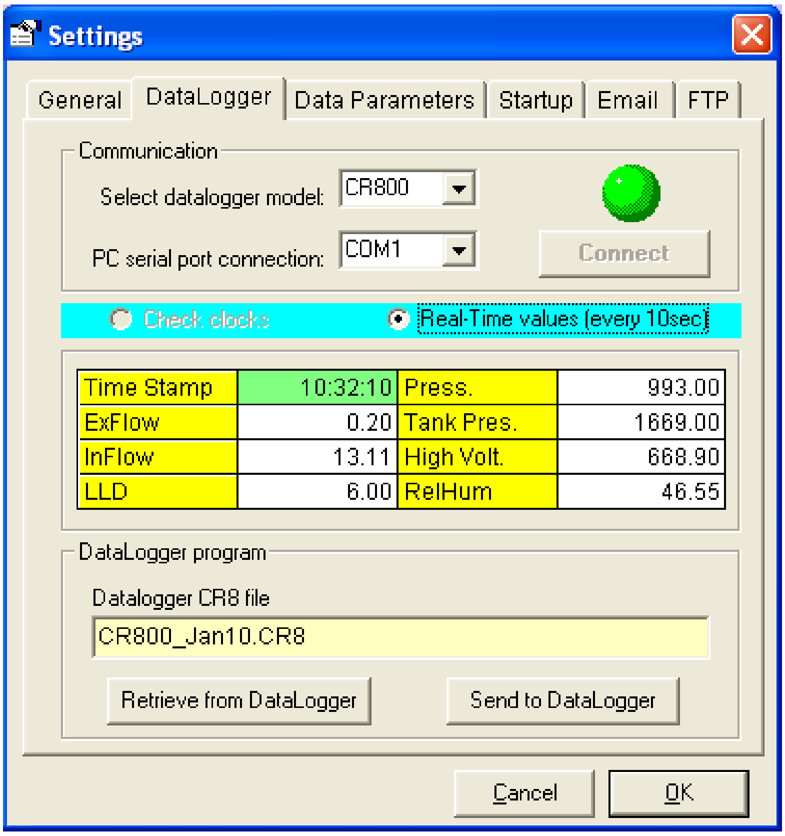
If communication cannot be established, check: (i) whether the correct COM port is selected in the drop down combo box, (ii) that an appropriate serial cable has been used for communication, and (iii) that both ends of the communication cable are correctly plugged in.

Check Clocks Option

After communication with the data logger has been established, the date and time from both the PC and data logger clocks are displayed. Since data loggers are disconnected from mains power in storage and transit, it is advisable to synchronise the logger clock to that of the PC (provided the PC clock is cross-checked to a reliable source). To do this, click the **Synchronise Clocks** button in the Clocks panel. If the computer is networked, it is advisable to set the computer up to have its own clock occasionally checked against an accepted time standard, and reset if necessary.

If the Time Difference text box shows an unusually high number, it means that the PC settings need to be changed in order to match the data logger clock settings. Go to Control Panel/Regional and Language Options and in Regional Options click on the Customise button.

View Real-Time Values Option



Once connected with the data logger, it is possible to display the 10-second average data of selected logger channels in real-time. Each time the data logger program executes, new values are written as input locations. These values are updated in the data logger every 10 seconds, as defined in the data logger program. This viewing option can be used to check the current values for selected parameters, as well as for performing the calibration on the tank pressure sensor.

Note: This option may not be available immediately after the connection has been established, since the program first needs to collect all the available data in the logger's memory (from the first to the last data storage pointer). In the event of this occurring, closing the Settings window and then reopening it a few minutes later should solve the problem.

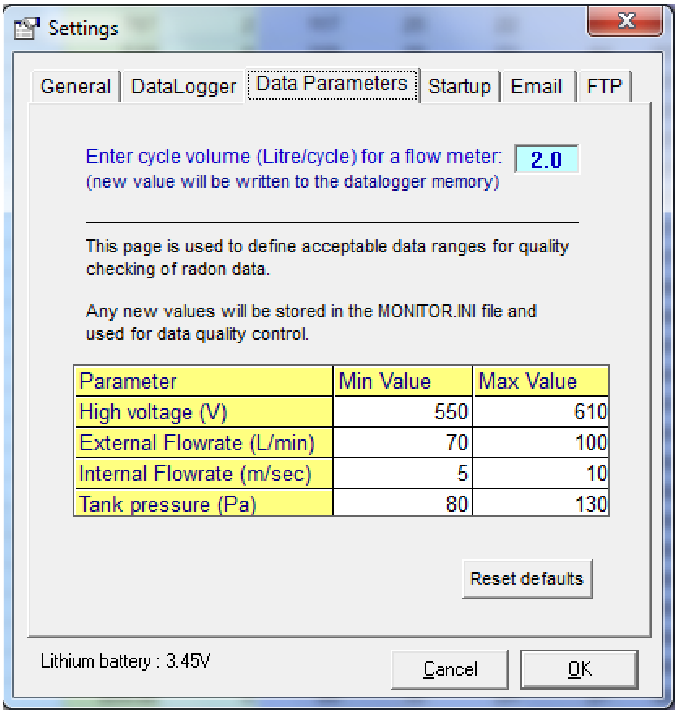
Datalogger Program Panel

When setting up the data logger for the first time it is necessary to upload (send) the compiled data logger program (CR800_MAR08.CR8) to the logger (where it resides in non-volatile memory). The program contains definitions for all data streams as well as all necessary instructions for the sampling/averaging protocol and data tables.
If a different *.cr8 data logger program file needs to be loaded (e.g. if an updated version becomes available), navigate to the appropriate file and then click on the Send to DataLogger command button at the bottom of the window. The program will then warn the user that all data in the logger will be overwritten. Also, all data tables will be cleared and variables re-initialised. If successful, the upload will be confirmed.

Retrieve from Data logger

This button enables the user to retrieve the existing logger program that is stored in the data logger's memory. An Explorer window is displayed in which to type a file name and path for the retrieved program. As a precaution, it is advisable to retrieve the data logger program and back it up before installing any updates.

5.3.3 RDM: "Data Parameters" tab



The radon detector is fitted with a gas meter that has been calibrated by the manufacturer. The gas meter's calibration constant (the "cyclic volume", expressed in litres per cycle) may vary depending on the model or manufacturer of the unit. The calibration constant is used to display the sampling flow rate correctly.

Whenever a new cyclic volume is entered in the text box provided (and the OK button pressed), the new value of this calibration factor is written directly to the data logger's memory. The updated cyclic volume is also written into the MONITOR.INI file. The AIR-BOX detector's gas meter has a cyclic volume of 2.0 – this value is displayed at the bottom of the analogue readout screen of the gas meter.

There are several components of the radon detector that, if not functioning correctly, will compromise the quality of the radon data. They include the flow rate, tank pressure, high voltage settings, blower current draws, and battery voltage. Regular quality checks to ensure that these parameters are within reasonable operational ranges provide a good indication as to the status of the overall detector operation. If a problem arises, careful investigation of the suspicious data period, noting the combination of signals that may or may not be malfunctioning simultaneously, is usually sufficient to accurately diagnose the cause of the problem.

The **Radon Detector Monitor** program comes with a set of default values for all data ranges based on typical values for the 1200 L detector sampling from a short intake line. All parameter range values can be modified to suit the requirements of a new site. New values are stored in the file MONITOR.INI and used as current settings. If a mistake is made when adjusting any parameter range input, it is possible to return to the default values by pressing the Reset defaults button (and confirming with OK). Alternatively, the user can return to the settings window and simply retype the correct value.

Note: In order for changes made in the Settings Window to take effect, the data file needs to be reloaded (to do this, click on the **Current File** button on the main screen of RDM).

One way to set site specific parameter ranges is to use values ±10% of parameter values at the time that the detector is first commissioned. By inspecting the range of each parameter after the first week of data has been collected the thresholds can be refined if necessary. However, for some parameters (e.g. high-voltage and flow rate), there may be seasonal changes, the size of which can only be quantified after the first complete year of data is available.

5.3.4 RDM: "Startup" options tab

Load most recent file on startup - if checked, the program will load the current month's data file on startup (default state is checked),

Enable logger download on startup - if checked, the program will be ready to connect to the data logger immediately after startup. It is advisable to uncheck this option when working with data files off line to prevent the program communicating with the data logger (default state is checked).

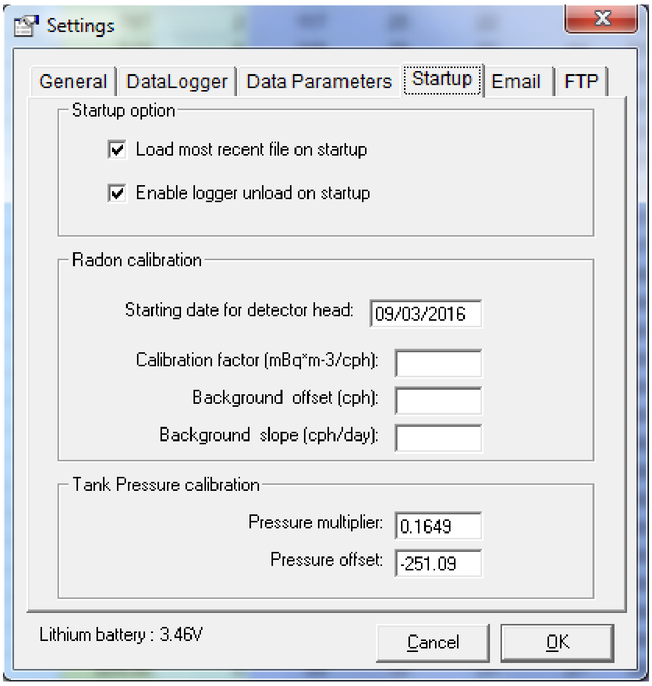
Radon calibration panel

Entering an approximate radon calibration factor and linear background model coefficients allows RDM to calculate and display an approximate radon concentration from the raw half hourly detector counts (LLD). If these fields are left empty, RDM will not display real-time calibrated radon concentrations. After entering new values for the calibration and background factors, the data file needs to be reloaded in order to recalculate the radon concentrations (click on the Current File button of the main screen).

Starting date for detector head – The date of commissioning of the detector, or when the most recent replacement detector head was installed. Each detector head has different characteristics and the following parameters are also detector specific.

Calibration factor – The sensitivity of a given detector head (in units of mBq/m^3 of radon per counts per hour from the detector head) determined from a calibration curve. Please note that the value entered for the approximate calibration factor should not be used to derive final concentrations. Final calibration is performed in post processing using monthly calibration curves.

Background offset and Background slope – The coefficients of a linear model of the detector background count rate. Values entered must be in the following units: cph (counts per hour) for the background offset and cph/day for the background slope.

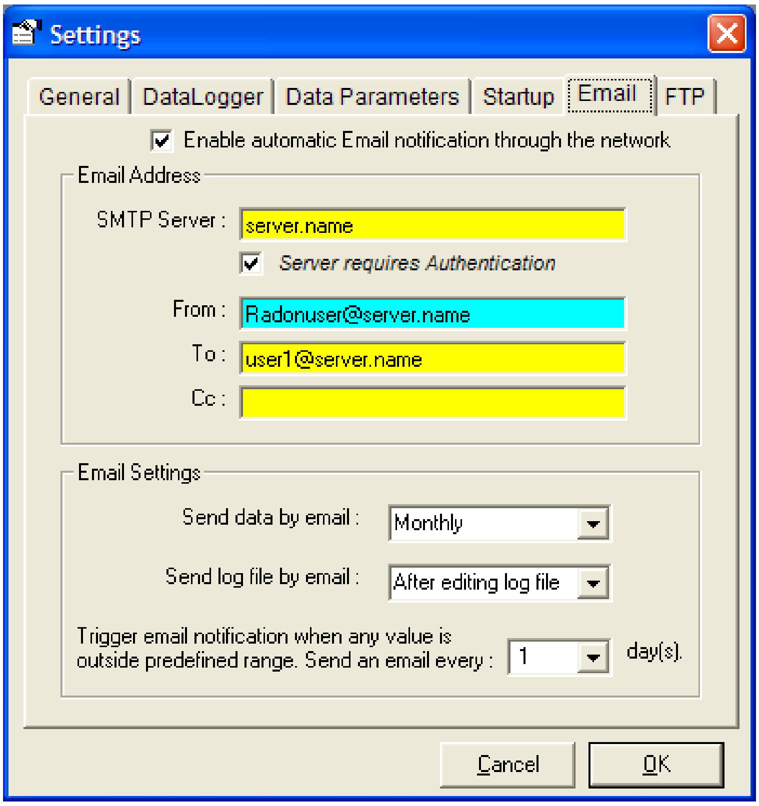


Tank Pressure Calibration

If the linear calibration coefficients for the detector's internal pressure sensor have been entered in the fields provided RDM will calculate the tank over-pressure in Pascals (from the raw millivolt output) for real time display and plotting. If these fields are left empty, the program will display the sensor's raw millivolt output as seen by the data logger.

The multiplier and offset values are obtained by performing an in-situ pressure calibration. Connect the differential pressure meter as described in Section 2.11 and start by opening the radon detector exhaust valve fully (for the lowest pressure reading). Compare the millivolt output of the pressure sensor to the calibrated readout of the hand-held unit. Repeat this process for 4 to 5 progressive restrictions of the exhaust valve until the valve is at least 75% closed (overpressure of at least 120 Pa). Plot the millivolt output against differential pressure. The whole curve will not be linear, but a linear approximation of the curve can be made over the normal operating range (of about 90-110 Pa). Enter these coefficients for the tank pressure to be displayed in Pascal (re-calibration of the loggers pressure sensor every 12 months is recommend.

5.3.5 RDM: "Email" options tab



If the computer logging the radon detector output is networked and connected to an SMTP mail server, this option allows Radon Detector Monitor to send various automatic notifications by e-mail to one or more recipients.

Enable automatic E-mail notification through the network box - if checked, the program will be ready to communicate with the specified users via the TCP/IP protocol when the PC is connected to the Internet (default state is unchecked).

E-mail Address Panel

SMTP Server – in this field it is necessary to enter the name of the SMTP mail server (also known as the outgoing mail server). That is, the server that the computer uses for sending e-mail to the specified addresses;

Server requires Authentication - in case the mail server requires user authentication, it is necessary to enter a username and password for the mail server to be used (the user needs to be registered with the mail server in order to use it);

From - this field is a string of characters that identifies the source of each e-mail message. It doesn't have to be an existing e-mail address, and, for example, could be composed of "station name" @ "location of the host computer";

To - this field is the e-mail address of the primary recipient of communications from the program;

Cc - an optional field that lists e-mail addresses of secondary recipients of communications from the program (a standard carbon copy, so that all recipient's names are visible to other recipients of the message).

E-mail Settings Panel

Send data by e-mail - this field stipulates the frequency of e-mail updates sent by RDM to the intended recipient(s) (the message contains the most recent data file). Options include: monthly, fortnightly, weekly, daily or never;

Send log file by e-mail - this field stipulates the frequency of e-mail updates of the most recent log file. Options include: every time the log file is edited (after editing file), monthly, or never;

Trigger e-mail notification when any value is outside the predefined range - this field stipulates the frequency of e-mail notifications to the intended recipients when one or more recorded data values is outside their defined acceptable range (based on values set in Data Parameters) for more than 2 consecutive hours (i.e. >4 consecutive samples). Notification frequency options include: from 1 to 30 days, or never. The e-mail notification of the transgression will also contain a copy of the most recent data file as an attachment.

5.3.6 RDM: “FTP” options tab

If the computer is connected to the network it is possible to send data and log files to the designated FTP server at regular intervals. The user can either send data to an FTP server of his/her choice, or to the ANSTO FTP server, or to both if selected.

FTP Server Info Panel

FTP Server - double click on Add New FTP server label to enter the FTP server name, or just click to select one if it exists. The second checkbox allows sending data and log files to the ANSTO server if required. All ANSTO parameters are preset and need no editing.

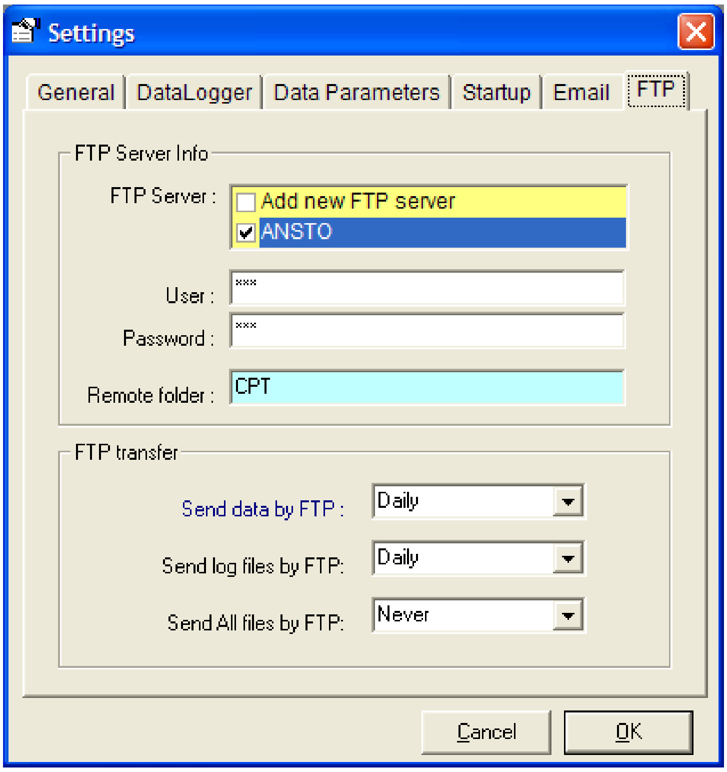
User - enter user name for the above FTP server,

Password - enter the password for the above FTP server,

Remote folder - enter the name of the folder where the data will be stored on the FTP server. If this field is left blank, it will be the same as the Project name.

FTP Transfer Panel

This panel allows the user to select the frequency at which the data and/or log files will be sent to the FTP server.



5.4 Calibration and Background

The scheduling of calibration and background event times is performed using the ***Cal&Back*** toolbar button in the ***Radon Detector Monitor*** program's main screen.

This option enables the user to set up parameters for conducting automatic calibration and background measurements using the unit provided.

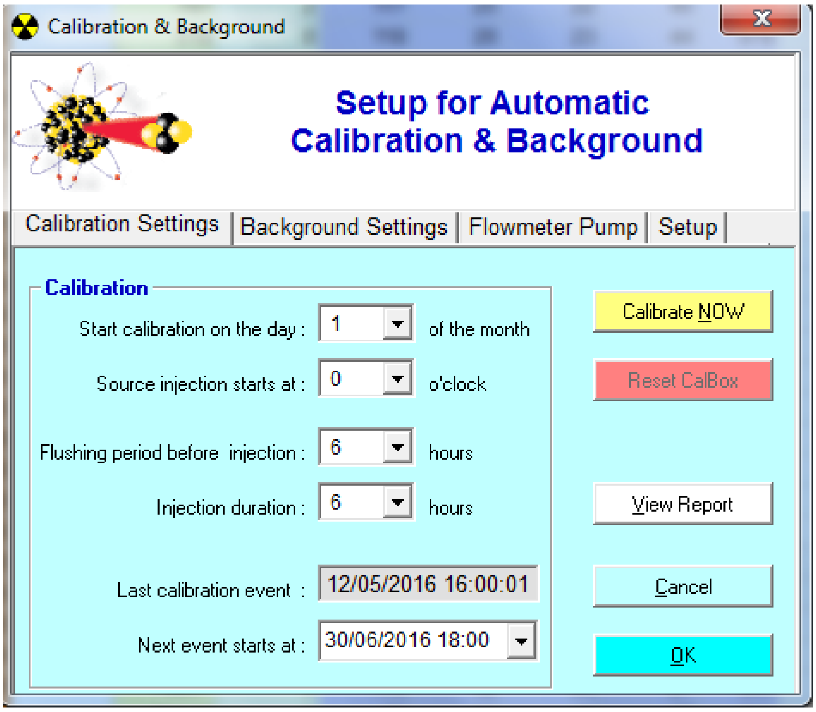
The function of the calibration module is to deliver radon from a well characterised radon source to the detector for a set period of time. Because the air-stream used to flush the source is not filtered for ambient radon and thoron progeny, the source flushing flow rate is kept very low (80-100 cc/ min) compared to the flow rate through the detector (55 L/min) to minimise any influence on measurements. A small 12V DC pump is used to aspirate the source.

The calibration module has three modes of operation: OFF (default), FLUSHING and INJECTING. In FLUSHING mode, a solenoid valve directs the air flushed through the source to an exhaust line. It is recommended to terminate the exhaust line outdoors, away from the sample intake point. In INJECTING mode the solenoid valve directs air flushed through the source to the radon detector.

The background module allows automatic background measurements to be conducted by scheduling a time to turn off power to the inlet stack blower (if present), internal and external blowers within the detector, and closing the inlet valve. After the designated time period the inlet valve is opened, all blowers are turned back on, and the detector resumes normal operation.

If the Calibration and Background unit is connected to the USB port and the unit is powered, the following icon will be shown on the main program screen's status bar in the right hand bottom corner:

5.4.1 C&B: “Calibration Settings” options tab



This tab enables the user to set all relevant parameters for automatic calibration events:

- Calibrations should be performed once a month and can be started on the same day of month as selected from the drop-down combo box,
- The time of day that calibration injection events will commence can be specified,
- The number of hours to flush the source before starting an injection can be set (**recommended 4 hours**), this clears the build-up of radon in the source container since the last time the pump was running,
- The duration of the injection period can be set (**recommended 5 hours**)
- The timing during the day for the calibration event can be critical. For inland sites, however, timing of the calibration peak should be such that the injection finishes around 1-2pm (when ambient radon concentrations are lowest).

Depending on the value specified for “Flushing period before injection”, the pump of the calibration unit will start sometime before the scheduled calibration event. During this time the calibration unit will be in FLUSHING mode. At the scheduled calibration time the unit will then switch from FLUSHING to INJECTING mode and radon will be injected to the detector for the length of time set in “Injection duration”.

Dates of the previous and next calibration events are displayed in two text boxes at the bottom of the screen.

When all parameters have been set, click the OK button to store the new parameters. A calibration event can be started at any time by clicking the Calibrate NOW button, for which the currently specified flushing and injecting time periods will be used.

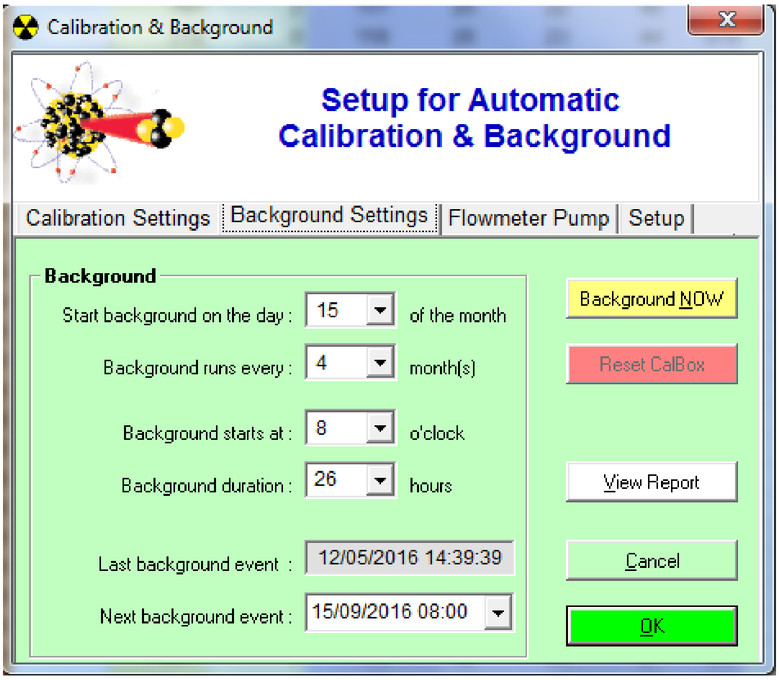
During a calibration event (in either flush or injection mode), it is possible to check the speed of air passing through the source by clicking on the Flowmeter Test tab. The flow rate can be adjusted using the regulator located beneath the small pump on the calibration unit.

To reset the hardware and all calibration and background input data for the current event to default values, click on the Reset CalBox button.

As for the background measurements, calibration parameters are set using the ***Calibration Settings*** tab of the Calbiration & Background Panel, which can be called by clicking on the ***Cal&Back*** button on the ***Radon Detector Monitor*** program toolbar.

5.4.2 C&B: "Background Settings" tab

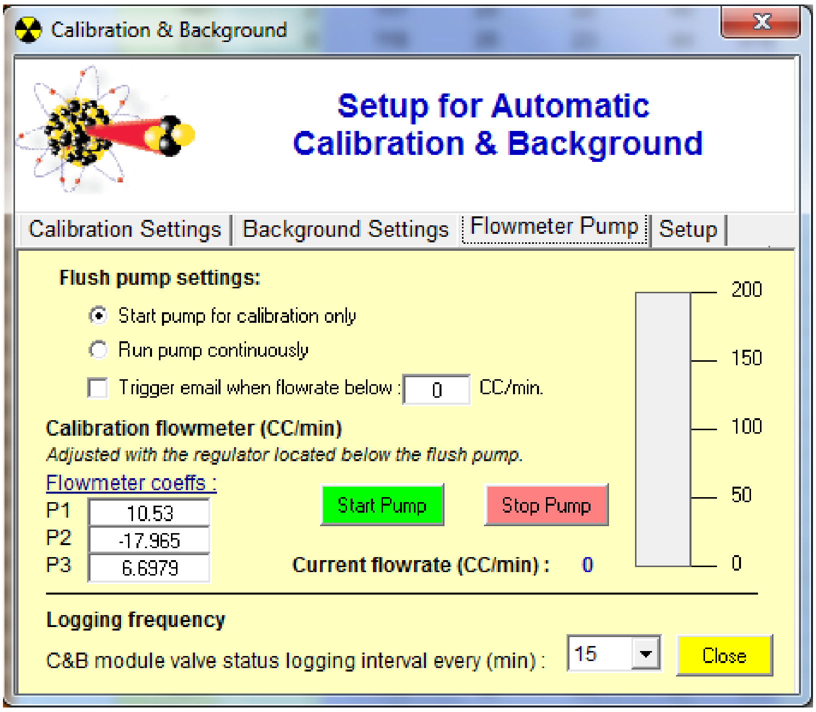
This tab of the Calibration and Background window contains scheduling information for the automatic background measurements.



This panel allows users to specify the day of the month, frequency, time of the day and duration of the background measurements. Once selected, the chosen parameters are saved in the INI file when the OK button is clicked. **We recommend back-grounds are scheduled to start and finish at midnight (only a single day affected).**

5.4.3 C&B: "Flowmeter Test" tab

This panel enables the user to monitor the C&B module analogue port connected to the digital flowmeter.



Once USB communication between the C&B module and PC is established it is possible to test the operation of the module. For example, by clicking the Start Pump button, the progress bar on the right hand side of the panel should display a reading of the analogue flowmeter (calibrated in CC/min). If necessary, the flowmeter calibration coefficients can be edited in the appropriate text boxes.

The logging frequency combo box allows the user to select the logging interval for analogue and digital outputs of the C&B module. All calibration and background events, as well as status ports, are logged in the yearly text data file, which can be used for troubleshooting and diagnostics of the C&B module.

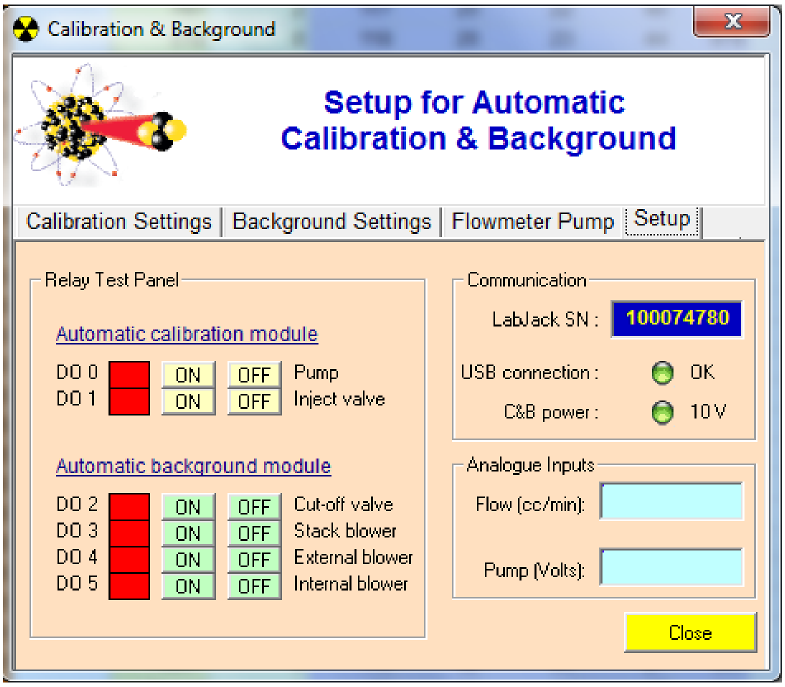
5.4.4 C&B: "Setup" tab

This tab shows the details of the connection to the Labjack module, which controls all analogue and digital ports in the C&B unit.

The communication frame shows the LabJack serial number as an indication that it is connected properly. Please note that the local address number should always be set to 1 for the first instance of the program and 2 for the second instance (in the event that two detectors are being operated at one site). The C&B power button shows whether the C&B box is powered and the voltage as an indication. If there is a problem with communication, all the above indicators will be red. The problem can usually be rectified by either checking the power on the C&B box, or checking the USB connection.

The Relay Test Panel allows the user to manually test all the relays by turning them ON or OFF while monitoring the display. This can be used for diagnostics and/or troubleshooting of the system.

The Analogue inputs panel allows monitoring of the flowmeter and calibration pump voltage. All values, including relay status, are recorded in the log file.



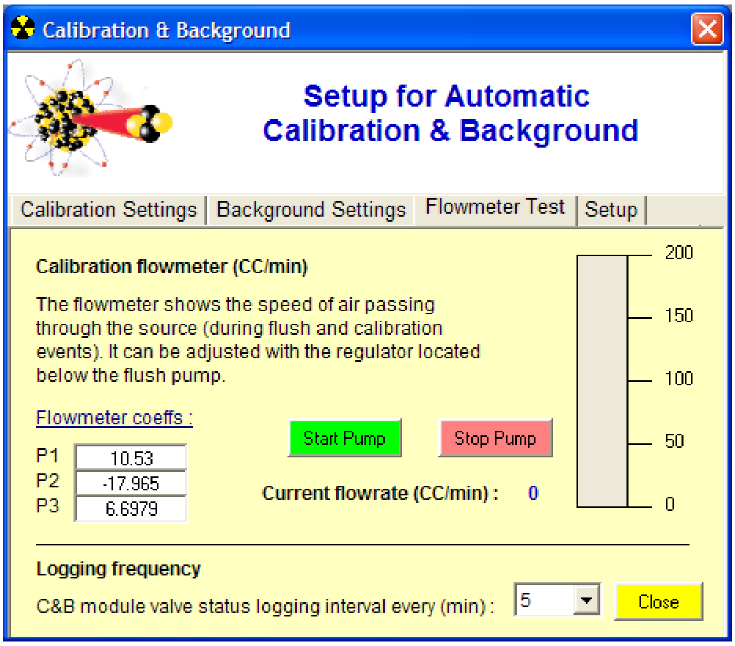
5.4.5 The C&B Log File

The RDM program allows continuous monitoring of the C&B module, and records its status in a text log file. This log file can be used to help identify problems related to the calibration and background measurements, such as communication problems or malfunctioning of any C&B unit hardware.

The naming convention for this log file is ***project_year.log***, where ***project*** refers to the detector site name identified in **Settings**, and ***year*** to the current year. The yearly log file resides in the project directory together with data files and activity log file. All entries in this log file are created automatically.

To access the log file from within the RDM interface, open the Calibration & Background window and click on the ***View Report*** button.

The logging frequency interval (in minutes) can be set by the user from the **Flowmeter Test** tab.



The C&B module data is logged continuously to assist with troubleshooting.

The log file contains the following data columns:

- **Date/Time** Date and time stamp,
- **Event** N for normal operation**,** B for background, C for calibration event,
- **Address** Refers to local address of the Labjack unit in the C&B module. It is recommended to keep the number 1 for single detector installations. Use number 2 for the second detector in dual detector sites,
- **Status** Descriptive label for calibration event (FLUSH, INJECT, FLUSH_OUT) and background (BACK, BACKEND),
- **Valves** Status of valves read from the digital IO values (1 – ON, 0 – OFF). The first two positions in the string indicate the state of valves during a calibration event (flush, inject), the next four positions indicate the state of the valves during background measurement (cut-off valve, stack blower, external and internal blowers),
- **Flow_CC** Calibrated air flow through the source (in CC/min) used to determine whether the small pump in the C&B module is operating,
- **Pump_Volt** Operational pump voltage in the C&B module,
- **CB_Volt** Operational C&B box voltage,
- **Comment** Automatically generated descriptive labels of calibration and background events with distinction between automatically (AUTO) and manually (MANUAL) started events.

5.5 Activity log

The user is encouraged to record any activity related to the operation and maintenance of the radon detector in the Activity Log file. Such entries can be very helpful in analysing the validity of recorded data, as well as maintaining a history of the work done on, and related to, the radon detector. The Activity Log is a plain text file located in the project directory.

In addition to the manual user entries, some Activity Log entries are created automatically, such as automatic calibration and background measurements and changes to the INI file.

To add a new entry, click on the **<u>Add Date/Time</u>** button. Use the mouse to position the cursor after the date, type the required information, and then click the **Save and Exit** button.

The Activity Log form contains one additional button, which enables the user to add a new flag to the data file if they are performing some kind of maintenance on the detector. This flag in the log file indicates that the data during that period may need to be discarded, since they may contain some invalid values.

<u>Maintenance</u> : this button sets the flag value to 3 and, unless turned off manually, will be re-set to 0 two hours after the blowers start working and the flow rate reaches the pre-set value.

After the desired activity has been selected, and the automatic entry added to the log file, click the ***Save and Exit*** button. The top label will display the systems current status.

6 Data file format

Radon Detector Monitor stores all data in comma delimited (CSV) format, which can easily be imported by MS Excel. An example of the CSV data file format created and read by Radon Detector Monitor is shown below:

Year	DOY	Month	DOM	Time	ExFlow	GM	InFlow	HV	Spare	LLD	ULD	TankP	Temp	AirT	RelHum	Press	Batt	Comments	Flag
2007	209	7	28	6:00	39.49	592	2.92	830	-9999	1755	0	2237	17.12	11.91	55.92	994.9482	13.99		0
2007	209	7	28	6:30	39.42	591	2.921	830	-9999	1714	0	2239	16.73	11.81	56.39	995.0812	13.99		0
2007	209	7	28	7:00	39.42	591	2.915	829	-9999	1809	0	2242	16.46	11.69	56.76	995.4387	13.99		0
2007	209	7	28	7:30	39.29	589	2.93	829	-9999	1749	0	2245	16.33	12.26	55.43	995.623	13.99		0
2007	209	7	28	8:00	39.29	589	2.949	829	-9999	1672	0	2239	16.52	13.23	52.5	995.8297	13.99		0
2007	209	7	28	8:30	39.29	589	2.964	830	-9999	1519	0	2240	16.86	13.85	50.56	996.1022	13.99		0

where:

- **Year** - Current year,
- **DOY** - Day of the year (three digit Julian day),
- **Month** - Month of year (calculated from Julian day, not actually stored in the data logger),
- **DOM** - Day of month (calculated from Julian day, not actually stored in the data logger),
- **Time** - Time stamp in hh:mm format,
- **ExFlow** - External flow rate (L min-1). Calculated from gas meter (GM) revolutions,
- **GM** - Gas meter revolutions / 30 minutes. Raw value used in calculations of flow rate,
- **InFlow** - Internal flow rate (m/sec) ,
- **HV** - High voltage (Volts),

- **Spare** - spare column for future use
- **LLD** - Lower level of discrimination (counts / 30 minutes),
- **ULD** - Upper level of discrimination (counts / 30 minutes),
- **TankP** - Tank pressure (millivolts or Pascals, depending on whether the pressure multiplier and offset values have been set in Settings) ,
- **Temp** - Logger temperature (ºC),
- **AirT** - Temperature inside the detector tank (ºC),
- **RelHum** - Relative humidity inside the detector tank (%) ,
- **Press** - Ambient air pressure (hPa),
- **Batt** - Internal battery voltage (Volts),
- **Comments** - comment line
- **Flag** - Sets one of the following data flag values:

  0 – normal radon detector operation
  1 – background
  2 – calibration
  3 – maintenance
  4 – other problems with the detector automatically detected

7 References

Chambers, S. D., A. G. Williams, W. Zahorowski, A. Griffiths, and J. Crawford (2011), Separating remote fetch and local mixing influences on vertical radon measurements in the lower atmosphere, Tellus, 63B(5), 843-859.

Chambers S.D., S.-B. Hong, A.G. Williams, J. Crawford, A.D. Griffiths, and S.-J. Park. Characterising terrestrial influences on Antarctic air masses using radon- 222 measurements at King George Island, Atmos. Chem. Phys., 14: 9903-9916, 2014.

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:

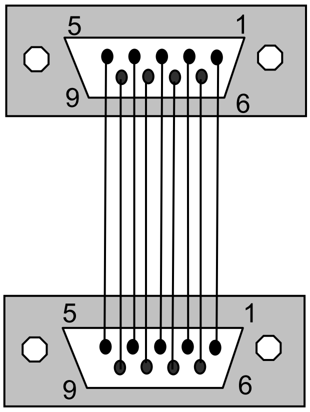
Name	**Comment (format/unit)**
Year	Current year (yyyy)
DoY	Day of year (xxx)
Month	Month of year (mm)
DoM	Day of month (dd)
TIME	Time of day (hhmm)
ExFlow	External flow loop (sampling) flow rate (L min^{-1})
GM	Uncalibrated output from the gas meter on the external flow loop
InFlow	Internal flow loop air pipe velocity (m/s)
HV	Photomultiplier high voltage (V)
Spare	Can be used to display the calibrated radon concentration (mBq m^{-3})
LLD	Counts per half hour at the lower threshold setting
ULD	Counts per half hour at the higher threshold setting
TankP	Average tank pressure (mV/Pa; depending on program setup)
Temp	Temperature inside the logger (^{o}C)
AirT	Temperature of air inside the detector (^{o}C)
RelHum	Relative humidity of air inside the detector ($^{\%}$)
Pres^{s}	Absolute pressure inside the detector (hPa)
Batt	DC supply voltage (V)
Comments	User comments on operational status
Flag	Processing flag indicating operational status of detector

8.2 Wiring Schematics

Sensors	**Pins**	**Signal**	***CR800 logger***
Tem/RH	9	Supply voltage	
	8	Power Ground	*G*
	7		
	6	Control port	
	5	Signal Ground	
	4	Signal #2	*SE # 4*
	3	Signal #1	*SE # 3*
	2		
	1		
Abs. Pressure	9	Supply voltage	
(PTB110)	8	Power Ground	*G*
	7		
	6	Excitation	*EX1*
	5	Analog ground	
	4	Signal	*SE # 5*
	3		
	2		
	1		
Flow sensor	1	Signal	*SE # 6*
	2	Signal Ground	
	3		
HV/Disc	1	Power Ground	*G*
	2	Supply voltage	*12V*
	3	Analog ground	
	4	LLD (lower level count)	*P1*
	5	ULD (upper level count)	*P2*
	6	HV/1000	*SE2*
Gas Meter	1	Signal Ground	*G*
	2	Signal	*C1*
	3	Power (5V)	*5V*
	4		
Power Supply	1	Ground (-ve)	*G*
	2	Power (+ve)	*12V*
Int. blower	1	Ground	
	2	Supply voltage (PCB)	
	3		
Ext. Blower	1	Ground	
	2		
	3	Supply voltage (PCB)	
Diff. Press	PCB	Signal	*SE1*

Figure 42: Description of the data logger wiring.

9 PIN D -SUB FEMALE



9 PIN D -SUB FEMALE

Note: The cable is a straight through type with two 9 pin D sockets.

RS-232 communication line for CR800

RS-232 pin-out for CR1000
ABR – Abbreviation for function name **PIN** - Pin number **O** - Signal out of CR800 to RS-232 device **I** – Signal into CR800 from RS-232 device

PIN	ABR	I / O	DESCRIPTION
1	DTR	O	Data terminal ready
2	TX	O	Asynchronous transmit
3	RX	I	Asynchronous receive
4			Not connected
5	GND		Ground
6		O	Connect to pin
7	CTS	I	Clear to send
8	RTS	O	Request to send
9	RING	I	Ring

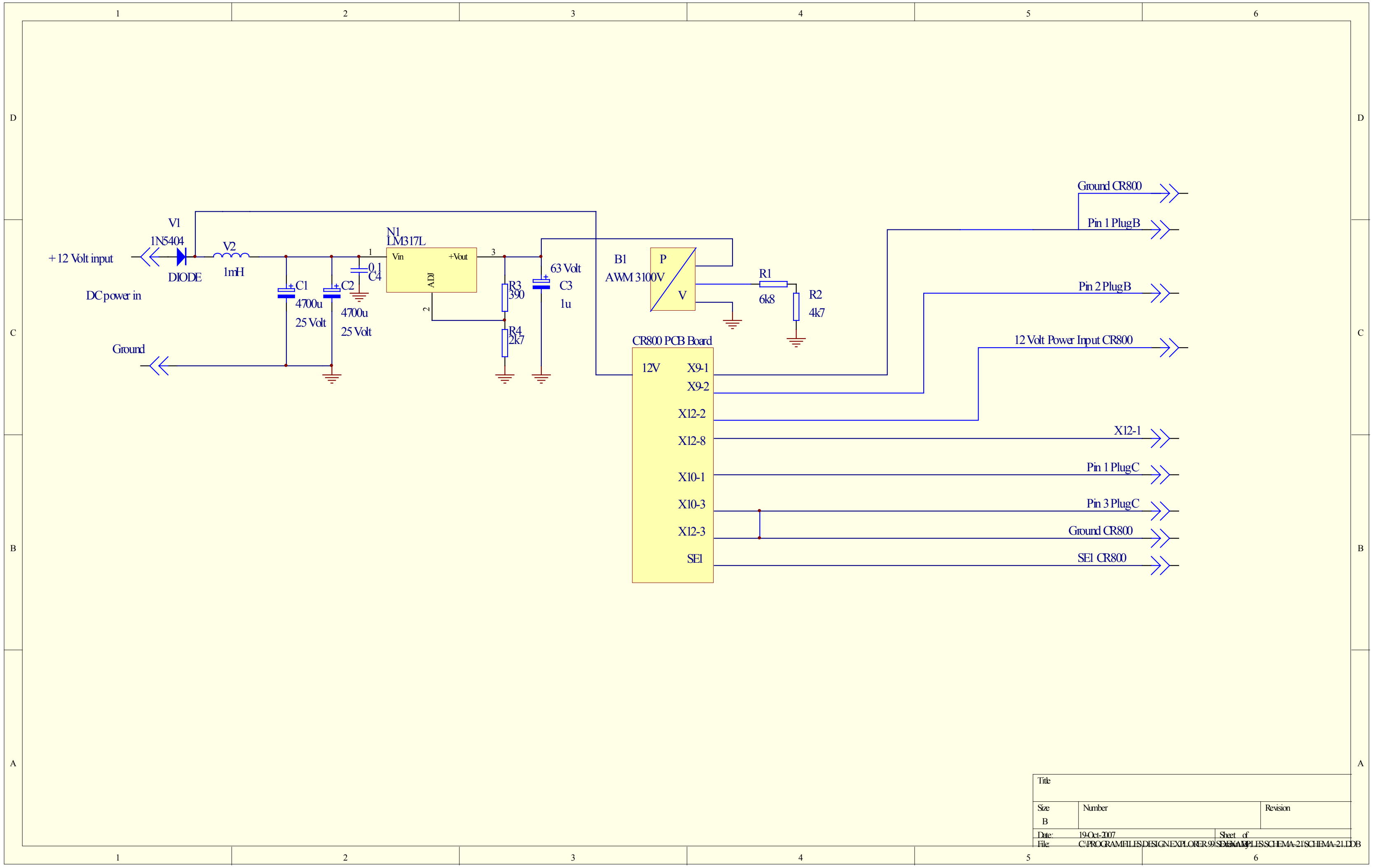


Figure 43: Schematic of the logger box integrated circuit board.

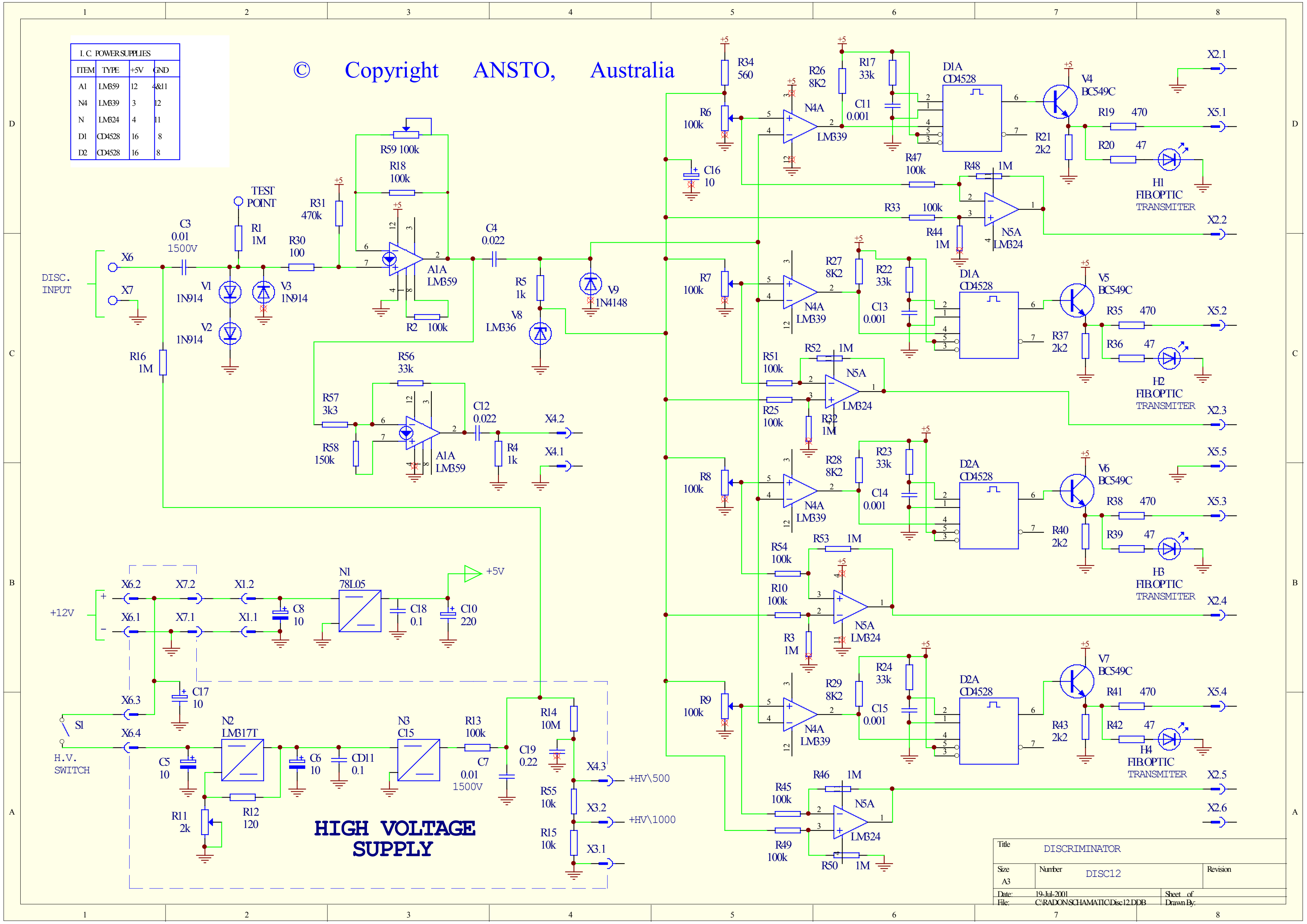


Figure 44: Schematic of the High Voltage/discriminator unit.