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Radon at Australian Antarctic Stations

Brendan Tate

Technical Report 176 - February 2017

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Executive Summary

The Australian Radiation Protection and Nuclear Safety Agency's (ARPANSA) principle objective is to "protect people and the environment from the harmful effects of radiation". One of the tasks of the Monitoring and Emergency Response Section of ARPANSA is to measure and assess occupational exposure to ionising radiation. One source of occupational exposure to workers is radon, an inert radioactive gas that originates from uranium and radium and is present in very low levels in rocks and soils around the world.

Australia's Antarctic (and Subantarctic) bases are all coastal stations built largely on rock. During the winter season the stations are blanketed with snow and ice, although during the summer months the weather can be warm enough that the ice and snow melts away. Under these conditions the underlying rock is mostly exposed. There have been many measurements made of radon outdoors in Antarctica, with the aim of using radon as a tracer for environmental or geological processes. However, there have been very few measurements of radon concentrations in actual living quarters and working facilities. In general, past measurements have indicated that the radon levels in Antarctica are low, and it was expected that this study would also find radon concentrations inside the buildings to be low. However, due to the nature of the construction of Australia's stations, there was a possibility that levels could be elevated during the summer season.

Two sets of CR-39 track-etch based radon monitors were sent to Antarctica to measure radon in all four of Australia's permanent Antarctic and Subantarctic stations. One set was intended to measure the radon exposure during the winter season, and another to measure the levels during the warmer months of the summer season. The winter monitors returned overall averages of less than 20 $Bq.m^{-3}$ at all four stations, whilst the summer monitors recorded increases of 300-400% at the three mainland stations, and an increase of 165% at Macquarie Island. No values were recorded in living areas above the 200 $Bq.m^{-3}$ limit specified for radon in dwellings as specified in Radiation Protection Series Publication No. 1 (RPS 1) *Recommendations for Limiting Exposure to Ionizing Radiation (1995) and National Standard for Limiting Occupational Exposure to Ionizing Radiation* (ARPANSA, 2002).

Although the results were acceptable, the monitors used in the summer portion of the study returned higher than desirable uncertainties due to the shorter than recommended duration of their placement.

Contents

1. Radon in Antarctica

1.1 Why measure radon?

The Australian Radiation Protection and Nuclear Safety Agency's (ARPANSA) principle objective is to "protect people and the environment from the harmful effects of radiation". One of the tasks of the Monitoring and Emergency Response Section of ARPANSA is to measure and assess occupational exposure to ionising radiation. One source of occupational exposure to workers is radon, an inert radioactive gas that originates from uranium and radium and is present in very low levels in rocks and soils around the world. Radon that emanates from the ground can diffuse easily into buildings and outdoor air and can subsequently accumulate in areas where there is limited ventilation. In high concentrations radon is known to be a risk factor for lung cancer. In Australian jurisdictions, Radiation Protection Series 1 *Recommendations for Limiting Exposure to Ionizing Radiation (1995) and National Standard for Limiting Occupational Exposure to Ionizing Radiation* (ARPANSA, 2002) sets Action Levels for naturally occurring radon in the workplace. This report provides details of the collaborative project undertaken between ARPANSA and the Australian Antarctic Division (AAD) to measure radon in buildings at Australian operated stations in Antarctica and the Subantarctic.

There have been many measurements made of radon in Antarctica, ranging from the mid-1950s (Lockhart et al. 1966) until the present day. However most of these seem to have been outdoor measurements using indirect methods measuring very low environmental levels (a good summary of these measurements can be found in Chambers et al. 2014), or were using radon as a tracer for other environmental or geological processes (Pereira 1990 and Illić et al. 2005). Radon in Antarctica is generally thought to be orders of magnitude less than that found elsewhere in the world, and has been measured from as low as 11 $mBq.m^{-3}$ at the South Pole (Maenhaut et al. 1979) up to 40 $Bq.m^{-3}$ at the Ukrainian research station Academician Vernadsky on the Antarctic peninsula (65°15´S, 64°16´W), with the average annual indoor radon concentration measured at the same location being 18 $Bq.m^{-3}$ (Illić et al. 2005). Long-range transport of radon from continental areas result in sharp short-term increases of radon concentration by as much as a factor of fifteen (Polian et al. 1986). These events are known as 'Radonic Storms'.

Australia's Antarctic (and Subantarctic) bases are all coastal stations built largely on rock. Although during the winter season the stations are blanketed with snow and ice, during the summer months the weather can be warm enough that the ice and snow is able to melt away. Under these conditions the rock is mostly exposed. The intention of this project was to measure the radon concentration in buildings built directly on soils or rocks. In general, the radon levels in Antarctica seem to be low, and it is expected that this study will find radon concentrations inside the buildings to be low.

1.2 Australian Antarctic Division station details

Australia maintains three stations on mainland Antarctica, and one in the Subantarctic (Macquarie Island). Australia has held a continuous presence on the mainland since the establishment of Mawson station in 1954. Casey (originally known as the United States research station Wilkes) and Davis were established shortly after in 1957. Casey has been rebuilt twice in new locations around Newcomb Bay. The current station was opened in 1988. The Macquarie Island station was opened in 1911 by Sir Douglas Mawson. The site was first occupied by ANARE (Australian National Antarctic

Research Expeditions) for scientific purposes in 1948. The geographic locations of the stations are shown in Table 1.1.

Table 1.1: Australian Antarctic Territory station locations

Station	Latitude	Longitude
Mawson	67° 36′ 10″ S	62° 52′ 26″ E
Davis	68° 34′ 36″ S	77° 58′ 03″ E
Casey	66° 16′ 55″ S	110° 31′ 39″ E
Macquarie Island	54° 37′ 12″ S	158° 51′ 40″ E

The three stations on mainland Antarctica were extensively refurbished during a reconstruction program undertaken during the 1980s, including many completely new buildings with modern construction and design. These buildings feature steel frames and steel exteriors, with plaster interiors and multiple insulation layers. Windows are typically triple glazed. All new buildings also include cold porches at entry points. These are airlock-style rooms with inner and outer weather-sealed doors designed so that building interiors are never exposed directly to the outside weather. The buildings are largely powered and air-conditioned from an external series of diesel generators and boilers. Most of the buildings at Macquarie Island were refurbished during this construction program, but are not completely new. As such, weather sealing and other factors are not as modern as found at the mainland stations.

The average temperatures at Macquarie Island are notably higher than at the mainland stations, with a six degree difference in summer and fifteen degrees or greater difference in winter. The wind conditions at the four stations are similar in summer and winter, with Mawson having the greatest wind run in both seasons. The wind runs at both Macquarie Island and Davis remain similar through both summer and winter. Weather conditions representative of the mid-points of summer (January) and winter (July) at each of the stations are presented in Table 1.2.

Table 1.2: Weather conditions in both summer and winter (data courtesy of Australian Bureau of Meteorology)

	January				July			
Station	**Mean Max temp**	**Mean Min temp**	**Wind run**	**Max Gust**	**Mean Max temp**	**Mean Min temp**	**Wind run**	**Max Gust**
	°C	°C	km	km/h	°C	°C	km	km/h
Macquarie Island	8.8	5.3	695	169	4.9	1.6	740	178
Casey	2.2	-2.5	470	163	-10.5	-18.7	716	241
Mawson	2.5	-2.7	789	198	-14.9	-20.8	979	221
Davis	3.2	-1.2	478	163	-14.3	-20.7	469	195

1.3 Measurement program

Measurements were conducted over the 2012 calendar year. This included the 2012 Antarctic winter season, and the 2012-13 summer season. The winter season is the name given to the period where the Antarctic mainland is cut off from sea travel, normally the months from April to October. The summer season is where the sea ice retreats and the bases are accessible by ship, normally from late October through to early April. Monitors were delivered to the stations by regular mail, which is normally carried by ship during the summer season to all four bases, and occasionally by aircraft from Hobart to Casey. The start and finish times for each of the stations were designed to match up as closely as possible, although these times were dictated by the arrival and departure dates of the voyages to each base. The program was handled at each station by the station doctor. Each base was supplied initially with thirteen monitors intended to be left for one year in location, and later an extra six monitors intended to overlap with the long-term monitors for the three month summer period. Each station was supplied with two additional monitors that were to be returned immediately on arrival. This was to give an indication of the contribution to radon exposure on the journey to and from the station and Australia. Even though stored in a nitrogen atmosphere when returned to Australia, these monitors obtained a higher background exposure than expected and their results will not be included in the program.

Human exposure to radon primarily falls into two categories, in dwellings (as members of the public) or in the workplace (as occupational exposure). The Australian Antarctic stations are comprised of structures that can fall in to either (and sometimes both) of these categories. The recommended action levels for concentrations of radon-222 in air (as set out in Annex C of RPS 1 (ARPANSA, 2002)) are 200 $Bq.m^{-3}$ for dwellings and 1000 $Bq.m^{-3}$ for workplaces. The main aim of the program was to observe the average radon concentrations in various locations, and to see if any of these locations on the stations exceeded the values specified in RPS 1.

2. Monitors

2.1 Passive measurement using CR-39

Radon is most often measured in homes and workplaces using passive-style monitors called solid-state nuclear track detector (SSNTD) systems. These monitors commonly use the material polyallyl diglycol carbonate (PADC) as their basis for measurement. PADC is formed using the monomer diethyleneglycol bis allylcarbonate (ADC) along with diisopropyl peroxydicarbonate (IPP) as an initiator for polymerisation. PADC is a clear, colourless material with the empirical formula $C_{12}H_{18}O_7$, known more commonly as CR-39 ('Columbia Resin number 39'). Any radionuclides that undergo alpha decay in the vicinity of the material leave small damage tracks in the plastic. These tracks can be enlarged by a chemical etching process that allows them to be observed under a microscope. CR-39 detectors housed in an appropriate container that allows radon to diffuse in, but does not allow dust and other contaminants to enter, can be left in the field for twelve months or longer. Radon measured in concentrations of approximately 10 $Bq.m^{-3}$ or less can be measured in this fashion.

Since 2010, ARPANSA has used an in-house developed system for measurement of radon track-etch data plaques, called SANTECS (Semi-Automated Nuclear Track Etch Counting System). The CR-39 sheets used for SANTECS measurements are of a proprietary brand known as Pershore. The individual plaques are 35 mm x 20 mm and 0.5 mm thick. After exposure, the plaques are etched for six hours in a 6.25 M potassium hydroxide (KOH) solution heated to 70 °C before reading. The SANTECS reader scans approximately 80% of the plaque, an area of 560 mm^2, or 5.6 cm^2. The development and operating principles of SANTECS are discussed in further detail in Brown et al. (2011) and Fairchild et al. (2011).

2.2 NRPB radon monitors

During the period of this study, ARPANSA used the black NRPB (National Radiological Protection Board) style passive radon monitors (Hardcastle et al. 1996), as pictured in Figure 2.1. These devices are able to measure very low concentrations of radon. The monitors contain a small diffusion chamber which is designed to keep out radon progeny and external dust. The chamber itself encloses a small plastic (CR-39) plaque which is used to record the alpha decays emitted by the radon gas in the chamber. The CR-39 plaque is designed to fit into the indentation in the base of the monitor case, and is held in place by the rim of the diffusion chamber in the upper lid. The plaques used by ARPANSA are slightly larger than the indentation, so additional pieces of cello tape are used to hold the plaque in place. The cello tape is placed in areas not normally counted by the SANTECS method. These monitors are designed to be left in place for a long period, typically from three months to a year.

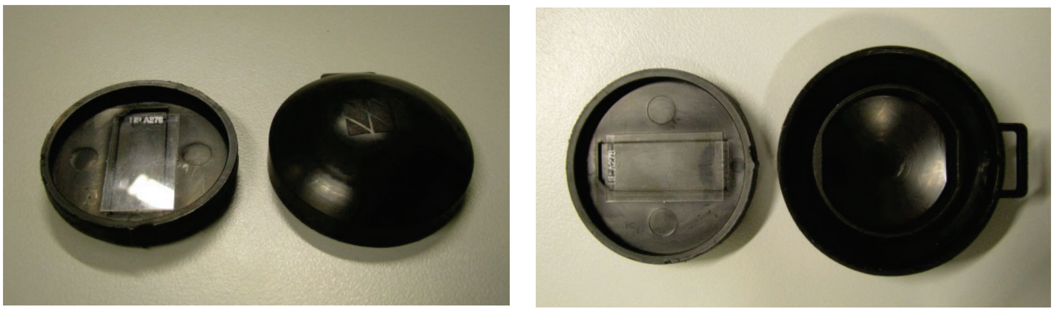

Figure 2.1: Photos showing external and internal structure of NRPB style radon monitor

2.3 Monitor locations and descriptions

Each station representative was provided with descriptive notes designed to allow the representative freedom to place their monitors in locations where they believed the monitor would provide a useful measurement of radon. The notes were intended to give the representative the knowledge required to place the monitors where radon was more likely to impact on human activities. The measurements needed to be accurate and not unnecessarily biased by such factors as stale air and close proximity to bricks and granite. These notes are presented in Appendix A1.1.

Figure 2.2 shows the method used by AAD staff at Mawson station for affixing the monitors to a wall using electrical or gaffer tape. This method allows the monitor to be fixed a few centimetres from the wall surface, and allows free air circulation around and under the monitor. It is not known if this method was adopted at the other stations.

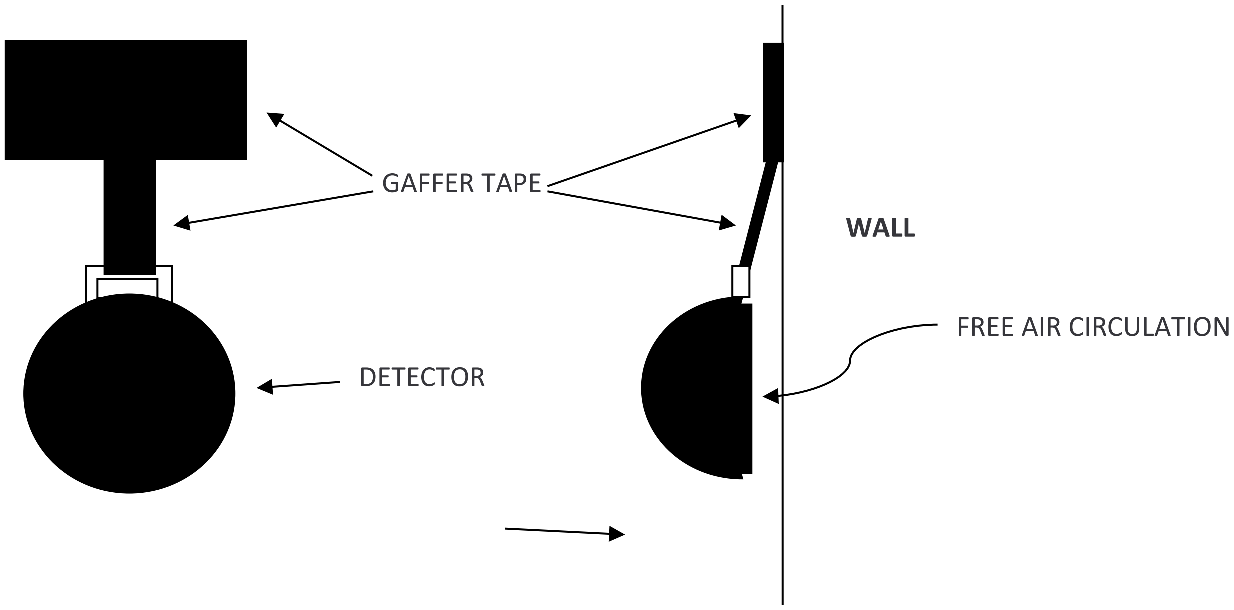

Figure 2.2: Method used for securing monitor to wall at Mawson Station (diagram courtesy Dr Malcolm Arnold, Mawson)

Table 2.1: Winter monitor locations summary

	No. of buildings	Building storey		Area type		
		Downstairs	Upstairs	Living	Common	Work
Mawson	4	10	3	4	3	6
Davis	1	9	4	1	10	2
Casey	3	10	3	1	8	4
Macquarie Island	10	11	2	3	2	8
Total	18	40	12	9	23	20

Table 2.2: Summer monitor locations summary

	No. of buildings	Building storey		Area type		
		Downstairs	Upstairs	Living	Common	Work
Mawson	2	4	2	2	1	3
Davis	1	6	0	1	4	1
Casey	1	4	2	2	3	1
Macquarie Island	4	6	0	2	1	3
Total	8	20	4	7	9	8

The winter measurement program comprised of 52 separate monitors, a summary of their placements is provided in Table 2.1. A further 24 were deployed for the summer program, summarised in Table 2.2. The location of the monitors was categorised using the following guidelines:

- The number of buildings is the number of separate buildings at the station that had at least one radon monitor installed.
- Each of the areas monitored were divided into the categories of living, common and work spaces.
- Multi-level buildings were divided into upstairs or downstairs.
- Single level buildings were defined as downstairs only.
- Living areas were defined as bedrooms and areas accessed mostly by a single person.
- Common areas were defined as areas frequented by a number of people, such as corridors and shared recreational spaces. Both of these areas could be used at any time of the day.
- Work areas were defined as areas used solely for work purposes mostly occupied during working hours, such as offices and other workspaces like a doctor's surgery or scientific laboratories.

Each separate building could encompass several of each of the categories. Photographs of some typical locations surveyed are shown in Figure 2.3 (Davis) and Figure 2.4 (Casey).

Figure 2.3: Typical locations used at Davis: basement brewery (L), western stairs new living quarters (R)

Figure 2.4: Typical locations used at Casey: Red Shed Wallow (L), met office west window (R)

For the long-term or winter monitors, 40% were located in occupational (or work) areas. The remaining 60% were located in living or common areas.

For summer monitors, approximately one third of the monitors were located in work areas. The remaining two thirds were located in areas classed as living or common areas.

2.3.1 Issues with monitor locations

The intention of the project was to take radon measurements in as wide a range of locations as possible at each station. It was expected that monitors would be deployed in common areas, personal areas (i.e. sleeping quarters) and working areas, encompassing both upstairs and downstairs (and possibly below ground) locations. It was also expected that a range of buildings at the station would be measured. The instructions given (see Appendix A1.1) gave as much latitude as possible to the AAD staff on site to make decisions on where to place monitors. These expectations have largely been met, with certain limitations. For instance, Macquarie Island had monitors deployed across a range of buildings, with no more than two in any given building, which was exactly as intended. Whereas, at the other end of the scale, Davis had all thirteen monitors deployed in various rooms in what appears to be a single building. This building does include areas that encompass the three classes of area, as well as upper and lower storeys. However, there is no information regarding any of the other buildings on the Davis site, so the data, whilst covering all of the required options is of limited use. Casey and Mawson were both similar in that three or four buildings were measured, with the bulk of the monitors in both cases deployed in various rooms of the main living quarters (usually referred to as the 'Red Shed') with the remaining monitors used in buildings designated as working areas. These limitations, although less than ideal, have given a good spread of data at some of the stations, and have allowed in-depth measurements of some high-use buildings at the other stations. The summer deployment showed similar traits, which was to be expected due to the reduced number of monitors, using previously identified locations.

3. Monitor raw results

There were two sets of monitors deployed to the four Antarctic stations. The first set of 52 monitors was intended to be left in place for as close to one year as possible. These monitors will be referred to as 'Winter' monitors. The second smaller set of 24 monitors was to be deployed alongside selected winter monitors for a one to two month period during the summer season only. These monitors will be referred to as 'Summer' monitors.

3.1 Winter

The winter monitors were deployed for a minimum of 295 days up to a maximum of 404 days. These periods are well above the recommended minimum exposure period for ARPANSA's SANTECS system to measure environmental levels of radon. The winter monitor radon concentration results are plotted in Figure 3.1. All monitors, with the exception of a single monitor from Davis recorded results less than 30 $Bq.m^{-3}$. There is a variation from a few $Bq.m^{-3}$ up to 25 $Bq.m^{-3}$ or greater at all four stations. The highest level recorded was by monitor #3 at the Davis 'Basement Brewery', an area partially underground with approximately half of the surface area of the room below the level of the underlying rock base. Also of interest was Mawson monitor #12. This monitor was placed under polyethylene sheeting in direct contact with the rock in the crawlspace beneath the Mawson 'Red Shed'. This monitor returned 30 $Bq.m^{-3}$, the highest value of the winter monitors placed at Mawson. The lowest 'maximum' value of the winter program was 21 $Bq.m^{-3}$, recorded in two locations at Casey, monitors 8 and 11. These recorded a stairwell in the 'Red Shed' and the plant inspector's office of the Workshop, respectively.

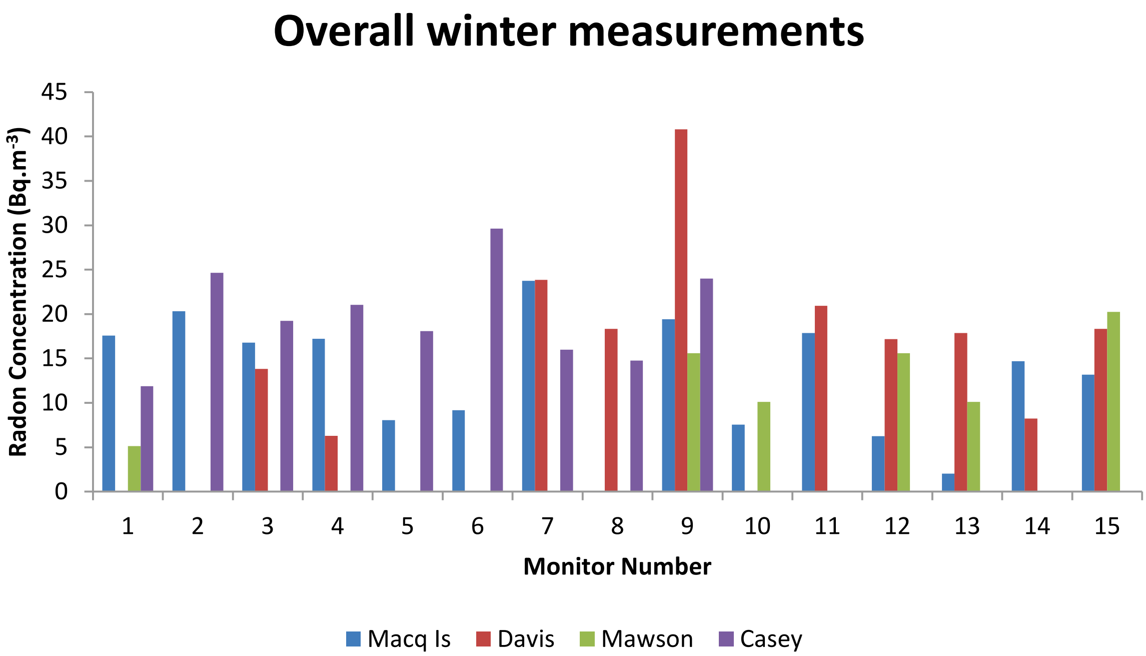

Figure 3.1: Radon concentrations for all monitors used in the full year/winter portion of the study

3.2 Summer

The summer season is usually thought of as the period of warmer weather where the sea ice retreats and the mainland stations are all accessible by ship. Over the period of this survey, the AAD was operating a single ship, the *RSV Aurora Australis*, to access the stations. The *Aurora* is only able to make two to three visits to each station over the summer period. Monitors were able to be left for a longer period at Casey (nearly double that of the other stations), as it has recently become accessible by air direct from Hobart during the summer season. This enables more visits to the station over a longer summer season, relative to the traditional shipping season. As a result, the maximum period that the summer monitors could be placed was 56 days, with a minimum of 27 days. These times are much less than the minimum recommended placement for ARPANSA's CR-39 track-etch monitors of 100 days (or approximately three months) (Tate and Long 2016). As a result, all data collected in this portion of the program are then subject to a larger than usual uncertainty, which could be as high as 50%.

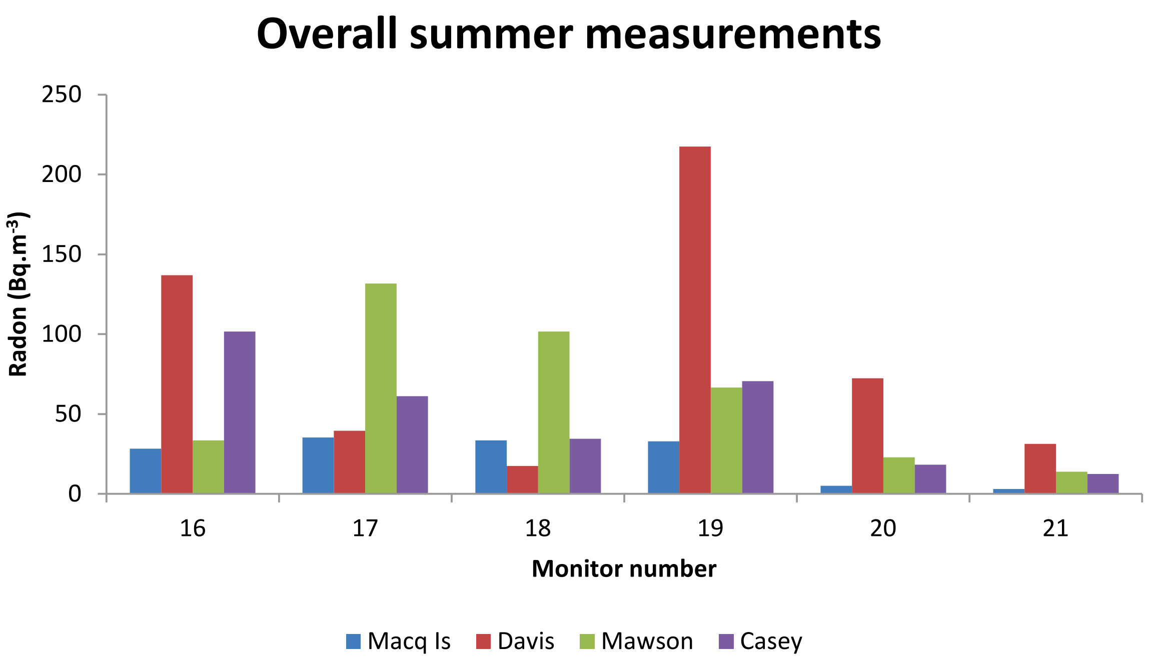

Figure 3.2: Radon concentrations for all monitors used in the summer portion of the study

The radon concentrations recorded at all four stations during the summer season are plotted in Figure 3.2. There were five monitors in total that exceeded 100 Bq.m^{-3}, two each at Davis and Mawson, and one at Casey. Of these, only a single monitor from Davis exceeded the 200 Bq.m^{-3} action level for radon in dwellings. No monitors at Macquarie Island exceeded 50 Bq.m^{-3}. The Davis monitors were #16 and #19, the basement brewery and western stairs. The basement brewery rose from 41 to 137 Bq.m^{-3}. This seems to be a likely increase as the room is partially underground, and has a single access door most often kept sealed. The western stairs rose from 5 to 207 Bq.m^{-3}. Such a large increase seems unlikely, as the area monitored is an open thoroughfare with access from both directions and good air flows. Other monitors in similar areas of the same building did not measure such an increase. Otherwise, the highest measured value in this building was 72 Bq.m^{-3}, by monitor Davis #20.

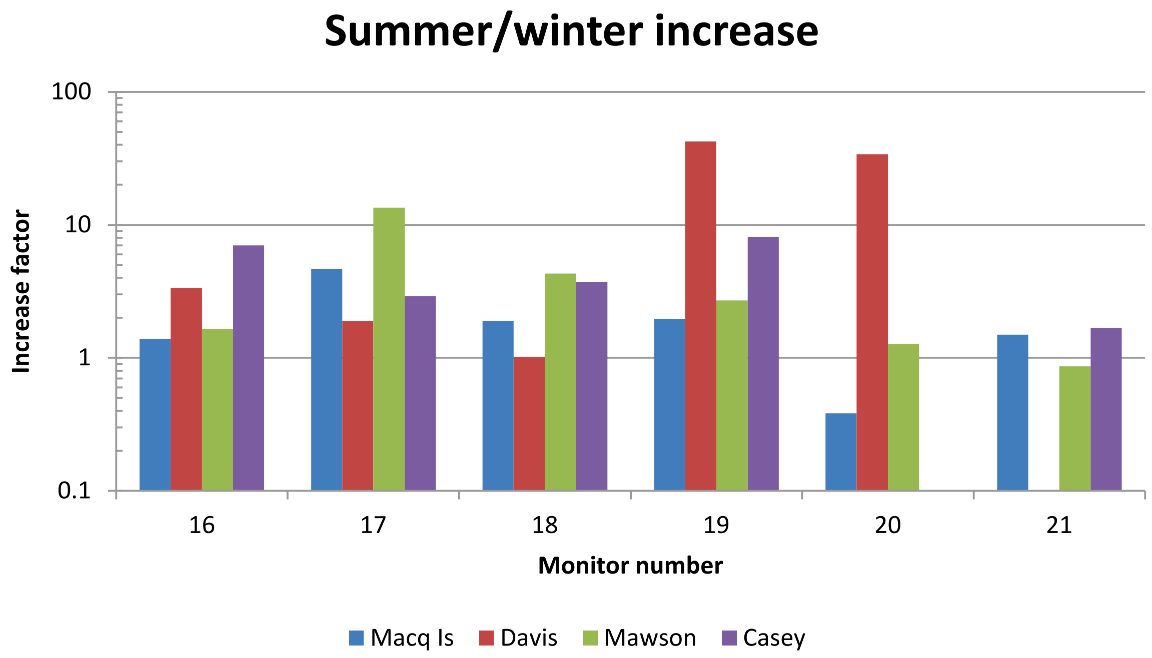

Figure 3.3: Summer/winter increase factor

At Mawson, the two monitors above 100 Bq.m^{-3} were numbered 17 and 18, described as the kitchen centre island and room 16 respectively. The kitchen area rose from 10 to 132 Bq.m^{-3} from winter to summer, whilst Room 16 rose from 24 to 101 Bq.m^{-3}. At Casey the largest increase was at the doctor's office, using monitors #9 and #16. The increase measured here was from 14 to 102 Bq.m^{-3}. This area is a secluded office with an open door during the day, which is kept closed during non-working hours. The summer/winter increase factor for the six summer monitors at each station is shown in Figure 3.3. It should be noted that two monitors (Macquarie Island #20 and Mawson #21) showed a decrease from winter to summer, whilst one monitor (Davis #18) showed virtually no change. Both locations to show a decrease (the garden cove donga and the Supervising Communications Technical Officer's office) are locations essentially unused (or subject to very occasional use) during the winter, but are subject to continuous traffic or are regularly opened to the exterior during the summer. Two monitors were not able to be compared as one (Davis #4) was lost during the winter, and one (Casey #20) was placed in a new location with no winter analogue.

3.3 Overall station averages

The radon concentration recorded at each station has been averaged for both winter and summer seasons and are plotted in Figure 3.4.

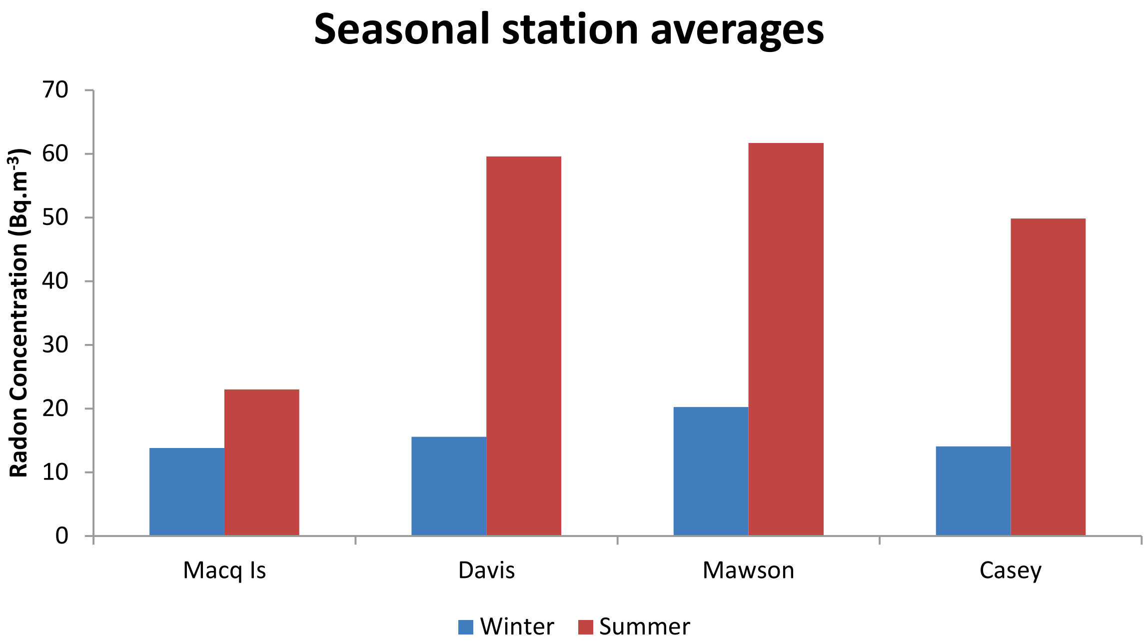

Figure 3.4: Average radon concentration recorded at each station in both winter and summer seasons

During the winter, the average radon concentration at all stations is 20 Bq.m^{-3} or less. There is a much wider variation in measurements over the summer season. Macquarie Island features a small increase over the winter readings. This is to be expected as the construction of buildings is of a different type to the mainland stations. Also, weather conditions at Macquarie Island are not as conducive to elevated radon levels compared to the mainland. The temperature variation from winter to summer is less at Macquarie Island, a difference of approximately 4 °C compared to up to 17 °C on the mainland. The other three stations show radon variation from 300% to 500% higher in summer over winter. Davis has the largest difference in radon concentration, with an average of nearly 90 Bq.m^{-3}. This is a 550% increase over the winter measurements. This higher value is largely due to a single monitor that recorded 217 Bq.m^{-3} in the summer period. The equivalent winter monitor in this location only recorded a value of 5 Bq.m^{-3}. Such a large rise in radon concentration in a single location compared to other sites at the station seems unlikely; it is possible that this value is in error. With this value removed from the dataset, the summer average for Davis reduces to approximately 60 Bq.m^{-3}. This fits into the same 300% to 400% range of increase recorded at the other mainland stations.

4. Time–based interpretation

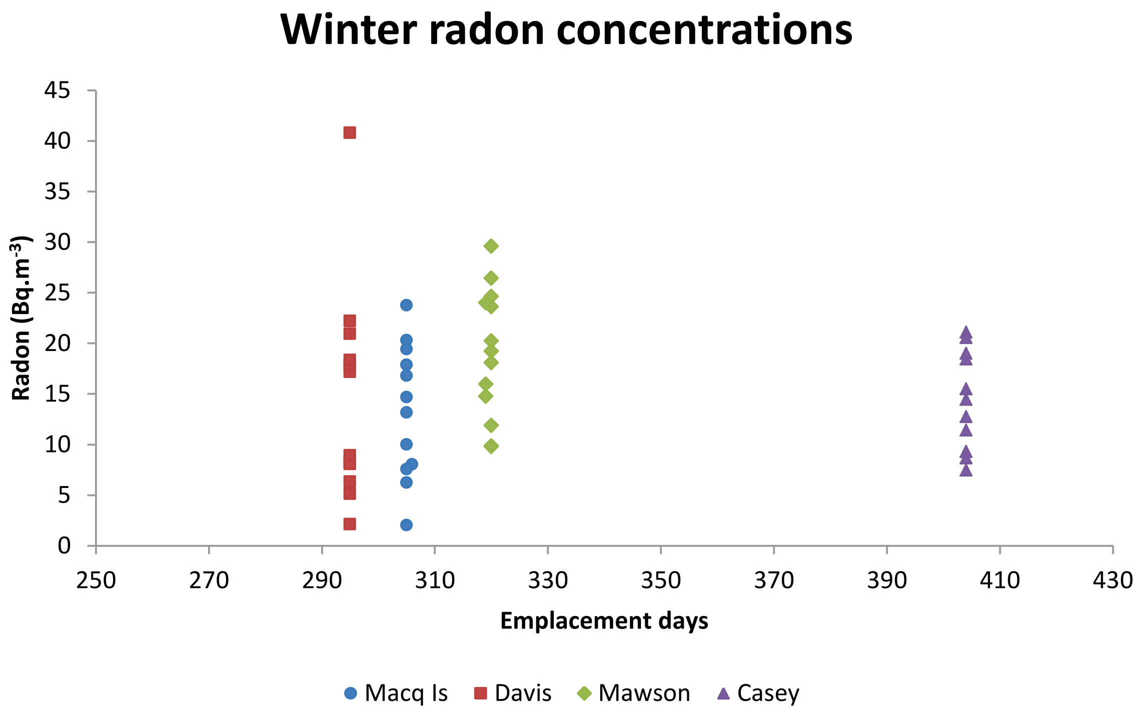

Figure 4.1: Winter radon concentrations plotted versus the time in days of the measurement period

The radon concentrations recorded at each station versus emplacement time are shown in Figure 4.1. This plot gives a good representation of the variation of radon concentration on each site, and identifies where 'clusters' of values appear. Any outliers can be clearly identified, where the concentration at any single site is markedly different to other values. This behaviour is most evident at Davis, where there are two distinct groups of data, centred at approximately 5 and 20 $Bq.m^{-3}$. Then there is a single point at above 40 $Bq.m^{-3}$. This outlier was recorded in the basement brewery, a room which lies partially underground. The Mawson, Casey and Macquarie Island feature data evenly spread over ranges from 2 to 30 $Bq.m^{-3}$, when an uncertainty of 20% on all measurements is taken into account.

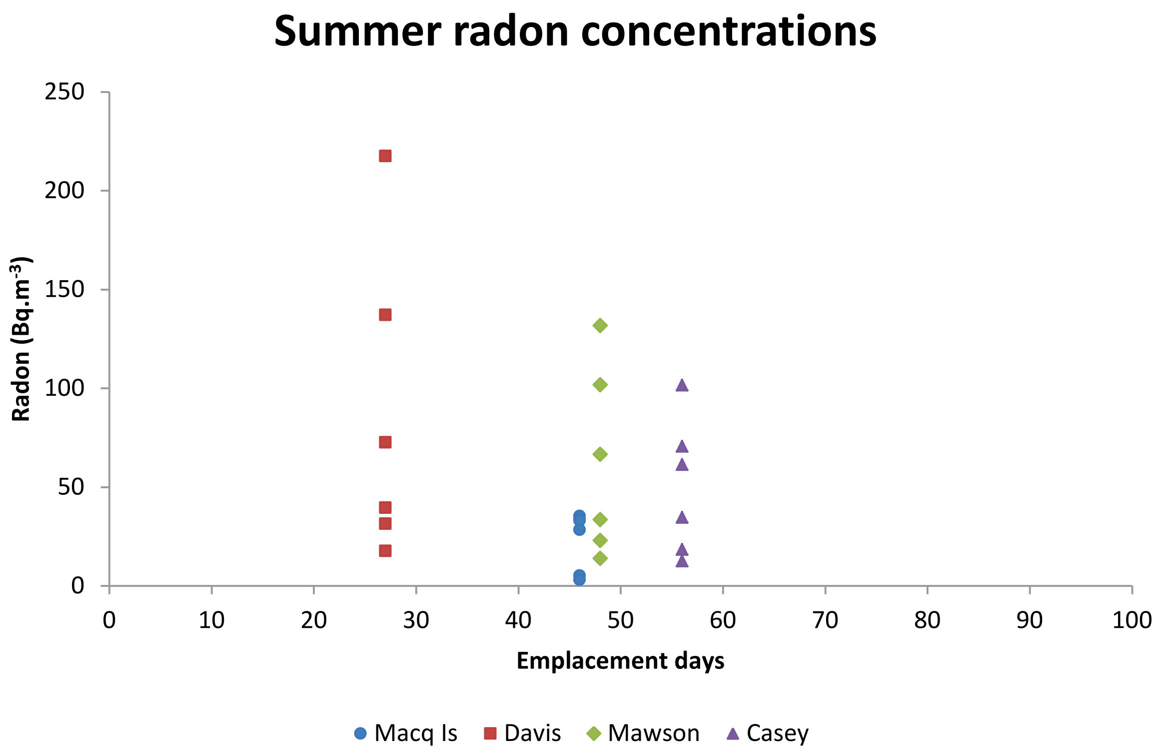

Figure 4.2: Summer radon concentrations plotted versus the time in days of the measurement period

Figure 4.2 illustrates the spread of data recorded at each station over the summer season. The Macquarie Island data is grouped into two distinct levels, one <10 $Bq.m^{-3}$ and another at approximately 30 $Bq.m^{-3}$. The other three stations have values spread over a much larger range. The outlier recorded at Davis during the winter (basement brewery) again features as an outlier in the summer group, recorded at 137 $Bq.m^{-3}$. There is another much higher outlier in the Davis data, the western stair, which was recorded at 217 $Bq.m^{-3}$. This value is higher than the recommended action level for radon in dwellings (ARPANSA 2002). Although, it is well below the action level for areas designated as workplaces. This is the only value recorded in the measurement program above the action level. As previously discussed in Section 3.3, it is possible that this value is in error, and possibly can be disregarded.

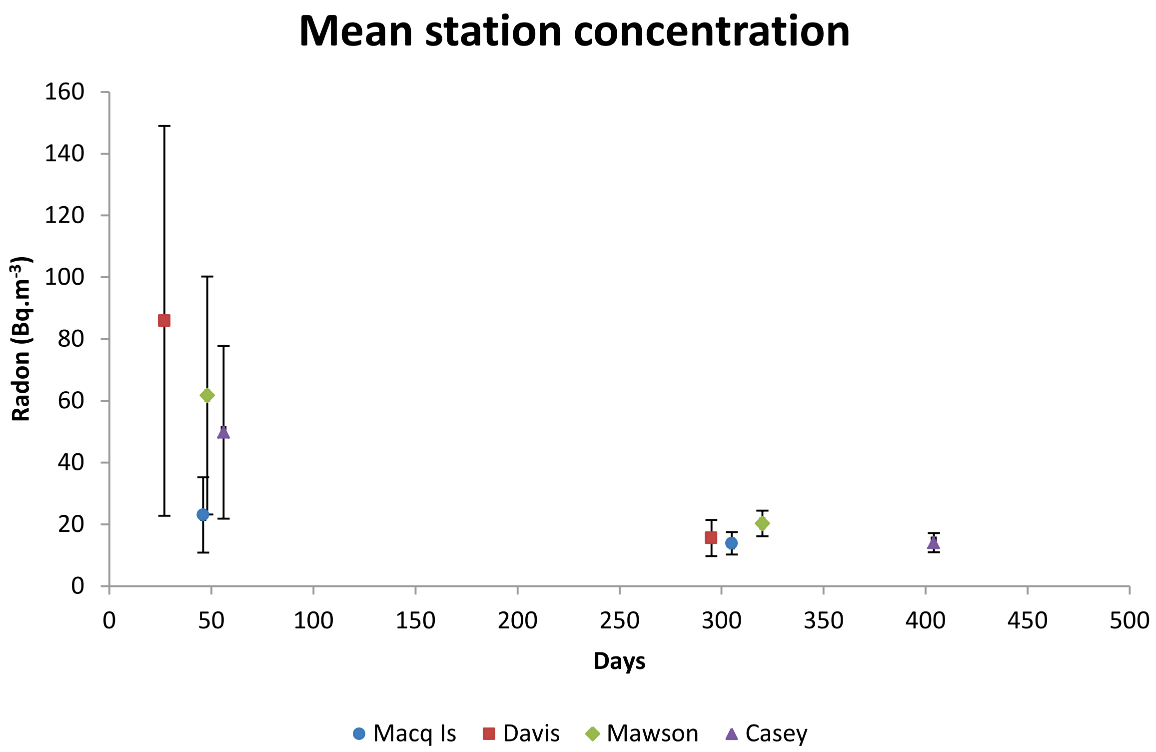

Figure 4.3: Mean radon concentrations at each station for both winter and summer

Figure 4.3 shows a condensed form of the data, where the mean value for each station for both summer and winter measurements is plotted. The uncertainties have been calculated from the standard deviation of the mean for each value. The error bars can be approximated by ±25% for the four winter values, and ±50% for the summer values. This is very consistent with previous results from ARPANSA's SANTECs CR-39 measurement system where any monitors exposed for thirty to sixty days or less tend to have an uncertainty of around 50%. This uncertainty falls to 30% or less with longer exposures. ARPANSA recommends three months (or 100 days) as a minimum placement period due to these limitations. Short period exposures are useful to decide if an area has a radon concentration above or below the recommended limits. They are not suitable to accurately measure radon levels at or around background levels.

5. Conclusions

As expected, it has been shown that the overall radon concentrations at Australia's Antarctic and Subantarctic stations are quite low, and should not be a cause of concern for staff based at the stations. The results obtained for the winter and summer portions of the study differ quite markedly, both in radon concentration and accuracy. The monitors in the winter portion of the study performed well, with very low levels of radon recorded at all four of the Australian stations. The average value recorded at each station was 20 $Bq.m^{-3}$ or less, with a minimum average value of 13.8 $Bq.m^{-3}$ recorded at Macquarie Island. As expected, the results of the summer portion were elevated in comparison to the winter results. The average values recorded over the summer period rose by 300% to 400% at all sites except Macquarie Island, where a 165% increase was noted. Less useful information was gained from the summer portion of the study than expected. This was due to the relatively short period that was open for monitors to be deployed. At such low concentrations, the 30-60 day period was not long enough to measure any radon concentrations on site with less than an associated 50% uncertainty. An alternative method for measuring radon at these sites during the summer period would be to use an active-type monitor. This style of monitor is designed to reliably measure radon in the 10-100 $Bq.m^{-3}$ range found at the stations with integrations times of less than an hour. An integration time of one hour or longer would provide results with an acceptable accuracy with only one day of measurements in each location. A week on-site (usually available during resupply operations) would provide accurate measurements at five to six locations. If left at each site for longer, any diurnal variation would also become apparent.

As expected, no reliable measurements were recorded above the 200 $Bq.m^{-3}$ action level for radon in dwellings as specified in Annex C of RPS 1 (ARPANSA 2002). A single value measured in a common area at Davis exceeded the limit, which was possibly in error and should be ignored.

Appendix 1 Monitor details

A1.1 Letter to Antarctic Staff on deployment of monitors

Antarctica Radon Survey – *Station Name* 2012

Recipient
Station Name

Thank you for participating in our Antarctica radon survey. I have enclosed fifteen monitors for your use. It is intended that the monitors will be left in place for approximately 12 months, depending on shipping schedules. I have also attached some notes on radon and some information on the monitors themselves.

Before placing the monitors on-site, could you please select two to be used as a control. Please place these monitors in a plastic bag and return them to ARPANSA in the addressed envelope provided. If this could be on the immediate return voyage it would be greatly appreciated.

Notes for Placement of Monitors

To give an accurate reading of radon exposure, each monitor can only be used in a single location, and the time spent in that location needs to be recorded.

Some dos

- Please put the monitors in highly occupied areas, such as recreation, work or sleeping areas
- Please distribute them over ground and second floor accommodation, where available
- Please put the monitors between about waist and head height
- Please put the monitors in a place where it won’t be moved about or in the way

And some don’ts

- Please don’t put the monitors near brick or granite surfaces
- Please don’t open the monitors, cover or seal the opening around the flat side of the monitor
- Please don’t put the monitors inside an enclosed space (such as a cupboard) where they will be isolated from regular air flows

These are inert monitors made of plastic that absorb radon. They are not electronic and not a Dangerous Good. Please do not hesitate to contact me if you have any questions or require any further information.

Best regards,
ARPANSA

A1.2 Monitor Results – Winter Placement

Table A1.2.1: Winter monitor details for Mawson

Monitor #	Description	Date Placed	Date Retrieved	Days in Location	Exposure (kBq.d.m^{-3})	Radon (Bq.m^{-3})
Mawson #1	Outer wall, medical consulting office, mid-chest height.	8/03/2012	22/01/2013	320	6.48	20
Mawson #2	Wall of room 3 ground floor Red Shed above head of bed, mid-chest height	8/03/2012	22/01/2013	320	8.46	26
Mawson #3	*Control sent back to ARPANSA*	9/03/2012	N/A	N/A	*Not*	*Used*
Mawson #4	Kitchen centre island above fire extinguishers	8/03/2012	22/01/2013	320	3.14	10
Mawson #5	Outer (east) wall Mess; on pillar 30 cm from window glass	8/03/2012	22/01/2013	320	3.16	10
Mawson #6	South dividing wall Room 16 Red Shed Upper; just above waist height	8/03/2012	22/01/2013	320	7.56	24
Mawson #7	Pillar west end of bar, Red Shed Upper	8/03/2012	22/01/2013	320	3.80	12
Mawson #8	Lounge Red Shed upper; window pillar, east facing, 30 cm from window glass, mid-chest height	8/03/2012	22/01/2013	320	7.89	25
Mawson #9	South dividing wall Room 8 west side Red Shed lower; mid-chest height	8/03/2012	22/01/2013	320	6.16	19
Mawson #10	*Control sent back to ARPANSA*	9/03/2012	N/A	N/A	*Not*	*Used*
Mawson #11	North wall Room 13 Red Shed lower; mid-chest height	8/03/2012	22/01/2013	320	5.79	18
Mawson #12	Under black PE sheeting on rock under Red Shed; access hatch ground floor; southern stairwell	8/03/2012	22/01/2013	320	9.48	30
Mawson #13	Outer wall above desk(west facing) SCTO office ; OPS building; mid-chest height	9/03/2012	22/01/2013	319	5.10	16
Mawson #14	Outer(north facing) wall MET office, OPS building; above desk; mid-chest height	9/03/2012	22/01/2013	319	4.72	15
Mawson #15	Diesel workshop; ground floor; south facing wall; mid-chest height	9/03/2012	22/01/2013	319	7.66	24

Table A1.2.2: Winter monitor details for Davis

Monitor #	Description	Date Placed	Date Retrieved	Days in Location	Exposure ($kBq.d.m^{-3}$)	Radon ($Bq.m^{-3}$)
Davis #1	*Control sent back to ARPANSA*	3/04/2012	N/A	N/A	*Not*	*Used*
Davis #2	*Control sent back to ARPANSA*	3/04/2012	N/A	N/A	*Not*	*Used*
Davis #3	Basement Brewery, service pipe to right of ladder	3/04/2012	23/01/2013	295	12.04	41
Davis #4	G07 bedroom SMQ downstairs	3/04/2012	23/01/2013	295	N/A	N/A
Davis #5	Surgery office door handle	3/04/2012	23/01/2013	295	6.18	21
Davis #6	Cinema - base of handrail support - back row	3/04/2012	23/01/2013	295	5.07	17
Davis #7	Firehose reel upstairs SMQ - next to SL room	3/04/2012	23/01/2013	295	5.27	18
Davis #8	Firehose reel upstairs - SMQ (near stairs)	3/04/2012	23/01/2013	295	2.43	8
Davis #9	Fire hydrant rack. New LQ cold porch	3/04/2012	23/01/2013	295	5.41	18
Davis #10	Kitchen - under back knife rack	3/04/2012	23/01/2013	295	1.87	6
Davis #11	Chrome leg supporting bench at communications console in mess	3/04/2012	23/01/2013	295	6.55	22
Davis #12	Left leg of bar near window (under the bench)	3/04/2012	23/01/2013	295	2.38	8
Davis #13	Eastern stair. New LQ next to top step (on the side)	3/04/2012	23/01/2013	295	2.63	9
Davis #14	Chrome leg supporting window bench in mess (under the middle window)	3/04/2012	23/01/2013	295	0.63	2
Davis #15	Western stair new LQ (barstairs) next to top step	3/04/2012	23/01/2013	295	1.51	5

Table A1.2.3: Winter monitor details for Casey

Monitor #	Description	Date Placed	Date Retrieved	Days in Location	Exposure ($kBq.d.m^{-3}$)	Radon ($Bq.m^{-3}$)
Casey #1	Red Shed Wallow corner bookshelf	7/01/2012	14/02/2013	404	7.45	18
Casey #2	Mess, next to safety suggestion box under clock	7/01/2012	14/02/2013	404	3.76	9
Casey #3	Splinters Bar, on beam behind drink dispenser	7/01/2012	14/02/2013	404	3.03	7
Casey #4	Mezzanine, near table tennis table	7/01/2012	14/02/2013	404	3.51	9
Casey #5	Doctor's room 'finster' 2nd floor Red Shed side of bookshelf	7/01/2012	14/02/2013	404	5.15	13
Casey #6	Room 214 2nd floor Red Shed side of bookshelf	7/01/2012	N/A	N/A	*Monitor*	*Lost*
Casey #7	West wing, bottom of stairs fire extinguisher	7/01/2012	14/02/2013	404	7.69	19
Casey #8	Outside Room 112 Red Shed on noticeboard	7/01/2012	14/02/2013	404	8.53	21
Casey #9	Doctor's surgery office	7/01/2012	14/02/2013	404	5.85	14
Casey #10	Met office west window #2	7/01/2012	14/02/2013	404	6.26	15
Casey #11	Workshop above P.I. desk under keybox	7/01/2012	14/02/2013	404	8.31	21
Casey #12	Kitchen storage/office above music control	7/01/2012	14/02/2013	404	4.62	11
Casey #13	Room 104 Red Shed 1st floor side of bookshelf	7/01/2012	14/02/2013	404	3.76	9
Casey #14	*Control returned to Australia*	7/01/2012	N/A	N/A	*Not*	*Used*
Casey #15	*Control returned to Australia*	7/01/2012	N/A	N/A	*Not*	*Used*

Table A1.2.4: Winter monitor details for Macquarie Island

Monitor #	Description	Date Placed	Date Retrieved	Days in Location	Exposure ($kBq.d.m^{-3}$)	Radon ($Bq.m^{-3}$)
Macq Is #1	*Control - RTA*	19/04/2012	N/A	N/A	*Not*	*Used*
Macq Is #2	Surgery - over sink	27/04/2012	26/02/2013	305	6.19	20
Macq Is #3	Mess - east wall of dining room	27/04/2012	26/02/2013	305	5.12	17
Macq Is #4	*Control - RTA*	19/04/2012	N/A	N/A	*Not*	*Used*
Macq Is #5	Cumpston's - station leader's office	27/04/2012	27/02/2013	306	2.46	8
Macq Is #6	Cumpston's - doctor's room (2nd Floor)	27/04/2012	26/03/2013	333	3.05	9
Macq Is #7	Greenstore	27/04/2012	26/02/2013	305	7.24	24
Macq Is #8	Rec room (2nd floor)	27/04/2012	N/A	N/A	*Monitor*	*Lost*
Macq Is #9	Fire hut	27/04/2012	26/02/2013	305	5.92	19
Macq Is #10	Comms hut	27/04/2012	26/02/2013	305	2.31	8
Macq Is #11	Bio/MIPEP hut	27/04/2012	26/02/2013	305	5.45	18
Macq Is #12	Mechanic's workshop	27/04/2012	26/02/2013	305	1.90	6
Macq Is #13	Southern Aurora donga	27/04/2012	26/02/2013	305	0.62	2
Macq Is #14	Hass. House donga	27/04/2012	26/02/2013	305	4.48	15
Macq Is #15	Garden Cove donga	27/04/2012	26/02/2013	305	4.02	13

A1.3 Monitor Results – Summer Placement

Table A1.3.1: Summer monitor details for Mawson

Monitor #	Description	Reference	Date Placed	Date Retrieved	Days in Location	Exposure (kBq.d.m^{-3})	Radon (Bq.m^{-3})
Mawson #16	Med Consult office	Mawson #1	5/12/2012	22/01/2013	48	1.61	33
Mawson #17	Kitchen centre island	Mawson #4	5/12/2012	22/01/2013	48	6.32	132
Mawson #18	Room 16 Red Shed upper	Mawson #6	5/12/2012	22/01/2013	48	4.88	102
Mawson #19	Lounge, Red Shed upper	Mawson #8	5/12/2012	22/01/2013	48	3.19	67
Mawson #20	Room 13, Red Shed lower	Mawson #11	5/12/2012	22/01/2013	48	1.10	23
Mawson #21	SCTO office	Mawson #13	5/12/2012	22/01/2013	48	0.66	14

Table A1.3.2: Summer monitor details for Davis

Monitor #	Description	Reference	Date Placed	Date Retrieved	Days in Location	Exposure (kBq.d.m^{-3})	Radon (Bq.m^{-3})
Davis #16	Basement brewery	Davis #3	27/12/2012	23/01/2013	27	3.70	137
Davis #17	Surgery office door handle	Davis #5	27/12/2012	23/01/2013	27	1.07	40
Davis #18	Cinema - back row back hand rail	Davis #6	27/12/2012	23/01/2013	27	0.47	18
Davis #19	Western stair	Davis #15	27/12/2012	23/01/2013	27	5.87	217
Davis #20	Chrome leg supporting window	Davis #14	27/12/2012	23/01/2013	27	1.96	72
Davis #21	Bedroom SMQ downstairs	Davis #4	27/12/2012	23/01/2013	27	0.85	31

Table A1.3.3: Summer monitor details for Casey

Monitor #	Description	Reference	Date Placed	Date Retrieved	Days in Location	Exposure (kBq.d.m^{-3})	Radon (Bq.m^{-3})
Casey #16	Doctor's office	Casey #9	20/12/2012	14/02/2013	56	5.69	102
Casey #17	Next to 113	Casey #8	20/12/2012	14/02/2013	56	3.43	61
Casey #18	Mess	Casey #2	20/12/2012	14/02/2013	56	1.94	35
Casey #19	Library entrance	Casey #4	20/12/2012	14/02/2013	56	3.96	71
Casey #20	Room 213	New Location	20/12/2012	14/02/2013	56	1.03	18
Casey #21	Bar	Casey #3	20/12/2012	14/02/2013	56	0.70	13

Table A1.3.4: Summer monitor details for Macquarie Island

Monitor #	Description	Reference	Date Placed	Date Retrieved	Days in Location	Exposure ($kBq.d.m^{-3}$)	Radon ($Bq.m^{-3}$)
Macq Is #16	Surgery over sink	Macq Is #2	11/01/2013	26/02/2013	46	1.30	28
Macq Is #17	Communications hut	Macq Is #10	11/01/2013	26/02/2013	46	1.63	35
Macq Is #18	Bio MIPEP	Macq Is #11	11/01/2013	26/02/2013	46	1.55	34
Macq Is #19	Mess	Macq Is #3	11/01/2013	26/02/2013	46	1.52	33
Macq Is #20	Garden Cove donga	Macq Is #14	11/01/2013	26/02/2013	46	0.23	5
Macq Is #21	Southern Aurora donga	Macq Is #13	11/01/2013	26/02/2013	46	0.14	3

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