PCI/WPB FINAL REPORT

Submitted to:

PA DER Bureau of Radiation Protection 1992-1993

Study # RT-1

A Study of Radon Testing Methods for Real Estate Transactions

Field Work Covering the Period
August 24, 1992 to February 17, 1993

REVISION 2
OCTOBER 12, 1993

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PENNSYLVANIA DER RADON TAMPER STUDY
FINAL REPORT

STATEMENT OF THE PROBLEM

Pennsylvania may, in the near future, mandate that all residential dwellings be tested for radon or radon decay products (RDP) if the dwelling is capable of being occupied for a minimum amount of time and is involved in a real estate transfer. In order to obtain a representative measurement for a typical short term test, it is necessary to maintain standard test conditions. It is widely recognized that it is possible to affect the results of a radon/RDP test by establishing non-standard testing conditions, e.g. by opening windows and doors, operating HVAC (heating, ventilation and air conditioning) equipment, covering or moving measurement devices, etc.

STUDY OBJECTIVE

The objective of this Project is to investigate the ability of a representative selection of the radon/RDP testing devices, methods and anti-tampering controls, in use in connection with real estate transactions in Pennsylvania, to detect the existence of non-standard test conditions and to quantify the effect that such conditions have on the results obtained.

STUDY OF NON-STANDARD TEST CONDITIONS

It is widely known that opening windows or turning on circulating fans can significantly affect the radon levels in a dwelling. This study is investigating the effect of such changes in four individual dwellings during three different seasons. During each round of testing in each house, four separate radon tests will be conducted, for a total of twelve tests per house and thirty-six tests for the whole study. The changes in radon levels will be noted, versus the degree in tampering that has taken place. Radon detectors and tamper controls vary in their susceptibility to being manipulated. It is unlikely that the detection of the most common methods of tampering can be determined by one method. More than likely, only by utilizing a number of tamper controls, can tampering be determined with any degree of certainty.

Tampering, to reduce the recorded radon or radon decay product (RDP) concentrations, can be divided into two broad categories: manipulating the test location conditions or manipulating the detector.

CONTINUOUS RADON EQUIPMENT

The following is a list of the Continuous Radon Equipment used in the basement and reference code letters.

PYRB	Pylon AB5 #261 or #317 w/PRD (Pylon Electronic Dev. Co., LTD)
RAD7	RAD 7 (Niton Corp.)
F210	F210 (Femto-Tech Corp)
F510B	F510 #144 (Femto-Tech Corp)
SURV	Surveyor (Sun Nuclear Corp)
HPRM	Honeywell Professional Radon Monitor (Sun Nuclear Corp)

GEMR Gemini radon monitor (Radonics)
RGM3 RGM3 (Eberline Instrument Corp)

CONTINUOUS WL MONITORS

The following is a list of Continuous Working Level Monitors used in the basement and reference code letters.

CIRAS Ciras II (Alpha Nuclear Corp)
PYWB AB5 #262 with AEP 25 head (Pylon Electronic Dev. Co., LTD)
TN TN-WL-02 (Thompson Neilson, LTD)
EBLB WLM #536 and WLR (Eberline Instrument Corp)

RADON INTEGRATING PROGENY SAMPLING UNITS - RIPSU

The following is a list of RIPSU detectors used in the basement and reference code letters.

CAIRS Cairs (Canadian Institute for Radiation Safety)
ER 300 & 400 E-RIPSU - (Rad Elec, Inc.)

SINGLE AVERAGE ELECTRONIC MONITOR

RA Radon Alarm (Enviralert Corp)

PASSIVE DETECTORS

The following is a list of passive detectors used in the basement and their reference code letters.

DMA ID#Open faced charcoal canister (DMA Radtech, Inc.)
EP # Standard E-Perm chambers with electrets (Rad Elec, Inc.)

FIRST FLOOR DETECTORS

F510F F510 #145 (Femto-Tech Corp)
PYW2AB5 #408 w/AEP 47 head (Pylon Electronic Development Co., LTD)
EBLF WLM #324 (Eberline Instrument Corp)

PRESSURE and VENTILATION MEASURING EQUIPMENT

The following equipment was used to help determine if changes in the pressure field or ventilation rate of the structure occurred.

MODUS T20 Pressure Transmitter (MODUS INSTRUMENTS, INC.)
TELAIRE (GAZTECH INTERNATIONAL CORP)
FURNACE RUN TIME Pressure relay switch (GRAINGER CO.)
RECORDAIRE DATALOGGER (GAZTECH INTERNATIONAL CORP)

SPREADSHEET (QUATTRO PRO)
TAPE SEALS (EQUITRON, INC) - (RADON ANALYTICAL LABORATORIES)
CAULK SEALS Clear Zip-A-Way Removable Sealant (RED DEVIL)
Tub and Tile Adhesive Caulk (Poly Seamseal)

HOUSE A - E - I DESCRIPTION

The first study house is a 1500 square foot rancher. The garage is separated from the house by an open concrete slab patio. The house is frame, however, the exterior walls and foundation are block. The exterior appears to be a thin brick attached to the block wall. The house has two additions added to the original construction, which were built by the original owner. The heating system is oil-fired hot water with no central air conditioning. There are two window air conditioners on the main floor.

The basement is divided into approximately five rooms that are all partially finished. The basement has an outside set of stairs and three windows. The family/TV room in the basement was chosen as the test location because it had the closest proximity to two of the outside windows.

HOUSE B - F - J DESCRIPTION

The second house in the study is a colonial with a walk-out basement. There is no attached garage. The siding is vinyl with some stone veneer. The foundation is block. The basement is broken into three rooms, separated by doors that were left open for the study. The basement has about 1290 square feet of floor space, with an eight foot drop ceiling and a foot of space above the drop ceiling. The heating system is a heat pump with back up gas. The radon detectors were set up in the center room of the basement.

The house has a radon sub-slab suction system using a single central suction point. The vent for the system is just under the deck above the exterior door of the walkout portion of the basement. The radon system was turned off for the study and the exhaust pipe was sealed with duct tape. An air-to-air heat exchanger, which was not being used, was kept off.

HOUSE C - G - K DESCRIPTION

The third house in the study is a colonial with a partial basement that is fully in the ground. The foundation is block. The house is frame construction with vinyl siding. A family room has a slab-on-grade floor that is one step down from the wooden first floor over the basement. The basement is one large room with a small furnace and storage room. A small closet contains the electrical panel and an open sump pit with no sump pump. The basement is finished. A two inch wide canal drain runs around the perimeter of the basement floor but is mostly concealed by a finished frame wall. The basement has about 900 square feet of floor space with an eight foot drop ceiling and a foot of space above the drop ceiling. The heating system is a heat pump with back up gas. The radon detectors were set up in the center room of the basement.

HOUSE D - H - L DESCRIPTION

The fourth house in the study is a split level with a partial basement that is fully in the ground. A half flight up is an adjoining slab on grade floor that contains a bedroom, study, and bathroom. On the other side of the basement is a garage that is a full height above the basement. A set of stairs allows direct access from the basement laundry room to the garage. The basement has a small center room with an adjoining laundry room and furnace room. The house is heated with a hot air oil burner and a central air conditioner. The basement is partially finished. The foundation walls are poured concrete. There is no sump pump or pit. The exterior siding is wood with a stone front veneer. The basement has about 700 square feet. The radon detectors were set up in the center room of the basement.

RUN A1 - 8/24/92 to 8/26/92 - DER TAMPERING

No tampering was done during Run A1.

RUN A2 - 8/26/92 to 8/28/92 - DER TAMPERING

A standard fan was run on medium speed about two feet off the floor during Run A2. The EQR which averaged 57% in Run A1 dropped 39% to a 35% EQR in Run A2. The fall off in EQR, without any significant climb at the end of run A2, did not indicate any tampering since this particular tampering was only capable of lowering the WL by 39%.

DER applied hairspray to DMA canister #111517 for five seconds. This canister gave an almost identical result with canister #111520 which was not tampered with. Both canister were however 40% low compared to the RGM3 monitor average. Both canisters gained excessive moisture of 8.6 and 10.9 grams. The basement average relative humidity was about 79%. The hair sprayed canister, however, gained less moisture. Although the hair spray adds weight, it must have blocked some of the moisture up take. Since both canisters had a low bias, it might be possible that the lab is over correcting for the moisture gain.

DER placed a box over the Eberline WL monitor #534 and placed a garbage bag over the box. The EBL tracked well with the other monitors but had a 30% low bias. The only indication of tampering would be the steep WL climb recorded at the last hour of exposure. This would, however, probable not be enough to be a flag that tampering had taken place.

A ziplock plastic bag was placed over EP #7161. The radon result of this EP was 15% lower than the other EP that was not tampered with. If the radon levels were constant over the exposure and radon was effectively sealed in the plastic bag with the EP, an approximate 12% drop would be expected over a two day exposure. Since passive devices do not give hourly results, some type of tamper resistant features are necessary to detect tampering. All EPs in the study included a tamper resistant lock tie, through the spring, to prevent closure of the lid. Even with this lock tie it is possible to partially close the lid and obtain a slightly reduced signal.

RUN A3 - 8/28/92 to 8/31/92 - DER TAMPERING

Upstairs windows were left open upstairs during Run A3. Radon levels had averaged 35.7

pCi/l with the RGM3 over the previous Run A2. The average dropped to 30.5 pCi/l, which is only a 15% reduction. It appears that opening upstairs windows in a ranch style house with hydronic heat during mild weather does not affect the basement radon levels significantly. The Equitron window seals were broken on the first floor windows.

The GEMWL monitor had the same box and plastic garbage bag placed over it that was used with the EBL monitor during the previous run. The average results of the WL monitor were 90% less than the TN while the radon results were unaffected. The WL graph shows the GEMW taking a steep climb down and maintaining a constant low reading till the last two hours of the run when it took a steep climb back up. This type of sharp fall and climb would definitely indicate tampering. The other tamper detecting features of the monitor, measuring movement, internal temperature, and EQR gave enough additional information for the manufacturer of the Gemini monitor to describe exactly what was done to the monitor and when. This detector is difficult to tamper with because of the multiple parameters that it records.

The DER reported that they had removed one of the vinyl tubes for the EPRIPSU #300. This unit was 30% low compared to the TN average. The other EPRIPSU, #400, recorded only 7% of the TN WL average. It appears that the wrong monitor number was recorded which would explain the very low readings of unit #400 but not why unit #300 was 30% low. Without some type of tamper seal on the tubing or a way to lock the lid closed on this unit it is difficult to detect if any tampering has taken place.

DMA canister #111246 had a magazine placed on top of its open face. This canister gained 45% less moisture than the other non-tampered canister and had a 40% lower result. It appears that this is an effective method in significantly reducing the final results with this type of detector. It is unfortunately not easy to detect this type of tampering without some type of cage or special tamper tape arrangement. It should be noted that the other charcoal canister was low by 32% compared to the RGM3. This might be due to the moisture correction used by the manufacturer. The Femto-TECH 510 indicated that the basement humidity was about 80%.

The WL Pylon, PYWB, had a coffee filter placed over its inlet but the unit was accidently unplugged so no data was collected.

The EBL had a 0.8 u filter placed over its inlet. The average for the EBL was only 14% less than the TN. It would seem logical that a filter of the same capacity would have affected this unit more than 14%. The EBL also tracked the other WL monitors with the same bias during the whole run. Possible the filter was not securely attached and RDP's were able to by-pass the restrictive filter. Small openings can allow a large percentage of the air flow to by pass a filter because of the pressure required to move air through the filter.

The PYRB had a clear tape placed over the inlet ports to the passive diffusion head inlets. This did not seem to have any significant effect upon the Pylon as it continued to track the other radon monitors with only a 4% low bias compared to the RGM3. If the radon levels had been changing rapidly, the Pylon might have had a delayed response but in this run the radon levels dropped a bit and then were level through most of the run.

The Honeywell HPRM monitor was also placed in a plastic garbage bag with almost no effect upon the radon levels. It appears that the garbage bag which was sealed with rubber bands was not sealed tight enough to prevent radon from entering the bag to replace that which was decaying out.

The Femto-TECH F210 had its two side intake grills taped shut. This unit also showed no effect from this tampering as did the HPRM and the PYRB.

RUN A4 - 8/31/92 to 9/2/92 - DER TAMPERING

During Run A4 the two basement 30" window were opened about 12", for a total opening of 720 square inches. The radon and WL dropped from about 27 pCi/l to about 7 pCi/l over about 3 hours. The basement to outdoor temperature difference would vary from 0 to 20 degrees during this run. This 74% reduction is an obvious sign of tampering. If the windows had, however, been opened three or four hours before the test was to begin and then closed only for the time that the tester was placing the monitors, it would be difficult to determine any tampering had taken place. In the hour that the windows were closed, at the end of the run, their was no significant rise in the levels back up.

The Equitron tape seals on both windows were broken, so it appears that these tape seals can indeed detect tampering with the windows.

The CO2 levels in the basement decreased by one half which indicates increased ventilation.

The pressure measurements between the basement and the outside became very erratic, which could easily be due to windy conditions. The average pressure difference decreased from a previous average of .005" to .002".

The basement EQR did not change significantly even though the increased ventilation would expect to lower the EQR. It appears from this that EQR measurements are not very useful for measuring ventilation changes.

The radon ratio between the first floor and the basement tripled from 34% to 91%. This may be due to a source of radon entering the first floor from the parts of the basement that did not have windows.

Both the Rad7 and the Surveyor, SURV, had their inlets connected to a tubing that ran to the outside through a basement window. The tubing must have been picking up some radon because both monitors only dropped 20% compared to their performance in relation to the other monitors in the previous run. All of the monitors recorded a large reduction because of the basement windows being left open. A desiccant drying agent was hooked in line to the tubing. It was noted at the end of the run that the Rad7 desiccant was unchanged while previous runs had depleted the desiccant. It was also noted that the desiccant column had been moved.

The PYRB was again sealed, this time with saran wrap. This time it took the PYRB almost 16 hours to catch up with the other radon monitors who had each taken a steep dive over about four hours. It appears that sealing a radon monitor simply slows down its response time and has little effect unless the radon levels change quickly. This effect can be seen to a lesser amount with the F510 which had its inlet blocked with aluminum foil. The F510 is less sensitive because the units box must allow radon to seep in even if the inlets are blocked.

The TN had two .8 u filters taped to its inlets but its response was only 16% less compared to the GEMW WL monitors. Either the filters were not installed well or the ventilation

increase from the windows being opened masks the effect of the filtering, although this would seem unlikely.

The PYWB had 2 coffee filters held in place over the inlet with a rubber band. The PYWB average was however only 11% lower than the non-tampered GEMW.

RUN B1 - 9/8/92 to 9/10/92 - DER TAMPERING

No tampering was done during Run B1.

RUN B2 - 9/10/92 to 9/12/92 - DER TAMPERING

A plastic bag was placed over the PYRB. The PYRB experienced a delay in its response to the radon changes compared to the other continuous radon monitors but its average was only 6% less than the RGM3.

Hairspray was again tried on a DMA canister. Although it was not specified which canister was sprayed, both DMA canisters averaged 29% and 38% low as compared to the RGM3 average. The canister with the lower average also gained slightly less moisture, so it might appear that this was the canister that was tampered with. The basement relative humidity was a high 83%.

The F510 monitor had a box placed over it, then a plastic bag was taped over the box. The F510's response was slow compared to the other monitors and it did not record the sharp spike that the other monitors saw. This lack of response to the spike caused the F510 to average 22% lower than the RGM3. This reduction would go un-noticed unless another continuous monitor was available for comparison. The tape seal to the table was broken which would have flagged that tampering could have taken place.

The PYWB had a coffee filter placed over its inlet and consequently averaged 36% lower than the TN monitor. The PYLWL still tracked the WL changes but with a reduced response. It appears that a significant portion of the decay products can get through a coffee type filter. This type of tampering which only reduces the response rather than eliminates it, would go undetected unless another continuous WL monitor was available for comparison. The tape seals from the monitor to the table, however, were broken which would flag that tampering had possible taken place.

The EBLB and CIRAS WL monitors had a fan blowing air directly on them. Interestingly, they did not appear to be influenced any more than the TN WL monitor which was on the same table. The EQR average only decreased from 50% for run B1 to 48% for run B2 although during run B2 the average shot up to 100% and then down to 30%. It appears this dramatic change was caused by the fan being turned on and off but this is not documented.

RUN B3 - 9/12/92 to 9/14/92 - DER TAMPERING

The F210 had its intake ports sealed with aluminum foil. There was no apparent affect from doing this. The F210 tracked the radon levels with the other radon monitors, however, the F210 did have a 20% high bias compared to the RGM3. The tape seals between the table and the unit were not disturbed.

The EBLB had its intake port covered with a filter but the data was lost so no comments can be made.

The top of EP #7092 was encased in aluminum foil. This EP averaged 12% less than the average of the two other EP's, although its average was closer to the RGM3 average. It appears that sealing the opening with foil has little effect.

Three kitchen windows were opened 7". Each night the windows were closed to 1" because of the cold outside temperatures. Unfortunately the CO2 tank ran out of gas during the middle of this run so ventilation changes cannot be evaluated. The first floor which had averaged around 9.1 during the previous run, B2, averaged 54% less at 4.2 pCi/l during run B3. The basement on the other hand was only 20% less than the previous run. In other words, the basement to first floor average went from 2 to 1 during Run B2 and 4 to 1 during run B3. This ratio spread is not, however, unusual and therefore would probable not be a flag that tampering had taken place. The EQR ratios were also not very different between runs, even on the first floor where the ventilation had taken place.

The first floor temperatures, which had been a steady 77 degrees, started to go up and down with the cycling of the heating system. The overall average was 76 degrees.

RUN B4 - 9/14/92 to 9/16/92 - DER TAMPERING

The basement 22" window was opened 11", a 6" fresh air feed to the furnace was opened and a green house window left open for a total opening of 300+ square inches. The basement window had a tape seal installed which was found missing at the end of the run. The radon levels, which had averaged 19.0 pCi/l during run B2 and 15.2 pCi/l during run B3, with the first floor windows open, now dropped to 2.7 pCi/l. This is an 85% reduction from run B2 without any windows open. The basement to outside temperature difference varied from 0 to 25 degrees.

Interestingly, the basement EQR went up during this increased ventilation from the previous run of 48% to this runs 64%.

The basement to first floor radon ratio which had averaged 58% and 65% during the non-ventilated runs suddenly shot up to an average of 222%. This unusual situation of the radon levels being twice as high on the first floor as the basement would definitely raise a flag that tampering had taken place. A similar situation had taken place in the previous house when only the basement windows in the test room were opened. It appears that the unfinished room which contains the air handler and was not ventilated, brought enough radon up to the first floor to maintain a higher level on the first floor than in the ventilated room of the basement.

The basement temperatures which had averaged 79 degrees during run B3 now dropped to 75 degrees, although the basement to outside average temperature did not get closer but farther apart compared to run B1, B2 and B3. It appears from this data that temperature monitoring is not very helpful in detecting tampering because the change is small when the basement is ventilated. It appears that the furnace maintains the basement temperature even with the windows open.

The basement to outside and basement to sub-slab pressure difference was significantly less during run B4 versus B3. This is especially true of the basement to sub-slab pressure

difference. With the basement windows open there is hardly any pressure difference between the basement and the sub-slab. This might be an indicator of tampering but it is a complicated measurement to make and difficult to interpret because of variables such as changing wind speed and direction.

The radon and WL continuous monitors all took a steep dive from about 15 pCi/l to 2 pCi/l during the beginning of this run. The WL dropped from about .08 WL to about .01 WL. Most of the monitors also started to climb upward during the last hour after the windows were closed again. This kind of graph, with such a steep drop at the beginning and small climb at the end, would definitely raise a flag that tampering might have taken place. It someone was, however, to open the windows before the test was begun and only close the windows while the tester was placing or retrieving the monitors, no significant change would likely be seen.

RUN C1 - 9/19/92 to 9/21/92 - DER TAMPERING

No tampering was done during Run C1.

RUN C2 - 9/21/92 to 9/23/92 - DER TAMPERING

The PYWB had a coffee filter taped over the inlet. The PYWB averaged 45% less than the TN WL monitor. The tape seal between the monitor and the table was not disturbed. This again indicates that a coffee filter allows about have of the RDP's to pass through it.

The PYRB was sealed in Saran wrap again. The PYRB averaged 5% higher than the RGM3. This slight bias was probably due to the fact that the radon levels dropped half way through the run and the PYRB took about twelve hours to drop down to the new RGM3 level. The decline of the PYRB is about twice what would be expected if the decline was only due to the decay of radon within the scintillation cell. This indicates that even with the Saran wrapped tightly around the inlet, radon still diffuses in and out but at a slower rate. Of course, it would be difficult to detect that this tampering is taking place, although it appears in most cases it won't be successful. It appears that even if the monitor is wrapped tightly when the radon levels are low there will be a slow climb up to match the room radon levels as some radon diffuses around and through the plastic covering.

The CIRAS was unplugged and the battery ran down. No data was recovered, which would of course void the test. The tape seal was broken, which would however have flagged that tampering might have taken place.

The EPRIPSU #400 was unplugged. The EPRIPSU averaged 85% low. The seals placed on the unit appeared not to be broken. It appears that the seals were not thorough enough to detect that the plug had been pulled out. This unit should have a built in time to detect periods of loss of power that might happen for other reasons besides attempted tampering.

The HPRM was covered with a box and then a plastic bag taped over the box. Unfortunately the data was lost and no printout obtained for this run.

A plastic lid was placed on top of the DMA charcoal canister. This caused the charcoal canister to average 71% lower compared with the other charcoal canisters. The moisture gain for the other canisters was 7.4 and 8.9 grams while the tampered canister only gained

0.9 grams. This small moisture gain might be enough to cause suspicion. It might be beneficial for a tester to measure the humidity at the time of placement and retrieval. If the approximate weight gain for the measured humidity is not achieved, tampering might be suspect. In this case the basement relative humidity was around 80%.

A fan was again run in the room during run C2. The basement EQR had averaged 58% during run C1 and then dropped to 20% in run C2. The drop in the WL was not however pronounced enough to raise a flag that tampering may have taken place. Twenty percent EQR can easily happen in houses with hot air heating systems. In this run, however, the low 16% basement to first floor radon ratio indicates the heating system was not running much.

RUN C3 - 9/23/92 to 9/25/92 - DER TAMPERING

The first floor windows were left open during Run C3. The first floor radon levels dropped slightly at the beginning of the run and then took another sharp drop down the morning of 9/24. The basement levels fell about 9% compared with the previous non-ventilated run. It would appear that the windows were closed at night or possibly the furnace was running more at night and this tended to replace the radon as quickly as it was lost out the windows. The run time on the furnace was not accurately recorded because the data logger only recorded the furnace condition once an hour. Even so, the data logger indicated the furnace was running 72% of the time. Once again the running of the hot air furnace and the mild outdoor temperatures did not allow temperature to be much of an indicator of any ventilation taking place. The kitchen window tape seal was, however, broken.

The TN had a coffee filter taped over its inlet. The TN averaged 18% lower than the CIRAS and 27% lower than the PYLWL. The TN tracked the other WL monitors closely but with a consistent low bias. Because the coffee filter only created a slight low bias it would be difficult to determine that the TN was tampered with.

A plastic lid was placed on top of a DMA charcoal canister. This caused the charcoal canister to average 72% lower than the average of the two other charcoal canisters. The moisture gain of 5.4 and 5.1 grams for the other non-tampered canisters was less than the previous run. The tampered canister only gained 1.2 grams, which although a small difference might be enough to cause a concern about tampering, especially if the humidity is measured when the canister is placed and retrieved. The basement averaged about 80% relative humidity. The tape seal attached between the canister and the table was not disturbed.

The EPRIPSU #300 had one of its hoses disconnected. The seal at the hose for this unit was broken which would raise a flag that the unit had been tampered with. The 300 unit averaged 89% lower than the CIRAS.

RUN C4 - 9/25/92 to 9/28/92 - DER TAMPERING

During Run C4 two basement 12" windows were left open 26" for a total opening of 624 square inches. The average radon and WL levels during this run declined by about 84% compared to the previous run levels.

In the initial part of the run, the humidity levels dropped only a few percentage points and then climbed back to their original levels. The humidity then climbed a few percentage points higher. It would appear that the humidity is not a good indicator of tampering when

the outside temperature is mild.

The outside temperature was only going down to 60 degrees at night. The average basement to outdoor temperature difference was only 9 degrees. The basement temperatures did drop a few degrees from the ventilation.

All the radon and WL continuous monitors took a steep dive down at the beginning of run C4 and were recording close to outdoor radon levels till the next morning. It would appear that this drastic drop was fan induced, although the basement window opening of this house is almost twice the square inch opening of the previous house. The furnace in this house does however de-pressurize the basement compared to the first floor about 4 1/2 pascals. Since the outdoor temperatures were their lowest during the beginning of run C4, the extra furnace run time might explain why the radon levels went so low. The other explanation is that a fan was placed in the window and removed the next morning but DER did not report this as happening. Overlaying the temperature difference between the basement and the outside shows similar but inverse curves. The other explanation is that a fan was placed in the window and removed the next morning but DER did not report this as happening.

The basement EQR climbed as the radon levels dropped, which again indicates that EQR does not seem to go down when ventilation is increased. The first floor to basement radon ratio went from 4 to 1 or about 25% down to 2 to 1 or 50%. When the basement was at it's lowest radon levels, the basement and first floor were the same levels. This might be suspicious but unlikely to flag a possible tampering situation.
The main indicator of ventilation would be the ambient levels followed by spikes up to 15 pCi/l. The initial rapid decline in radon levels would not have taken place if the house was ventilated before the tester arrived to place the monitors.

The basement window seals were surprisingly not broken when inspected at the end of the run.

RUN D1 - 9/30/92 to 10/1/92 - DER TAMPERING

No tampering was done during Run D1.

RUN D2 - 10/1/92 to 10/3/92 - DER TAMPERING

The F510 had a bucket placed over it that was caulked to the table. The F510 did not seem to be effected by this in any degree since it averaged 2.4% higher than the RGM3 for this run. The radon levels were fairly stable during the run so the response time of the monitor to changing radon levels could not be determined. The colored tape that was applied from the monitor to the table was not found disturbed.

The PYRB had its inlet holes sealed with caulk. The response of this monitor, although 9% lower than the RGM3, was not significantly different from the first non-tampered run. The tape seals were also not found to be disturbed.

The TN had a five gallon trash bucket sealed over it. The TN averaged 70% less than the PYWB. Although the tape seals were not found to be disturbed, it was obvious from the graph that the unit had been tampered with. The WL took a large drop down in the first three hours, remained low through the run and then shot up during the last three hours.

The CAIRS #341 had a one gallon plastic bucket placed over it. This RIPSU monitor measured 48% lower than the other non-tampered CAIRS monitor.

EP #2985 read 31% lower than the average of the other two non-tampered EPs. The tampered EP had a cup sealed over it. The tamper tape seals were not disturbed from this. From the graph it appears that the initial radon levels were about 29 pCi/l. If this amount of radon was captured in the cup sealed over the EP and allowed to decay for two days, it would average about 25 pCi/l. This is approximately what the EP measured.

DMA canister #112565 had a plastic lid placed over the top of the canister. The canister average was 66% lower than the other canister. No tampering was noticed from this other than the weight gain was 1.3 grams versus the non-tampered canister weight gain of 3.5 grams. Without a large cage or some other indicator of the canister being covered it would be difficult to detect this tampering other than the weight gain. The relative humidity was about 73% during the run.

A fan was run on high in the same room as the monitors. The average basement EQR which had been 30% during the previous run D1, now dropped to 22%, a 27% reduction, which is not unusual enough to raise a flag of concern about this type of tampering. Once again it appears that running a fan in the same room as the WL monitors does not effect the performance significantly. Although the WL dropped about 40% during the first six hours of the run, the levels rose back to their original levels and actually rose 30% higher than the initial levels at the end of the run without a corresponding rise in the radon levels. It appears that the fan had little effect on the WL during this run. The effect of a fan may, however be more pronounced in a test room where the air is less disturbed than in this study where there were at least ten monitors operating with pumps running, sampling the air.

The basement temperature dropped from 76 to 74 degrees even though the outside temperature averaged higher. This again is too small of a difference to be noted.

RUN D3 - 10/3/92 to 10/5/92 - DER TAMPERING

The HPRM had a bucket sealed over it. The HPRM had been averaging 8% and 9% lower than the RGM3 in the previous runs. During this run it averaged 14% less than the RGM3 average. The seal to the table must not have been very thorough because the HRPM tracked the slow climb of radon in the room. No disturbance was found to the tape seals. The tape printout indicated the unit had been tilted during the first interval, however this indicator is not considered important because it is so easy to disturb the unit during the set up.

The TN had a bucket sealed over it again. This time the TN averaged 93% less than the PYWB. Although the tape seals were not found to be disturbed, it was obvious from the graph that the monitor had been tampered with. The WL took a large drop down in the first four hours, remained near zero and then shot up during the last three hours. Covering a WL monitor appears to cause a dramatic drop in the WL because of the filtering of the air within the box by the sampling pump and detector filter.

One of the DMA charcoal canisters had a can placed on top of the canister, while another canister had a plastic cap placed on the canister. These canisters were 55% and 69% lower than the third non-tampered canister. Both canisters gained only a third or a quarter of

the moisture gain of the non-tampered canister. One of the tampered canisters was found upside down on the floor so that it was obvious that it had been tampered with. The other canister had a double stick tape crossed over the top of the canister. The tape seal was found collapsed on top of the canister at the end of the run indicating that something had been placed on top of the canister. Looping the double stick tape above the canister may be a method for deterring or detecting directly covering the canister.

A bucket was placed but not sealed over EP #2985. This caused the EP to be 24% lower than the average of the two other EPs. The tape seal of the tampered EP was found to be disturbed upon retrieval of the detector. Because the bucket was not sealed, the rising radon levels in the room were able to enter the bucket at a decreased rate but in enough quantity to raise the final EP average higher than the initial radon levels entrapped in the bucket.

RUN D4 - 10/5/92 to 10/7/92 - DER TAMPERING

DER indicated that both basement windows were opened 2" by 12" for a total of 48 square inches. Only one, however, of the window tape seals was discovered broken. The window seals consisted of self sticking paper dumb bells that had a touch of white acrylic latex caulk placed over the outer edge of the seal to make them more resistant to removal. The average basement radon levels with this additional ventilation only dropped 29% from the previous run's level. It would appear from the graph and averages that only one window was open and that this opening was not sufficient to reduce the radon levels significantly. Even if two windows were opened, the total opening was from one fifth to one thirteenth the total opening of the other houses. This is the most likely reason why the ventilation only reduced the radon levels by 29% compared to 74% to 84% reductions in the other houses.

The basement temperature did not change from the previous run even though the outside average temperature dropped. The basement to outside pressure difference actually increased so that this did not correspond with opening the window in the way one would expect. The basement EQR average dropped slightly from 31% to 23%. The basement to first floor radon levels went from 37% to 56%. Although this change in the first floor to basement radon ratio was the biggest change of any of the variables, it would not be unusual enough to raise a flag about tampering.

The PYWB had its inlet filtered with one of the RGM3 pre-filters. This caused the PYWB to average 83% lower than the TN level. The graph clearly shows tampering because the WL dropped rapidly during the first three hours and stayed very low till the final two hours when the WL shot back up.

Two EPs were placed in a dresser drawer without any measurable effect. No tape seals were used so the change in location was not noticed upon retrieval.

Two charcoal canisters were moved to the outside for the last hour of the exposure to determine if the radon would rapidly escape and lower the radon result significantly. The canisters, however, only read 10% lower than the non-tampered canister. One of the canisters was found with its tape seal broken which would have indicated possible tampering.

RUN E1 - 10/19/92 to 10/21/92 - DER TAMPERING

No tampering was done during Run E1.

RUN E2 - 10/21/92 to 10/23/92 - DER TAMPERING

The inlet to the PYWB was covered with a filter paper. The filter must have leaked or was not capable of capturing the decay products because the PYWB average results were only 28% less than the GEMW monitor. In the graph it appears that the PYWB is tracking the other WL monitors with a low bias. The caulk seal from the monitor to the table was not disturbed.

Monitor F510B was placed upstairs. Its overall average was 43% less than the RGM3 average. F510B averaged close to the first floor radon monitor F510F, as would be expected. If the graph of F510B was viewed alone it would not appear unusual and not have raised any flags.

Interestingly, the DER reported that the first floor windows were opened and yet the radon levels both averaged around 13.8 pCi/l. The outside average temperature was 46 degrees. The basement to first floor ratio of 67% was the same as the first run's 66%. Both the radon and WL averages of both floors was the same from the first non-tampered run to the second. It appears that opening the first floor windows (if they were really opened) has no effect upon the radon or WL levels. The CO2 levels on the first floor did however drop from about 2500 PPM to about 1500 PPM. This CO2 change is the only indicator that the first floor was being ventilated. The EQR did not vary significantly from the first run.

The EPRIPSU #400 had the electret removed and placed outside. This unit averaged 83% low compared to the GEMW. The tape and caulk seal were found to be loose upon retrieval which would have flagged that there was a possibility of tampering.

EP #5178 had a can placed over the EP with a weight on the can to hold it securely down. The caulk and tape seal were not disturbed. The EP was only 4% lower than the other non-tampered with EP. The radon levels were fairly steady during this run.

EP #5121 was removed and placed outside for most of the run. This EP was 67% lower than the other non-tampered EP. The caulk and tape seal were found to be loose upon retrieval and this would have flagged that tampering may have taken place.

DMA canister #113119 had a plastic lid placed on top of it. Its average was 64% lower than the average of the non-tampered canisters. The caulk seals were found broken upon retrieval. The moisture weight gain of 1 gram was considerable less than the 2.7 and 3 gram gain of the other two non-tampered canisters. The basement relative humidity average was about 66%.

RUN E3 - 10/23/92 to 10/26/92 - DER TAMPERING

The PYRB had the inlet to the PRD covered with aluminum foil and held in place with a rubber band. The PYRB tracked the RGM3 almost perfectly and averaged within 1% of the RGM3. It appears that the foil had no effect upon the PYRB during this run when the radon levels were fairly consistent.

The F210 had masking and duct tape placed over all of its inlets. This unit also tracked the RGM3 very well and its average was within 2% of the RGM3 average. It appears that

covering this unit's inlets has little effect, especially when the radon levels are stable.

DMA canister #113130 had a coffee can taped over the canister. This canister averaged 85% below the non-tampered canister and its weight gain was 1.2 grams compared to the other canisters 3.8 grams. The basement humidity was around 65%. This reduced weight gain might be a flag that tampering had taken place, especially if the test location humidity is known. No tape or caulk seals were found disturbed.

RUN E4 - 10/26/92 to 10/28/92 - DER TAMPERING

The CIRAS monitor had a metal garbage can placed over the monitor. The monitor's average was 66% low compared to the PYWB. The graph shows a steep decline over the first four hours and then a consistent low bias. The caulk seal placed between the monitor and the table was disturbed which would have a raised a flag of suspicion about possible tampering.

The RAD7 had its intake connected to its exhaust by attaching vinyl tubing from one to the other. The graph indicates that this appears to have had no effect upon the performance of the unit. The radon levels were however very consistent so that the monitors ability to track changes in radon levels with this type of tampering was not able to be observed. The average of the RAD7 was 17% higher than the RGM3. No tampering was noted because no caulk seal was installed on the tubing to detect this. The internal humidity indicator recorded 0% relative humidity so that it appears that the desiccant column was included in the tubing loop.

Two fans were run in the same room as the monitors. One was on the floor and the other was on the table. The EQR ratio dropped from 44% in the previous run to 28% in this run with the fans, although during the last part of the run the EQR dropped to an unusual 15%. What produced this extra drop is not clear. It appears that fans can reduce the WL, however they do not have near the effect of covering a WL monitor. It appears that the typical variations in EQR both before and while the fans were running make it difficult to use EQR data to determine if a fan is being used in the test area.

RUN F1 - 10/30/92 to 11/2/92 - DER TAMPERING

No tampering was done during Run F1.

RUN F2 - 11/2/92 to 11/4/92 - DER TAMPERING

The PYWB had a 1" thick piece of foam placed in the inlet of the monitor. The WL average was 31% lower than the GEMW. It appears that the foam has a similar capacity as coffee filter paper to reduce the amount of decay products that reach the WL monitor's filter. This amount of reduction would not be a clear flag that tampering may have taken place.

The HPRM was moved to a location close to a small opening around an exterior basement window. Unfortunately the movement caused the HPRM to lose its data. The caulk seal was missing from the monitor to the table.

A coffee can was caulked over the top of a DMA charcoal canister. The canister averaged 80% low compared to the RGM3 average. The moisture gain for this canister was slightly

less at 2.4 grams compared to the non-tampered canisters of about 3.6 grams. The basement relative humidity averaged about 65%. This reduction in moisture uptake would probably not be enough to indicate tampering. One of the non-tampered canisters was taken outside and closed. This canister was 15% lower than the canister that was sealed up in the basement where the final basement levels were about 22 pCi/l.`

An EP also had a coffee can caulked to the table over the EP. It did not appear to have any effect upon the EP results.

RUN F3 - 11/4/92 to 11/6/92 - DER TAMPERING

The SURV had its intake tubing connected to its exhaust port. Even with this arrangement the SURV averaged 37% higher than the RGM3 average which is similar to its performance in other runs where it is not tampered with. The desiccant column appeared to have gained little moisture upon retrieval of the monitors at the end of the run. This, however, is a small flag to indicate tampering.

The TN also had its tubing connected from its intake to it exhaust. The TN averaged 74% low, which is due to the circulating air filtering most of the decay products. The graph shows the TN climbing sharply up with the other WL monitors and then falling back. At the end of the run the TN records a sharp rise up. Without the other monitors for comparison it would be difficult to see the first climb as tampering, however the final two hour sharp climb might be enough to cause a flag to be raised.

The F510B was sealed in a bag that contained outside air. This time the sealing was adequate enough to cause the monitor to drop from 15 pCi/l to 5 pCi/l over two hours. Radon slowly leaked back into the bag as the monitor slowly climbed back up to the 20 pCi/l level of the other radon monitors. The overall average was 28% lower than the RGM3 average. The tape seal from the F510B to the table appeared wrinkled, as if someone had removed it and then replaced it. Without careful observation these small indicators of tampering would probable go unnoticed. It is not likely however that a novice would be skilful enough to seal a bag of outdoor air around a continuous radon monitor.

DMA canister #113141 had so much hairspray sprayed into the canister that it completely saturated the top. The canister averaged 94% low compared to the other non-tampered canister. The canister gained 14.3 grams of moisture compared to the other canisters only gaining 4 grams. The basement humidity was 68%.

DMA canister #113131 was left open outside for one minute before closing. It measured 10% less than the other canister that was closed up in the 10 pCi/l basement.

EP #5101 had the lock clip removed. This caused the EP to average 64% low compared to the other EP's. DER attempted to re-glue the clip back together but were not successful. The clip was found broken upon retrieval. One of the dumb-bell seals was also found broken upon retrieval which would have flagged that the detector had been moved.

RUN F4 - 11/6/92 to 11/9/92 - DER TAMPERING

The GEMR and GEMW monitor had 2.3 lpm of outdoor air ducted to its front intake. Both averages were within the range of the other monitors. It appears that either outdoor air

was not coming out of the blower or the blower outlet was placed at the wrong location on the monitor.

The RAD7 had a column of charcoal hooked up to the inlet tubing. The radon levels fell from 9.7 pCi/l to 0.5 pCi/l in three hours. Over the next forty hours the radon levels stayed near zero. The radon levels at this point began to rise slightly over the next twenty hours to about 1.4 pCi/l. This is probably caused by some radon breaking through the charcoal bed. There is a sharp climb up from 1.5 pCi/l to 6.9 pCi/l during the last two hours. No disturbance to the void tape from the monitor to the table was seen. Unfortunately it is difficult to apply a seal over an inlet tube to determine if another tube is connected to the inlet. It is unlikely that a homeowner would be able to locate a charcoal filled column and attach it to the inlet of a pumped radon monitor.

The EPRIPSU #400 had one of its tubings disconnected which caused it to read 92% lower than the other EPRIPSU. No disturbance of the tubing was noted upon retrieval of the monitor.

DMA canister #113142 had a coffee can placed but not sealed over the canister. This canister averaged 60% less than the other two canisters as compared to an 80% reduction when the coffee can was sealed around the charcoal canister. The moisture gain of 1.2 grams was about half the 2.8 and 2.1 gram moisture gains of the non-tampered canisters. The basement relative humidity averaged 61%.

EP #5701 was found with its seal to the table missing. DER placed the EP in a zip-lock plastic bag. This EP did not vary significantly from the other EP's, so it appears that sealing the EP in a container or plastic bag has little effect unless it is sealed very well and the initial radon levels are low in the bag.

RUN G1 - 11/10/92 to 11/12/92 - DER TAMPERING

No tampering was done during Run G1.

RUN G2 - 11/12/92 to 11/14/92 - DER TAMPERING

A fan was run on low speed and aimed directly at the PYWB and EBLB WL monitors from five to six feet away. The EBLB averaged only 5% less than the non-tampered TN while the PYWB averaged 17% lower. This is about the same variation from the TN that these two monitors had during the previous non-tampered run.

The PYRB had a bag sealed over it that contained low radon outside air. From the graph it appears that this caused the monitor to read 60 pCi/l while the other radon monitors read up to 100 pCi/l. After twenty hours the PYRB caught up with the other radon monitors and tracked them well as the levels fell from 70 pCi/l to 50 pCi/l. The PYRB averaged close to the other radon monitors.

The EPRIPSU #300 averaged 63% less than the other EPRIPSU. It had a cloth laid over the monitor with the door partially closed. This must have caused the air to be circulated under the cloth and the decay products filtered out.

DMA canister #104723 had a hair dryer set on high directed at it for ten minutes at the end of the run. This caused the canister to read 11% lower than the average of the two non-

tampered canisters. The moisture gain was not significantly different between canisters.

RUN G3 - 11/14/92 to 11/16/92 - DER TAMPERING

F510B was wrapped up in a bag containing outside air and then taped shut. It did not appear to have any effect upon the F510B. This was probably due to the fact that the basement windows were opened a "crack". Even though the basement window was opened only a crack all of the radon monitors results dropped about 58% from 60 pCi/l to about 25 pCi/l in about four hours and then the levels stayed fairly steady till the last three hours when the levels shot back up to 50 pCi/l. This strong response to a small window being opened was probable amplified by the fact that the average basement to outdoor temperature difference was 33 degrees. This decrease in the ambient radon levels allowed the F510B to keep pace with the other monitors as they fell. It would be obvious from the graph that some over all tampering had taken place since a number of the monitors had the same sharp changes. The F510B was sealed to the table with weatherstripping caulk with noodles attached. All the seals were broken.

The other indicator of something unusual was the fact that the first floor radon levels averaged 16% higher than the basement RGM3 average. The basement CO2 levels also dropped about 500 to 1000 PPM. The radon levels and CO2 levels tracked very closely which indicates that the ventilation rate was a primary factor in the radon levels. This house in the study seemed to be able to create the largest effect from opening a window.

The basement temperature dropped about three or four degrees with the windows open a small amount and the outside averaging about 35 degrees. Once again it appears that basement temperature does not change enough with increased ventilation to be an indicator of tampering.

The TN had its pump turned off. This caused the TN to average 87% low compared to the CIRAS. The graph clearly shows that something is wrong since the TN recorded a steep drop in WL at the beginning and a steep climb at the end.

The CIRAS had a piece of 1" thick porous foam attached over its inlet. The CIRAS averaged the same as the EBLB and 11% higher than the PYWB, so it appears this foam had little if any effect. Possible it was not sealed well. During run F2 the PYWB averaged 31% low when the same type of 1" foam was wedged into the head of the PYWB intake.

The CAIRS monitor was placed in a bag and averaged 88% lower than the CIRAS monitor. No disturbance to the seals was noted upon retrieval.

A DMA canister #113801 was moved from the table and placed near the open window. The canister only averaged 29% lower than the other canisters on the table. The canister was found with the caulk seal un-stuck, which would indicate that the canister was moved. It is surprising that the average was still 20.5 pCi/l at the open basement window.

The lid of EP #9967 was closed 1/2 down and caused the EP to average 20% lower than the other EP. No disturbance to the caulk seals was noted upon retrieval.

RUN G4 - 11/16/92 to 11/18/92 - DER TAMPERING

The RAD7 was sealed with tape in a plastic tub. The RAD7 averaged 24% less than the RGM3

average. The monitor stayed around 40 pCi/l while the other radon monitors climbed up to 60 pCi/l and then back down to 45 pCi/l. A few of the noodles that were protruding out of the caulk were found to be broken, especially the ones attached to the desiccant column.

The F210 had its inlet holes taped shut. This appeared to have no effect upon the performance of this monitor. None of the caulk or noodles were disturbed.

EPRIPSU #400 had the electret inside unscrewed and capped during the run. The monitor average was 96% lower than the CIRAS average. The electret caulk seals were found missing upon retrieval which would definitely raise a flag that tampering had possibly taken place.

DMA canister #113799 had a static guard spray sprayed into the canister for 3 to 5 seconds. This canister averaged 67% lower than the RGM3. The weight gain was close to the other canisters so that less spray must have been used than the previous time this was tried.

One of the EP's had its inlet taped shut. All of the EP's averaged within about 1% of each other so it appears that it had no effect upon their performance.

RUN H1 - 11/30/92 to 12/2/92 - DER TAMPERING

No tampering was done during Run H1.

RUN H2 - 12/2/92 to 12/4/92 - DER TAMPERING

The PYRB had its inlet sealed with plumbing putty. The sealing appears to have no affect upon the performance of the PYRB as it averaged the same as the RGM3 and they tracked each other closely. The noodles protruding from the detector head that were attached with weatherstripping caulk were broken which would indicate that the monitor had been touched.

The PYWB had its pump shut off which caused the average WL result to be 87% lower than the CIRAS average. The Noodles attached to the caulk were also broken. The WL graph showed an unrealistic flat almost zero reading accept the beginning and end of the run when the levels declined and rose steeply. The printout tape also clearly showed that the pump had been turned off for most of the run.

DMA canister # 113814 had hair spray for 3 seconds. This raised the weight gain to 5.4 grams which is high because the basement relative humidity was down to an average of 57%. The canister averaged 42% low.

An EP was sealed with tape. This did not affect the performance of the EP as compared to the two other detectors. The noodles were however broken which would indicate some handling of the detector had taken place.

A fan was run again in the test room. The EQR declined slightly from 27% in run H1 to 21% EQR in the second run when the fan was operating. This is equal to a 22% reduction in the WL. The basement to first floor ratio for radon did not change much from run H1 with the fan on during run H2. The WL ratio for basement versus first floor went from 81% to 122%. Although this method might be able to spot one type of tampering it would be unlikely that two WL monitors would be available to measure both the basement and the first floor WL.

RUN H3 - 12/4/92 to 12/7/92 - DER TAMPERING

The F210 had its inlets taped shut again without any measurable affect. Some of the noodles were broken off from the weatherstripping caulk seals.

The TN had a fan blowing directly on it. This did not seem to have much of any affect upon its performance.

A can was placed over the CAIRS monitor. Although the average was 31% low compared to the PYWB, the CAIRS units were averaging about 20% low without the can sealed on the top. The caulk seals were missing upon retrieval of the monitors.

The DMA canister #113800 had hairspray used on the canister again. The canister averaged 46% low compared to the average of the two other non-tampered canisters. This caused the weight gain to be more than twice that of the other canisters. The un-tampered canisters weighed from 1.2 grams to 1.5 grams.

An EP was taped shut but again it appears to have little affect upon its performance. The caulk seal was found broken loose which would flag that the EP had been moved.

One basement window was opened 4" X 10" or 40 square inches. The average radon levels dropped only 37% from the previous run average when the windows were not opened, even though the average basement to outside temperature difference was 41 degrees. This amount of drop is not significantly different from a typical diurnal change and would tend not to be a flag that tampering had taken place.

The caulk seal to the basement window was not found to be broken upon retrieval however the basement to garage doors had both of the seals broken. It is unclear how the basement window could have been opened without breaking the seal.

The pressure measurements between the basement and the outside or the basement and the sub-floor also did not change significantly.

Interestingly the temperature in the basement actually rose two degrees as compared to the previous non-ventilated run. The outdoor temperatures were averaging 32 degrees so it appears that the furnace must have compensated for any additional fresh air.

The basement CO2 went from 721 PPM in the previous run to 650 PPM and then climbed back to 734 PPM in the final run which had no ventilation. This 11% drop in CO2 might be a small flag but would tend to be dismissed because of all the other variables that affect CO2 levels.

The basement relative humidity did decline from 57% to 50% and then returned to 59% during the next run. This was due to the colder outside air being drier and reducing the basement humidity. This, however, would not be a likely flag because basements would tend to vary in their humidity levels, dependent upon the leakage rate of the basement, available moisture and outdoor absolute moisture content.

The basement EQR ratio did drop from 21% to 17% but this would not be significant enough to be a flag of tampering.

The basement to first floor radon ratio did get closer, from 52% to 78%. This might cause some suspicion of basement ventilation.

Overall it appears that opening basement windows at this particular house does not produce the same dramatic effect as at the other houses although the size of the window opening needs to be taken into consideration. Opening the basement windows during run D4 at this same house also produced a small effect. The fact that the basement to outside pressure difference did not lessen while the windows were open also might be an indicator that the amount of opening was not sufficient to have a significant effect.

RUN H4 - 11/7/92 to 12/9/92 - DER TAMPERING

Tubing was run from the inlet of the RAD7 through the desiccant column and back to the exhaust. The RAD7 average was similar to other runs in its comparison to the RGM3. The graph indicates that the radon levels did not vary significantly during the run so that it cannot be determined if the response time of the monitor would be affected. The noodles attached to the inlet of the desiccant column were broken which would indicate that the column had been touched.

The DMA canister # 113819 was sealed with duct tape. The average was 83% lower than the average of the other two canisters. The caulk seals were, however, found to not be disturbed. The person installing the duct tape must have been very careful.

The EP had duct tape around the inlet. No difference in the readings between EP's can be seen.

RUN I1 - 1/4/93 to 1/6/93 - DER TAMPERING

No tampering was done during Run I1.

RUN I2 - 1/6/93 to 1/8/93 - DER TAMPERING

The EBLB was unplugged and placed inside a plastic bag that had been filled with outside air. The PYWB had a foam ball placed inside its inlet. The EBLB averaged 93% low as compared to the CIRAS average. The PYWB averaged 89% low compared to the CIRAS. The WL graph displays both the EBLB and the PYWB recording a steep decline over a three hour period and then recording almost no WL for most of the run. During the last hour of the run both the EBLB and the PYWB recorded a short steep climb up. The graph of this would flag that tampering had taken place. The void tape seal from the PYWB to the table was not disturbed. The void tape seals for the EBLB were however disturbed in order to place the bag around the whole monitor.

The HPRM was unplugged and moved. Unfortunately the monitor was set up with 24 hour count intervals. Only one interval was available for each day so it was impossible to detect tampering from this. The first day of this run, the HPRM averaged about 70% low. The void tape seal between the unit and the table had been disturbed which would have indicated that the monitor was disturbed.

The EPRIPSU was turned off and moved upstairs. The void tape showed that it had been disturbed. The final average was 88% low as compared to the other EPRIPSU.

The PYRB was unplugged and moved upstairs. The monitor averaged 43% low as compared to the RAD7 average. The graph displays that the PYRB took a plunge down at the beginning of the sample and then tracked closely to the first floor F510F monitor till the last two hours when the PYRB monitor climbed steeply to match the basement levels. Although the PYRB records a steep change at the beginning and end of the run, it might be seen as falling within the normal variation of radon levels. The void tape seal was however disturbed. The disturbance of the void tape provides a good stimulus to check the graph closely for unusual variations.

DMA canister #113802 was hung from the ceiling inside a mesh bag. A plastic bag that contained fresh outdoor air was placed around the canister. The detector average was low 61% compared to the RAD7 average and only gained 1.3 grams of moisture compared to the 2.3 grams of the non-tampered canister. The basement relative humidity averaged about 61% during the run. The other DMA canister, #113798 was moved to a low radon area. This detector also had a reduced moisture gain of 1.6 grams, although this moisture gain is probably not significant enough to raise a tamper flag. The canister average was 66% low as compared to the RAD7 average. No tape seals were installed on either canister.

EP #2317 was moved to a low radon area. The EPs average was 49% low as compared to the RAD7. No tamper seals were used on this detector.

RUN I3 - 1/8/93 to 1/11/93 - DER TAMPERING

The CIRAS had its inlet port carefully covered with a filter that was sealed all around the edges. This caused the WL monitor to average 76% low as compared to the PYWB average. The graph displays the typical tampering pattern of a steep drop at the beginning of the run and a steep climb at the end. The void tape seals were not disturbed between the monitor and the table. It is difficult with most WL monitors to place a tamper indicator in such a manner that it detects someone covering the inlet to the monitor with a filter and at the same time does not block the inlet.

The TN also had a filter placed over its inlet. The filter must not have been attached very well because the TN only averaged 7% low as compared to the PYWB. In addition the graph shows that the TN continued to track the other WL monitors very well during all of the test run. Since the tape seals were not disturbed it would have been impossible to detect any tampering although the tampering that was done was not effective.

The SURV was moved to the garage. The monitor average was 94% low as compared to the PYRB average. The void tape seal showed the word void at the end of the run which indicates the tape was removed and then replaced. In addition the graph shows a steep decline at the beginning of the sampling and then a continuous low reading throughout the run. Both of these factors would have indicated tampering.

The CAIRS monitor was placed in a tyvek bag. Its average was 97% low as compared to the PYWB. The seal placed between the plug and the outlet was not disturbed. No seal was used between the monitor and the table because it was felt that the constant vibration of the internal pump would disturb the seal by itself.

The DMA canister #113939 was placed in a ziplock bag as it hung from the ceiling. Upon retrieval at the end of the run, the hanging strip was observed to be torn. This canister

averaged 84% low as compared to the PYRB. The moisture gain was a low 0.9 grams, while the other canisters gained over 2 grams. The basement relative humidity averaged only 56%.

The EP #5796 was hung from the ceiling and placed in a plastic zip lock bag. It appeared that tape had been used to seal the detector because some of the tape adhesive remained on the hanging strip. This EP averaged only 12% low as compared to the average of the two other EP's. This is exactly what would be expected if the EP was sealed very tight and the radon levels were fairly consistent during the whole run.

RUN I4 - 1/11/93 to 1/13/93 - DER TAMPERING

The DER reported that they used a 2.3 LPM pump to blow outside air towards the inlet of the RAD7. This must not have been done very well because the RAD7 averaged very close to the non-tampered PYRB. The graph also indicates that the RAD7 tracked closely to the other radon continuous monitors. There was no disturbance noted to the caulk seals or noodles that projected out of the caulk next to the inlet ports.

The EPRIPSU #400 had its flow rate readjusted from 1.33 LPM to .5 LPM. This is a 62% reduction in air flow. The EPRIPSU actually decreased 68% as compared to the other EPRIPSU. No seal was placed on the flow adjustor knob.

DMA canister #113948 had a hair dryer, set on low, blowing on the canister for twenty minutes at the end of the exposure. The canister averaged 51% lower than the average of the two other non-tampered canisters. Interestingly, the canister moisture gain of 1 gram was only slightly less than the 1.2 gram gain of the other two canisters. The basement relative humidity had dropped to an average of 54%. None of the caulk seals or noodles were disturbed.

EP #5616 was moved so that it was near a leaky window. The EP only recorded a 10% lower average than the other two non-tampered EP's. There must not have been much outdoor air coming through the window crack as compared to the ability of radon to maintain the radon concentration at that location. A sheet of photographic paper was placed under the EP with the assumption that if the EP was moved, it would change to the color of the paper that was not being covered by the EP. In fact, no change was noted. The paper takes 15 seconds to begin showing some color change. If another object of similar size is placed on the same space, the color change can be prevented. If the main lights in the room are turned off the paper changes color very slowly.

RUN J1 - 1/15/93 to 1/18/93 - DER TAMPERING

No tampering was done during Run J1.

RUN J2 - 1/18/93 to 1/20/93 - DER TAMPERING

The first floor thermostat was adjusted so that the HVAC fan remained on continuously. The basement WL average dropped 35% compared to the first non-tampered run. The first floor WL average dropped 22%. The basement radon levels dropped 29% while the first floor radon average dropped 18% compared to the first non-tampered run. The basement to first floor WL and radon ratio increased from an average of 54% to about 79%. The only changes that might be significant enough to raise a flag that tampering had taken place is the close ratio

between the basement and first floor for both radon and WL. A 79% ratio would tend to indicate that the furnace air handler was on a high percentage of the time, which actually might be the case for a heat pump system during cold weather or an air conditioning system during very hot weather.

RUN J3 - 1/20/93 to 1/22/93 - DER TAMPERING

The SURV monitor had tubing connected from the monitor's inlet to the outside air. The SURV averaged 73% lower than the RGM3 average. The graph shows the SURV taking a moderate decline from 11 pCi/l to 3 pCi/l over three hours. At the end of the run, the SURV recorded a steep climb up from 11 pCi/l to 30 pCi/l. This steep final climb would be significant enough to flag a possible tampering situation. The tamper seals between the monitor and the table were not found disturbed at the end of the run. It is difficult to place a tamper seal on an inlet opening to a monitor without blocking the opening.

The CIRAS WL monitor had pot scrubbing steel wool taped over the intake to the monitor. The WL average was only 11% low compared to the PYWB average and the WL graph indicates that the CIRAS tracked the PYWB very closely. The caulk seals were not found to be disturbed. The inlet to the CIRAS is very difficult to make tamper resistant although in this case the filter material used was not fine enough to stop a significant amount of RDP's from passing through.

EP #3394 was sealed in a tyvek bag that had first been filled with outdoor air. Even though the bag had been filled with outdoor air the Tyvek is so porous to radon that the EP averaged about the same as the other two non-tampered EP's.

RUN J4 - 1/22/93 to 1/25/93 - DER TAMPERING

The exhaust of the SURV was hooked to the inlet of the RAD7. Neither monitor showed any significant difference in their readings as compared to the other radon monitors since neither unit absorbs any radon. The caulk seal however between the RAD7 and the table was found missing at the end of the run.

The F210 was placed outside. The F210 averaged 92% low compared to the RGM3 average. The graph shows that the F210 radon levels declined from 30 pCi/l to zero for most of the run and then climbed up during the last hour of the run. It appears that the background subtraction of this monitor is set too high in order for it to record a flat zero pCi/l outdoors. This type of graph would clearly indicate some type of tampering had taken place.

The GEMW and GEMR had foam placed over the back grill to the unit. This must not have been the intake to the equipment because their was not a significant difference from the other WL or radon continuous monitors. Either the foam did not filter any significant percentage of the RDP's or the filter was placed over the wrong inlet location.

EP #6550 was placed outside. It averaged 87% less than the average of the other two non-tampered EP's. Upon retrieval, new caulk that had not fully set up was discovered under the original sealant. This would indicate that the EP had been tampered with and that someone had attempted to restore the caulk seals.

EPRIPSU #400 had the EP shell closed. This caused the EPRIPSU to average 87% less than the other non-tampered EPRIPSU. Although the EP lid was closed and not detected, it was noted that the caulk sealing used at the switch was missing, which would have flagged that some tampering with the monitor had taken place.

RUN K1 - 1/27/93 to 1/29/93 - DER TAMPERING

No tampering was done during Run K1.

RUN K2 - 1/29/93 to 2/1/93 - DER TAMPERING

The PYWB had its high voltage switch adjusted from 600 to 300 volts. This amount of adjustment apparently had no significant affect upon this monitor.

The EBLB had a paper towel placed in front of its intake. The EBLB average dropped by 52% as compared to the TN. The WL graph showed the EBLB dropped sharply for the first four hours from .045 WL to .01 WL and climbed the same amount over the last four hours. Although this would appear to be tampering, actually the WL in the basement was taking a steep drop and climb at the same time as the monitor was being moved. It was just by chance that the actual WL changes corresponded to the same direction of changes that takes place during tampering. This possible erroneous interpretation about tampering is especially true in this case because the EBLB monitor had turned off before the paper towel was removed.

EPRIPSU #300 had its electret removed and placed face down on the table. The EPRIPSU average 71% low as compared to the other EPRIPSU. Caulk sealant was not placed between the electret and the EP shell, so that tampering was not detected.

DMA canister #113930 had hairspray sprayed for 10 seconds onto the top of the canister while it was inside a tamper resistant box. The box must have still been moved because the box tamper light was on, indicating that the box had been moved. The hair spray caused the canister to gain 3.5 grams versus the other canisters gaining 2.7 and 1 gram. It is unclear why canister #113919 gained 2.7 grams and averaged 14% higher than the RGM3 while canister #113915 gaining only 1 gram and averaged 60% higher than the RGM3. It is also unclear why the wide variation in canister results. The hairspray canister averaged 25% below the RGM3 average. The basement relative humidity average was a low 38%.

EP #9961 was moved to the edge of the storage room window. The EP averaged 82% less than the average of the two other non-tampered EP's.
The EP was hung from the drop ceiling with a band and lockclip. The EP, however, must have been removed by unclipping the drop ceiling since no disturbance to the tamper devices was noted upon retrieval.

RUN K3 - 2/1/93 to 2/3/93 - DER TAMPERING

The SURV was disconnected from the desiccant column. There appears, however, to be no loss of performance from this. The basement relative humidity was 57%. The caulk seals on the tubing that connected the monitor to the desiccant were found at the end of the run to be disconnected.

The TN had its flow rate adjusted from 1 LPM to 0.5 LPM. The TN average was 60% lower than the PYWB average. The WL graph shows the TN tracking the other WL monitors with a low bias. The WL graph reveals a steep climb at the end of the run that might flag a tampering situation. No disturbance of the tamper seals was noted.

The CIRAS WL monitor had filter paper placed over its inlet. The monitor averaged 27% low as compared to the PYWB. The WL graph shows the bias of the CIRAS but their is not enough variation or changes at the beginning or end of the run to indicate tampering might have taken place. The caulk seals were not found to be disturbed at the end of the run. This tampering would have gone un-detected.

The CAIRS monitor was unplugged. It averaged 91% lower than the PYWB. No sign of tampering with any seals was noted at the end of the run.

DMA canister #113927 which had been placed in the tamper cage and the EP #9961 which had been hung from the ceiling were placed in a tupperware container that had been filled with outside air. The EP averaged 7.6 pci/l versus the RGM3 average of 31.6 pCi/l which is 76% lower. The DMA canister averaged 5.3 pCi/l which is 83% lower than the RGM3 average. The tamper cage was found at the end of the run with a red light displaying instead of green, indicating that it had been disturbed. The EP must have been removed by un-assembling the drop ceiling since the hanging strip and lock tie had not been broken. It is interesting to note that the canister in the sealed tupperware gained the same amount of moisture as the non-tampered canister. During this run one of the non-tampered EP's averaged 56% higher than the RGM3 average for no apparent reason.

RUN K4 - 2/3/93 to 2/5/93 - DER TAMPERING

The RAD7 was disconnected from the desiccant column. The increased moisture from the air can cause the RAD7 to bias low. In this run, the RAD7 averaged 23% low as compared to the RGM3 average. The low bias of the RAD7 actually started to take place in the previous run when the moisture began to break through the desiccant column which must not have been changed with fresh dry desiccant. Once the moisture content of the RAD7 reached 7%, at about 5:37 AM on 2/2/93, the low bias increased till the moisture content reached 20% around seven hours later at 12:37 PM. When the desiccant column was disconnected 9:12 AM the next morning, it only increased the internal moisture content from 25% to 29%. It is obvious that the desiccant column must be kept filled with fresh desiccant to avoid producing this low bias.

The EPRIPSU #400 had its pump turned from 1 LPM flow to 0 LPM flow. The EPRIPSU averaged 89% low as compared to the other non-tampered EPRIPSU. No sealant was found to be disturbed on the flow control knob either because no sealant had been installed or it was not observed at the end of the run as being broken or missing.

It appears that DMA canister #113921 was covered by the tupperware container since it had the lowest result. The average of this canister was 67% low as compared to the RGM3 average. Unfortunately it was not labeled if this was the canister that was initially placed in the tamper cage and the tupperware container was then placed over the top of the cage. The cage light was still green at the end of the run, so it appears that the cage was not moved. The unusual thing about the result is the moisture weight gain of 2.6 grams for this canister is almost twice the gain of the other two canisters, which was 1.4 and 1.0 grams. It is also unusual that canister #113916 had a 32% high bias.

EP #9961 that was hung from the ceiling tiles with a tamper strap and lock tie had its electret removed, placed on the table and covered with a can. This EP averaged 91% low as compared to the average of the two non-tampered EP's. Either a caulk seal was not applied to the electret to detect someone removing it or it was not noticed at the end of the run that the seal had been broken.

The furnace fan was left on during this run. It appears that this makes little difference. This is probable because during the previous run the furnace run time averaged 79% and in this run the data logger recorded that it increased to 96% run time.

RUN L1 - 2/8/93 to 2/10/93 - DER TAMPERING

No tampering was done during Run L1.

RUN L2 - 2/10/93 to 2/12/93 - DER TAMPERING

The PYRB had its high voltage setting changed from 6.0 to 2.0. This caused the PYRB to average 50% low as compared to the RGM3 average. The graph of this shows no decline at the beginning of the run but there is a steep climb from 25 pCi/l to 45 pCi/l over the last two hours of the run. This steep climb might be enough to flag that tampering had possibly taken place. No caulk tamper seal was used on the high voltage setting knob. It would be an unusual person who would know which knob to turn and how much to turn in order to reduce the instrument response.

The HPRM was moved out to the garage. It averaged 96% low as compared to the RGM3 average. Because of the four hour counting intervals, it is not possible to see the decline or rise as the unit is moved out of and returned to the basement. The tamper indicator on the printout shows that the monitor was moved on a number of occasions. This would definitely flag that tampering might have taken place. Also, the current light was blank, which means that the power was lost or disconnected near the end of the run. Upon retrieval, the caulk seal and void tape were found to have been disturbed. The broken caulk seal would lead a tester to investigate the tilt indicators of the printout sheet more closely.

The PYWB had its pump turned off and it averaged 93% lower than the CIRAS. The graph, however, clearly shows that tampering has taken place because the WL drops steeply from .05 to 0 WL and then the last three hours it climbs steeply up. In addition, the data print out from the PYWB marks each hour the pump is either on or off. The sudden reduction of WL to zero would alert a good tester to check the printout tape if the pump was operating since a pump failure could have caused the same response.

The EPRIPSU was unplugged. This caused the unit to average 82% low compared to the CIRAS. During this run there was a caulk seal on the plug and it was found broken upon retrieval. The broken seal along with a very low result would definitely flag that tampering may have happened.

EP #9967 had a tupperware carton sealed over it that had been filled with outdoor air. The EP averaged 72% low as compared to the average of the two non-tampered EP's. The EP must have been placed in the carton in such a way so as to minimize room air entering the carton and then sealed especially well in order for this tampering to have worked so well.

The caulk seal was, however, found broken between the detector and the table. Possibly they took the EP outside in order to accomplish a better filling of the tupperware with outdoor air and then sealing it in. If a person did not want to leave the EP outside, this technique could work quite well. The only way to detect this from happening is to have a tamper seal or lock tie that doesn't allow the EP to be moved without breaking the seal.

DMA canister #113925 was placed in the tamper cage at the beginning of the run. Hairspray was sprayed for ten seconds into the canister through the cage. The canister averaged 38% lower than the RGM3 average. A large percentage of the hair spray must have made it through the cage into the canister because it gained 4.3 grams of moisture as compared to 0,7 and 1.6 grams of moisture gain for the non-tampered canisters. Upon retrieval, the cage light was still green, which means that it had not been moved. The other two DMA canisters for some unexplained reason averaged 24% and 41% higher than the RGM3 average.

The RTCA canister #1362964 was placed in a cage supplied by RTCA. The cage was sealed on the outside with duct tape. This caused the RTCA canister to read 70% low as compared to the average of the other two non-tampered RTCA canisters. The cage that the canister was placed in was not found disturbed upon retrieval.

RUN L3 - 2/12/93 to 2/15/93 - DER TAMPERING

The TN and the CIRAS both had paper towels carefully taped over the inlets. The CIRAS was effected to a greater degree than the TN. This is probably due to the fact that the TN flow rate of 1 LPM is eight times greater than the CIRAS flow rate of .125 LPM. The greater flow rate of the TN pulls a higher percentage of the RDP's through the slight filtering of the paper towel. The CIRAS averaged 22% low while the TN averaged only 9% low as compared to the GEMW. Both monitors tracked the other WL monitors but with a low bias. It might be noted that for an unexplained reason the PYWB biased 40% high this run and 32% high for the next run.

The EPRIPSU #300 had a paper towel taped over its inlet. The EPRIPSU average, however, was 26% greater than the GEMW average. Possibly the pump flow rate went out of adjustment and compensated for the loss due to the extra filtering.

The F510B was moved so it would be right next to the closed basement window. This caused the F510B to average 34% low as compared to the RGM3 average. The graph shows the bias, however it does not indicate any tampering because the initial drop did not take place because the radon levels spiked up at the beginning of the run which tended to correct for this. The movement of the monitor back to the center of the basement at the end caused too small of a change to be noted as unusual. It might be noted that the F510B does tend to seesaw more as it tracks the radon levels next to the window but this would not likely indicate tampering. The tampering indicators on the printout sheet marked the first hour and the second to last hour as having been tilted. The first hour tilt would probable not draw must suspicion because it is easy to bump the monitor after it is programmed. The final tilt would, however, be suspicious because it happen a full hour before the data was retrieved from the monitor. A thorough evaluation of this printout record by the tester would reveal this, especially if a tamper seal between the detector and the table was also found to be broken. The temperatures recorded by the monitor are another indicator that the monitor was being exposed to outdoor air. The monitor temperature started at 68 degrees but quickly fell to 62 degrees and then down to 58 degrees. At the coldest point the monitor measured 54 degrees, which is well below the normal basement temperature.

EP #9961 and EP #9835 had their lids taped as far down as they would go with the lock tie still in place. One EP was 35% low and the other was 27% low as compared to the non-tampered EP. This type of tampering could easily be done without the tester knowing although the reduction may not be great enough to obtain the desired result. An alternative method would be to place one of the thin noodles through the drilled hole in the lid stem with some caulk to hold it in place. Any movement of the lid would break the noodle.

Five DMA charcoals were placed in a tight circle to determine if they would bias each other low from such close proximity. The opposite took place. DMA canister #113957, placed in the middle, surrounded by four canisters, gave the highest average, 3% higher than the RGM3 average. The surrounding canisters averaged 3%, 7%, 11% and 12% less than the RGM3 average. The variation in results was inverse to the moisture gain of the canisters which varied from .5 to 1.9 grams. As the moisture gain increased the canister results decreased. This may indicate that the lab is not making corrections for moisture gain below 2 grams. This amount of moisture gain is within the same range of moisture gain of non-tampered canisters exposed during the two previous runs at this house. It is interesting that the center canister had the least moisture gain as if the other surrounding canisters did reduce the moisture uptake of the center canister.

An RTCA grab sample canister #6002657 had room air pumped through the canister for ten minutes. The canister reported a result of 35.7 which was 18% lower than the RGM3's 43.7 pCi/l displayed on the monitor during the same time period.

A number of RTCA canisters were sealed in containers of varying sizes in order to determine what effect limiting the volume of the test area would have upon charcoal detectors. A 4" open face canister #1362933 was sealed in a 68.2 liter plastic container. The initial radon levels in the room as measured by the RGM3 were 43.7 pCi/l. The canister averaged 83% low or 7.5 pCi/l. A similar test was done with canister #1362922 in a smaller 6.5 liter plastic container. The result was a 98% reduction, giving a 0.8 pCi/l result. Two and one half inch RTCA diffusion barrier canisters were also placed in small plastic containers. RTCA canister #1386405 was sealed in 1.15 liter container. This caused a 98% reduction, giving a 0.8 pCi/l result. A diffusion canister #1386418 was sealed in a .35 liter container that caused the canister to average 99% low with a 0.5 pCi/l result.

RUN L4 - 2/15/93 to 2/17/93 - DER TAMPERING

The basement window was opened 10" by 14", for a total of 140 square inches. The average radon levels dropped 47% as compared to the previous run while the WL average dropped 73%. The average EQR decreased from the previous run's 29% to 19%. This decrease is still less than the other houses that had decreases of 74% to 84%, but the total basement window opening was two to five times larger.

The CO2 average decreased 21% from 771 PPM to 610 PPM. Interestingly the first floor CO2 levels decreased by 23%, slightly greater than the basement. The graph that over lays the basement CO2 levels on the radon levels shows a very close tracking of the two. This tends to indicate that the radon levels correspond closely to the ventilation changes in this basement.

The outside temperature averaged around 34 degrees for this run and 33 degrees for the previous run. The basement average temperature went from 70 degrees for the previous run to an average of 63 degrees for this run with one basement window open. This was the only

time during the study that temperature measurements might have been able to indicate tampering, although without a background measurement even this example would be difficult to use as a tamper indicator since 63 degree basement temperatures are not unusual. This is especially the case since the first floor temperature decreased almost the same amount, which tends to indicate the temperature drop was due to the thermostat being turned down rather than the basement window being opened.

The basement average relative humidity of 33% did not change from the previous run as one might expect with the increased amount of cold, drier air entering the basement.

The basement to outside pressure difference which had been averaging from .010" to .013" of water for the previous three runs, now dropped to .005. Without having a background measurement to compare it to, this measurement would not indicate tampering.

The ratio of first floor to basement radon had been averaging from 44% to 49% during the first three runs. During this run the ratio between floors jumped to 97%. This might raise enough of a flag to investigate other tamper indicators more closely.

Two RTCA grab samples, canister #6002664 and #6002476, were taken in the test room near the RGM3. The grab results of 23.3 and 22.5 are 13% and 16% lower than the RGM3 reading of 26.8 for the same time period. This low bias compares with the previous run low bias of 18%.

A number of DMA and RTCA canisters were again sealed in varying size containers. A DMA canister #113928 was sealed in a 68.2 liter plastic container. The initial radon levels in the room as measured by the RGM3 were 26.8 pCi/l. The canister averaged 83% low again as in the previous sealing of a canister in this size container or 4.5 pCi/l. A similar test was done with RTCA canister #1362884 in a smaller 6.5 liter plastic container. The result was again, as in the previous run, a 98% reduction, giving a 0.5 pCi/l result. RTCA canister #1362856 was sealed in a 1.15 liter plastic container. The result was a 98.5% reduction or a 0.4 pCi/l result. A two and one half inch RTCA diffusion canister #1386407 was placed in a small 0.35 liter plastic container. This caused a 99% reduction as produced in the previous run, giving a 0.2 pCi/l result. A DMA canister #113926 was sealed in a .41 liter container. This caused the canister to have no net counts produced at the lab, or a 0.0 pCi/l result. It would appear that the lab was using too high of a background subtraction for this to take place. Both of the DMA canisters that were sealed in plastic containers had moisture weight gains of .4 and .3 grams which is less than half of the .9 gram moisture gain of the non-tampered canister. The basement had a low 33% relative humidity. If the basement temperature and relative humidity is known, it is possible to know how much moisture gain can be expected and significant deviations from this could be an indication that tampering had taken place.

FINAL CONCLUSIONS FROM THE STUDY

I - TAMPERING OCCURRENCE

The first question to be raised is whether tamper resistant features or methods need to be included in a test at all. This question is important because some of the methods and equipment reviewed will obviously complicate the measurement process, increase the measurement cost and make measurements that are not tamper resistant suspect. Some testers feel that the use of tamper resistant features increases any skepticism the public may have about the integrity of a short term measurement, especially one done during a real estate transaction. If there is a 1% risk of someone tampering with a measurement, is it worth

all the costs to make all measurements tamper resistant? As the public becomes more knowledgeable about radon and how it is measured, will there be more tampering?

On the other hand, if a tester cannot assure his customer that the proper test conditions were maintained during the test, what value is the test? Is not the reason for using a professional tester that is EPA listed so that the measurement will be done according to EPA and DER protocols? One should keep in mind that tampering often happens inadvertently because someone disturbs the necessary test conditions without knowing that he has done so? This may in fact be the larger percentage of tampering.

The EPA in the latest protocols has specified that testers shall verify that proper test conditions are being maintained. The protocols have listed equipment and methods that might accomplish this although they have not specified what should or should not be used.

The objectives of this study were to first determine what affect altering test conditions or equipment might have upon the final test results. This in itself was a major undertaking because radon measuring equipment itself gives varying results depending upon the detector used, the condition of the detector and the conditions to which it is subjected to. Although specific instruments were designated to be the reference and were not tampered with, they themselves would occasionally produce results that were suspect. No instrument could be counted on to always produce the correct answer. Every monitor except the Pylon with the PRD attachment, the Femto-TECH 510 and the Gemini WL monitor had at least one measurement that was greater than 20% from the reference. This conclusion emphasizes the need to always maintain good quality control and quality assurance procedures to limit the uncertainty of measurements.

In general the active monitors had greater precision than the passive detectors. The TN, CIRAS and HPRM had only one measurement outside 20% after correcting for bias. The RAD-7, EBL, GEM-RN, F210, SURV, and EP's averaged from 5.3% to 8.5% of the measurements off the mark greater than 20%. The PYL-WL and EPRIPSU's had 13% and 16% of the measurements off greater than 20%. The CAIRS had a 25% low bias and 23% of its measurements were off greater than 20%. The Radon Alarm had a 55% low bias and over 80% of the measurements were off the mark greater than 20% if the bias was corrected. The DMA canister had an overall average of 26% of its measurements greater than 20% off. The percentage for the DMA canisters was however only 15.7% before run H, which began on 11/30/92. For runs H through L, from 11/30/92 to 2/17/93, the percentage off increased to 38.3%. This is almost two and a half times worse and seems to indicate that the lab must not have been functioning as well as before.

Along with good QA/QC and tamper resistant features, this study showed clearly that making multiple measurements in the same location dramatically increases ones confidence in the accurateness of the final result and helps to disclose problems quickly.

The other objective of the study was to determine the effectiveness of different tamper resistant methods or equipment and to determine which methods were inexpensively and easily accomplished. If the testing industry is to embrace the use of tamper resistant features, it needs to be given techniques that are not only effective but are easily implemented.

II - TAMPERING METHODS

Producing a low radon result can be accomplished by exposing the detector to a lower radon/WL concentration or by altering the detector performance.

1 - LOWERING RADON/WL CONCENTRATIONS

Reducing the radon concentration is primarily accomplished by diluting the air the monitor is sampling with outdoor air. This is most easily accomplished by opening windows or exterior doors but can also be accomplished by moving the detector to a low radon/WL area or by pumping outside air directly to the detector.

A: Opening Windows and/or Exterior Doors

Opening basement windows was one of the easiest and most effective ways to reduce the radon/WL concentration. It appears that the effectiveness depended upon the amount of window area opened. In the two story house, run B4, a 242 square inch (si) opening dropped the radon 85%. In the split level house the radon levels only dropped 29% in run D4 with a 48 si opening, 37% in run H3 with 40 si and 47% drop in run L4 with 140 si opening. The ranch house dropped 74% during run A4 with 720 si opening. The other two story house dropped 84% in run C4 with a 624 si opening.

The change in basement negative pressure as compared to the outside was inconsistent. In most cases the larger the window opening, the greater the basement to outside pressure reduction but in run C4 with 624 si opening there was not a measurable pressure difference even though the radon levels went down 84%. In run B4 with 242 si opening the pressure difference was reduced by 66% and the radon levels went down 84%. In run D4 with 48 inch opening the pressure difference was reduced about in half with a 29% radon reduction.

Large increases from ventilation can typically be detected with continuous monitors as dramatic shifts in radon or WL's. It would be difficult, however, to detect tampering if the basement windows were opened before the test is begun and then only closed for the time the tester is at the house either leaving or retrieving the detectors. Window seals can, however, be an effective method to detect this type of tampering.

Opening upstairs windows had a much smaller affect upon basement levels. In the four runs where only the first floor windows were opened, the basement reductions were as follows; run A3 -15%, run B3 -20%, run C3 -9%, E2 -0%. The smaller reductions of run C3 and E2 were probably due to the fact that the owner did not keep the first floor windows open consistently. It is obviously more difficult to leave first floor windows open if the building is occupied and the outdoor temperatures are cold.

B: Diverting Outdoor Air to Detector

Three of the continuous radon monitors and all of the WL monitors have pumps for sampling the air. If the detector's inlet can be easily connected to additional tubing such as with the Surveyor, RAD7, and RGM3, a piece of tubing can be run from the detector inlet to an outside source of air. It is actually not even necessary with this technique to open the basement window which may have a tamper seal in place. The tubing inlet can be simply placed close to a crack around a window that is letting outdoor air in. The tubing will effectively be sampling outdoor air without disturbing the window seal. This type of tampering is typically detected by observing a dramatic drop in the levels at the beginning and or end of the exposure. During run J3, the Surveyor inlet was connected to tubing that was run to the outside. Although the initial drop was not dramatic you can see a sharp

climb up with the Surveyor during the last two hours of the sampling. This caused a 73% drop in the reported results although it still averaged 6.1 pCi/l which is well above ambient. During run A4, tubing was run from both the RAD7 and the Surveyor through the rear window to the outside covered porch. At the same time the basement windows were opened. The RAD7 and the Surveyor compared to the RGM3 dropped 12% and 20% as compared to their previous relationship to the RGM3 in the previous run. This reduced effect is partially due to the fact that all the monitors dropped because of the windows being opened but this does not explain why these two monitor did not reach ambient radon levels. It appears that some basement air was still entering the monitors.

Running tubing from the inlet of a monitor to the outside is more than a typical homeowner would manage to do to tamper with radon monitors. It would be unlikely that he would have the correct tubing size available nor the resourcefulness or desire to go to such extreme.

A small air pump was used to bring outside air directly to different detectors. This degree of sophistication would also not be expected of an average homeowner. It was tried on run I4 with the RAD7, however it did not appear to work in this case. It was tried a second time during run K2 on the HRPM and unfortunately the data was lost.

C: Moving Detector to Low Radon Environment

Obviously if you move a radon detector to the outside you will achieve a large reduction in the radon result. This was tried four times with E-PERM's and produced a 49% to 87% reduction. During run I2, a charcoal canister result was 66% low from being moved outside and its moisture gain was not significantly different from the non-tampered canisters. During run G3 a canister was moved in front of a basement window that was open a crack. This resulted in a 29% drop in its average although the weight gain was 5.8 grams compared to the average of the other non-tampered canisters gain of 3.2 grams. Canister weight or gain may be an indicator of tampering. The Surveyor, F210 and HPRM were moved to the outside causing a drop exceeding 90% in each case. This movement could be typically detected with continuous radon monitors that report hourly averages because the radon levels would change dramatically at the beginning and end of the exposure. The HRPM would depend on its tilt indicator to detect this type of tampering A passive detector would required tamper seals or tamper box in order to flag that it had been moved.

During run D4, the canister was exposed to the outdoor air for 55 minutes and then returned to the basement for another hour before it was sealed up at the end of the run. This only caused a 10% reduction. During run F2 and F3, single canisters were taken outside and aired out for a few minutes and then sealed up. These canisters were 15% and 10% lower than the other non-tampered canister that was sealed up normally in the basement. The slight difference in results may be due to the fact that the radon levels had been dropping through run F3 which only had a 10% reduction. There was not a significant decrease in moisture weight gain from this airing out of the canister.

D: Agitating Air

The WL concentration can be reduced by agitating the air in order to increase the plateout of RDP's. The effect of agitating the air with a standard room fan varied from as little as a 4% reduction during A2 with the fan on the floor, to as high as a 65% reduction during run C2. In the seven times this was tried a typical reduction of the WL was 22% to 39%. There was 39% reduction in run A2 and a 37% in run E4 when two fans were used. Using two

fans does not appear to give a significantly improved reduction in WL compared to using one fan. The use of a window fan in the room is very difficult to detect.

Twice the furnace fan was set to continuous on operation. In run J2 this reduced the WL by 35%. In run K4 it made no significant reduction to the WL's at all. This may be due to the fact that house K uses a heat pump system with the furnace fan running far more continuously than if it had a combustion fuel furnace. It appears that the furnace operation only increased from 76% to 96% in run K4 and thus their was a very limited increase in agitation of the air. During run G2 a fan was directed at the EBL WL monitor from five or six feet away but it did not appear to affect its performance as compared to the other WL monitors. The overall basement EQR did decrease from 48% to 23% which is a 52% reduction. During run H3 a fan was directed at the TN monitor but it appeared to have no effect. The EQR dropped from a previous average of 24% to 17% which is a 29% reduction. This house is difficult to understand because the first floor EQR was often twice that of the basement.

E: Filtering Room Air

No air purification filters were run in the same room as the detectors during the study.

2 - ALTERING EQUIPMENT PERFORMANCE

A: Bags, Buckets, and Coverings

Different bags, buckets and coverings were placed over or around the different detectors. In general, all the WL monitors were dramatically affected if they were placed within a confined space because the detector's air sampling acted like a filtering system and quickly reduced the RDP's.

The effect of covering the monitor ranged from a 30% reduction with the EBL during run A2 when it was placed in a garbage bag to a 93% reduction for the TN during run D3 when it was sealed in a five gallon bucket to the table. When the TN was placed under the bucket without sealing it to the table during run D2, it caused a 70% reduction. Even sealing a WL monitor under a metal garbage can as with the CIRAS during run E4 was enough to drop the WL by 66%. One of the CAIRS detectors was placed in a tyvek bag which is porous to radon but not WL during run I3 and it dropped the response by 97%.

The charcoal detectors were covered in all manners and fashions during the study. In general charcoal detectors are very susceptible to being placed in a confined space because of their characteristic of adsorbing radon out of the surrounding air. During run L3 and L4, charcoal canisters were carefully sealed in various size containers. The initial radon concentrations in the air were noted at the time of sealing. If the container was as small as 12 or even 39 ounces, the radon average decreased 98 to 99%. Even with containers as large as 68 liters, the radon average was decreased by almost 80%. It appears from a rough calculation that charcoal adsorbs about 2000 times its volume from the surrounding air. To check if the adsorption of radon would be affected if canisters were placed next to each other, five canisters were placed side by side while still being open to the room air. The adsorption of radon by the canisters did not however appear to affect each others adsorption of radon although there was a slight less moisture take up from the middle canister. This slightly less moisture take up may have contributed to the center canister averaging 11% more than the average of the canisters that were placed around it.

Overall any covering or bagging of the charcoal canisters caused a significant drop in its performance. The least drop caused from covering the canister was 40% during run A3 when just a magazine was laid on top of the canister. Typical reductions from covering or bagging the canister was from 64% to 85% reduction.

Hair spray was laid on top of the charcoal canisters at the beginning of a number of runs in order to slow down the diffusion into the canister. During run A2, a five second spray of hair spray was sprayed into both DMA canisters. They both gained extra moisture as the previous average gain of 5.5 grams went to 8.6 and 10.9 grams in this run. This caused a 29% drop in the average compared to the previous run. A 3 second spray at the start of run H2 caused the moisture gain to go from 1.6 grams to 5.4 grams and dropped the average result by 42%. During run G4, static guard was sprayed onto a canister for 3 to 5 seconds which caused the canister average to drop by 67%. This canister, however, did not appear to gain any additional weight from this. During run F3, so much hair spray was applied to the canister that its weight gain was 14.3 grams compared to the average 4 gram weight gain of the other non-tampered canisters. This large amount of hair spray caused this canister to average 94% low.

The use of a hair dryer for ten minutes on high at the end of an exposure blowing onto the charcoal was tried during run G2. This caused an 11% reduction. During run I4 the hair dryer was again used but for twenty minutes. This time the canister averaged 50% low.

E-PERM's were placed in zip-lock bags, wrapped in foil, placed under metal cans, moved into drawers. In most cases this appeared to have no affect upon its performance. If the container that the E-PERM was placed into was able to be completely seal from radon entry or exit, then sealing it is the equivalent of a grab sample. A grab sample over a two day exposure will lose approximately one quarter of the radon, which would give an average reduction of approximately 13%. It appeared that the zip-lock bags could seal out radon while aluminum foil and tape over the inlet was not effective at stopping it. If the container was radon tight than the initial radon levels at the time of sealing are significant. During run K3 and L2 the tampered E-PERM's were taken outdoors and sealed in Tupperware containers and returned to the basement. This caused a 72% to 76% reduction in the final average.

Numerous coverings and seals were used on the continuous radon monitors to determine if their performance could be altered. In general, if the detector was placed in a bag or had its inlets blocked it made little difference upon the performance. Since the detector removes no radon from the air, it does not take much of a hole to allow radon to enter the container and replace what small amount has decayed away. Occasionally, the radon levels would take a sudden change such as in run A4. The Pylon, with the PRD attachment, had its inlet covered with Saran wrap which caused a 16 hour delay before it caught up with the changing radon that the other radon monitors were measuring. During run F3, the F510 was taken outside and placed in a bag and then returned to the basement. This caused a 28% reduction of the F510 average which did finally catch up with the other continuous radon monitors.

B: Charcoal or Paper Filters

During run F4, the RAD7 inlet had a charcoal filter placed in line. This caused the RAD7 to average 95% low.

Paper filters of different capacities were placed in front of the inlets to the WL monitors.

Coffee filters were used with the Pylon WL monitor during run A2 and B2, and were installed with tape on the TN WL monitor during C3. This caused an 11% and 36% reduction for the Pylon and a 22% reduction for the TN WL monitor. During run C2, the coffee filter attached to the Pylon WL monitor must not have been installed properly because the average was 5% high.

Paper towels were used for filters for the TN and CIRAS during run L3, which reduced the WL average by only 9% and 22%. A paper towel, however, was taped over the EBL WL monitor during run K2 and it reduced the level 52%.

During run F2 and G3, 1" foam was placed over the Pylon WL monitor and the CIRAS. The average was reduced 31% and 0% as compared to the previous run. This difference might be explained by the fact that the filter fits tightly into the Pylon WL head adaptor and the air flow for the Pylon was set at 1 lpm. The CIRAS slits in front of the monitor are more difficult to cover with a filter and the air may have been by-passing around the filter. Another possible explanation might be that the air flow for the CIRAS is only 0.125 lpm which would tend to capture less RDP's. During run J4, 1" foam was taped over a rear port of the GEMWL monitor but this must not be the actual intake because their was no reduction in its performance.

A piece of dish cleaning steel wool was placed in front of the CIRAS for run J2 and it only reduced the WL by 11%.

Regular filter paper was placed or sealed over the inlet ports during the following runs with the following WL monitors. The Pylon WL monitor averaged 28% and 83% low in run E2 and D4. The CIRAS averaged 27% and 76% low during run K3 and run I3. For an unexplained reason the TN in run A4 and run I3 averaged only 16% and 7% low compared to the reference WL monitor. The EBL WL monitor averaged only 14% low in run A3 with a pre-filter. The difference in reductions in the above results is probably due to how complete the inlet opening is sealed with the additional filter or possibly with the quality of the filter used rather than the type of monitor the extra filter was added to.

C: Removing Tubes or Connecting Exhaust Ports to Inlets

The EPRIPSU box could not be closed because the electrical cord was in the way. The most recent version of this unit has changed that deficiency. It is possible to now place a tamper seal on the edges of the lid to keep someone from removing the electret or any one of the tubings. This type of tampering can easily cause a 90% reduction in the result which without the tamper seal would go undetected.

The exhaust port of the TN WL monitor was connected to its inlet during run F3. This caused the average to be 74% low. The ramp up and the decrease at the beginning of this run was not dramatic enough to be suspicious. The final two hours of the run did revealed a ramp up in WL that was still not distinct enough to definitely highlight possible tampering.

The RAD7 during run H4, the Surveyor during F3 had their inlets hooked to the exhaust and

neither result was significantly different from the previous run. During run J4, the RAD7 had its inlet hooked to the Surveyor exhaust without any significant alteration in its performance. During run K4, the RAD7 had its desiccant column unattached. This caused the average to fall by 23% from the RGM3 average. The printout revealed that the internal moisture level went above the recommended level and this moisture change may have flagged the tester that a problem had occurred which would affect the test results. No sign of tampering was seen with the caulk and noodle seals.

D: Turning off or Changing Pump Flows

The EPRIPSU and the CAIRS were easily tampered with during run C2 and L2 and during K3, by removing the plug or turning off the power to the outlet. This deficiency has been corrected with new versions of the EPRIPSU by installing a timer clock that records the number of hours that the pump was operating. The pump was turned off on the Pylon WL monitor during run H2 and L2. The pylon printout, however, records pump on time so this type of tampering can be spotted. It is also suspicious when the WL drops to 0 for all of the run except the very beginning and end. The TN also had its pump turned off during run G3. Although the TN printout does not indicate pump on time there was almost no measurable WL while the pump was off, with steep climbs at the beginning and end of the run.

The pump flow rate on the WL monitors can be reduced unless a tamper seal is placed over the adjustment screw or knob. During run I4 and K4, the EPRIPSU had its normal pump flow rate of 1.33 lpm reduced to 0.5 and 0.0 lpm and this caused the average to be 68% and 89% low. The TN had its pump flow rate reduced from 1.0 to 0.5 lpm and this caused the monitor to average 60% low.

The Pylon WL monitor showed no loss of performance when its high voltage switch was adjusted from 600 volts to 300 volts in run K2. During run L2 the Pylon radon monitor's voltage was turned down to 200 volts which caused it this time to average 50% less. It appears there is a threshold were voltage adjustment final makes a significant difference on the monitor performance.

The EPRIPSU shell was closed during run J4 and the average result dropped 87%. A clip seal had to be broken for this to happen. The new version of the EPRIPSU would have had a broken lid seal. All the EP's had clip seals through the spring closures to keep the lid from being closed. During run F3, the clip seal was cut and the EP closed to give an average that was 64% low. Careful inspection of the broken clip seal upon retrieval would reveal that it had been cut. During run L3, two of the EP's were closed down as far as possible without breaking the clip seal by using duct tape to hold the lid down. This caused the EP's to average 27% and 35% low. A tamper seal of the EP to the table may or may not be broken by such a method. During run G3, the EP lid was closed down half way and this caused a 20% reduction in the final average in comparison to the other non-tampered EP's.

During run K2, the electret was removed from the bottom of the EPRIPSU and placed upside down on the table. This caused the EP averages to be 71% low. The caulk seal was found missing between the electret and the shell which indicates some tampering had taken place. During run K4 the electret was removed and covered with a metal can. This caused the EP average to be 91% low. The caulk seal was again found missing.

II - TAMPER RESISTANT TECHNIQUES

1 - TAPE SEALS

Tape seals can be an effective method for ensuring that windows are not opened, radon detectors are not moved, and unused doors are not opened. A number of tape seals were tried. Some worked well while others did not. It is important that the surface that the tape is sealed to is clean. Some furniture polishes or a silicone oil spray will leave a slick film on the surface that makes it difficult to attach the tape or for the void wording to attach itself to the surface. The tapes will, however, stick to most surfaces although the surface around a typical basement window will need to be cleaned first. Basement exterior doors can also be sealed, since no one should be using this door during the test. It is questionable if all the first floor windows should be sealed if the test is being run in the basement. Opening the first floor windows reduced the radon levels in the basement only 10 to 20% while opening basement windows caused as much as an 85% reduction.

A: Equitron Tape

The Equitron tape is manufactured just for tamper detection. It is partially sliced so that after it is in place, any attempt to remove it might cause it to be easily torn. It works well as a tamper seal, however it has a major fault. Once it is firmly pressed into place, it does not come easily off. The tape also tends to shred as it is removed which makes removal difficult and time consuming. The extra effort to remove it might end up damaging the surface it is attached to.

B: Void Tape

Both the void tape sold by RAL and RTCA was used. Any attempt to remove this type of tape after it is in place will cause part of the glue to separate from the tape spelling the word "void" on the surface. Even if an attempt is then made to replace the tape in its exact location, the word "void" still reads through the tape. It is helpful to use a flashlight to carefully inspect the condition of the tape upon retrieval of the detectors. The void lettering that is left on the detector and the surfaces after the tape is removed can be rubbed off the surface with a rubber eraser.

C: Office Tapes

There are numerous types of tapes that are sold in office supply stores that could be possibly used for a tamper seal. A number of these types of tapes or seals were used. Plan scotch tape was tried. If it is carefully sliced in the middle so that only a small portion is left, it is difficult to remove without tearing. This type of tape, however, can be duplicated easily. Other more unusual seals were tried. One tape was in the shape of a small dumbbell. The smaller center section of the seal made it likely to be torn if removed. This tape can however be removed and replaced without marking the tape if one is extra careful. To reduce the possibility of someone removing the dumb bell seal, a small amount of white acrylic latex caulk was laid over both edges of the tape. Although this made it more difficult to remove, it was removed on two occasions without being detected. A better caulk might remedy this situation.

Standard double stick tapes can be used to reduce the chance that a canister have something placed directly on top of it. If two separate loops are arched over the canister

so that one loop is higher than the other and not touching it is difficult to place anything on top of the canister and still maintain the tape in its original condition. This method does not however prevent someone from placing a container over the tape and canister.

2 - CAULK SEALS

A: Acrylic

Acrylic caulk was used to seal the office supply tape seals. It was also tried as a stand alone window/door seal. Although it was effective for this, it was difficult to get off the woodwork after being in place for 2 to 3 days.

B: Weatherstrip Caulk

Weatherstrip caulk is used to weather seal openings such as around double hung windows. The caulk sticks lightly to the surface but can be removed easily without damaging any existing woodwork, even if it has been in place all winter. The caulk used in this study is manufactured by Red Devil although there are other companies that manufacturer similar products. Its easy application and removal makes it ideal as a window, door, and monitor seal. A small amount is placed on the surface the detector is to be placed on. The detector is placed onto the caulk. Without some type of seal it is easy to move the detector to a low radon environment or to even remove the electret and place it upside down on the table.

For windows and doors, a small amount is spread across the window or door frame. Upon retrieval of the detector, each seal is gently pressed to ensure it is still adhered to both surfaces. It is then simply pulled away. The caulk that is removed is checked for consistence to determine if fresh caulk was attempted to be reapplied. The caulk did not appear to leave any marks on any of the surfaces during the study.

C: Sorba Noodles

Two of the most difficult detectors to protect against serious tampering is the WL monitors and the charcoal canisters. A completely satisfactory method of protecting the WL monitor inlet was not found. If the WL inlet is pre-filtered or diverted to outside air, large reductions are possible in its performance. To try to safe guard against this, the weatherstrip caulk was used to hold Japanese sorba noodles in place. The noodles are inexpensive, very thin and tend to break easily. The idea is that any attempt to hook a pre-filter or fresh air tube to the inlet would cause the noodle to be touched and most likely broken. This worked with limited success. The exact location and length of the noodles needs to be documented each test so that any small changes can be noted upon retrieval of the detector.

Preventing or detecting someone from placing an object on top of a charcoal canister or a container over it was a difficult. There are a number of cages now being manufactured but a tester might not have one available for every test. One low cost solution, although it was rather awkward, was to place a small amount of caulk on the side of the canister and run sorba noodles straight up and out. This made it difficult to cover the canister or place something on top of it. A container larger than the height and width of the noodles might be used. This deficiency could be remedied by placing the canister so that it hung

over the edge of the table, chair or stand that the canister was attached to. Careful notation of the location and position of the noodles was necessary to ensure accurate analysis upon retrieval.

3 - DETECTOR PLACEMENT

Placing the detector in a certain location or on top of a grid pattern that is attached to the table or detector stand can be a method of detecting detector movement or preventing it from being covered. The location of the detector must be carefully noted after it is placed and checked carefully when it is retrieved. If the detector is also susceptible to being covered, it should be placed over the edge of the table or stand.

4 - LOCK TIES

Equitron can supply two additional tamper seals. One is a locking clip called a "home buyer seal" that has an individual serial number. Once it is snapped in place it creates a small 3/4 inch circle that cannot be opened except by cutting it.

This type of clip works very well with E-PERM's. If the clip is inserted through the drilled hole in the shaft portion of the E-PERM, it is impossible to close the cap without cutting the clip. If the clip is just hooked through the spring of the E-PERM, then the E-PERM can only be partially closed. During run L3 two of E-PERMs had the cap forced down on the clip that was just run through the spring and held in place with duct tape. This reduced the average by 27% and 35% and would be difficult to detect.

Equitron also makes a hanging strip that has holes punched in either end. The strip is ideal for hanging E-PERMs. Simply loop the strip over a metal water pipe or similar object and attach an E-PERM with the lock clip. Make sure the part that the E-PERM is attached to cannot be removed. On a few occasions the PA DER took apart a drop ceiling in order to remove an E-PERM without breaking the clip seal. Note that the electret still needs to be sealed between the electret and the E-PERM chamber in case someone was to try and remove an electret and cover it during the exposure. During run I3 an E-PERM was hung from the ceiling and it was sealed in place in a zip-lock plastic bag. This caused the E-PERM to average 12% low. The tape used to seal the zip-lock bag frayed the hanging strip and it was noted as being tampered with.

The hanging strip and lock clip can also be used with other passive detectors. A plastic fish net was used to hang a charcoal canister with the hanging strip and lock tie. In order to tamper with this method it is, however, only necessary to wrap the whole hanging net and canister in a plastic bag. This was done in run I3 and caused the charcoal to average 84% low. The hanging strip was found torn upon retrieval of the detector.

The E-PERM can also be placed inside a tyvek envelope and hung from the ceiling with a lock clip and hanging strip in order to prevent someone from moving it, closing it or removing the electret. This method would not work with the charcoal because the tyvek slows down the radon entry just enough to bias the results slightly low.

5 - MULTIPLE TEST LOCATIONS

Multiple test locations can reveal unusual ratios between them that might indicate one area

but not the other is ventilated or the equipment is tampered with. If the basement is divided into rooms and only the room that the detectors is in is ventilated, first floor levels often reach or exceeded basement levels. Since the basement is usually from 2 to 4 times higher than the first floor in the winter and from 2 to 10 times higher in the summer, any significant variation from this could indicate tampering. The ratio between the basement and first floor radon levels will also typically be closer if the air handler for a forced air system is operating in the basement.

During the first half of run A the basement to first floor radon ratio was 38%. When the first floor windows were opened during run A3 the ratio only dropped slightly to 34%. This is probable due to the lack of much stack effect because the outdoor temperature was very warm. When the basement windows were opened during run A4 the ratio went to 91%. The outside average temperature was 72 degrees.

During run B1 and B2 the basement to first floor radon ratio was 61%. The ratio dropped to 24% when the first floor windows were opened during run B3. During run B4 when the basement windows in the test room were wide open, the ratio went to 222%. The first floor had more than twice the average radon of the basement. This would definitely raise some suspicion. The outside average temperature was 65 degrees.

During the run G1 through G3 the basement to first floor radon ration averaged from 29% to 77%. When the basement windows were opened the ratio went to 129%. The outside average temperature was 42 degrees.

During run L1 through L3 the basement to first floor radon ratio average 47%. When the basement windows were opened during run L4 the ratio went to 97%. The outside average temperature was below freezing. Unfortunately the temperature probe only went down to 0 degrees Celsius.

6 - HOURLY MEASUREMENTS

Hour by our measurements were instrumental in determining that tampering had taken place when drastic changes or unusual levels were recorded. The first hour or two of the measurements would often show a sloped decline that was not duplicated till the end of the measurement when the levels would climb back up. The fall during the beginning of the measurement would not, however, be as dramatic under real test conditions because the monitor would be brought in from the outside and therefore only coming into equilibrium during the first three hours. The homeowner could also open windows before the test is begun in order to reduce the chance of a sudden drop off in levels. If the windows are opened immediately upon the tester leaving the house, the drop in levels will probable happen before the monitors can detect this change.

During this project the radon monitors were always in equilibrium with the room when tampering was begun. If the WL monitors had their pump turned off for a few hours or the filter changed they would, however, not be in equilibrium at the start of the measurement. A tester might have better success seeing the climb of radon or WL's at the end of the measurement when his instrument was in equilibrium with the test area. At the end of run G3 the basement windows were closed and the last three hours showed a steep climb back up for both the radon and WL monitors. The open basement window reduced the radon levels 51%. During run H3 the basement windows were opened and it only reduced the radon levels 37% from previous runs. The radon levels had also been varying considerable over the exposure and thus the final climb at the end of the run does not look significant.

One method to enhance the visibility of any steep climb in levels at the end of the measurement is to delay the pick up of the detectors to allow for this ramp up. A tester could tell the client that he would be returning within a two hour window and then return at the end of that period since the owner would most likely have to close the windows before the earliest return time.

Tampering with equipment performance may be too effect and thus display an usually low and stable period during the test. If a continuous monitor is placed in a garage or a WL monitor has its pump turned off, inlet filtered or the monitor covered, the results might appear so low as to be suspicious. During run D3 the TN result dropped so low that it was obvious something had been done to the monitor. In this case a bucket was sealed over the monitor. No other tampering seal or motion indicator would have indicated any disturbance with this type of tampering. The lack of any diurnal variation is also a give away that the monitor has been disrupted from measuring any radon or RDP's.

7 - MOVEMENT INDICATORS

Some of the continuous monitors and the passive detector tamper cages had movement indicators. These devices were obviously helpful in determining if tampering had taken place. The continuous monitor movement indicators were significantly more helpful then the cage movement indicators because they could record each time and hour that the movement took place. An alternative movement indicator is a tape or caulk seal which like the tamper cage just gives a yes or no indication. It may, however, be advisable to use both since the visible seal would tend to discourage tampering.

The Gemini monitor had a built in infrared room motion detector. A recent passive detector cage built by RTCA also included an infrared motion detector. The main benefit that such a detector has is in determining if the monitor or cage has been covered with a large bucket or box. The draw back is that the room motion detector cannot distinguish someone coming into the room and walking innocently by, from someone who is trying to interfere with the detector. Gemini might consider RTCA's approach of aiming the infrared detector up and having a thirty second delay so that it would only be tripped if something was placed over the detector for more than thirty seconds.

If the radon test is done only on the first floor then an owner might try ventilating the house by leaving a door open that is being used for entry and exit from the house. Since a tape or caulk seal cannot be used on an active door there is no way to be sure that the door is left open, especially if the test device is a passive detector. RAL has developed a door motion detector that records any door or window opening that is longer than a specified amount of time. The information is not only stored in the combination receiver and computer but is also able to fax the changes to the tester so that he can correct the situation before it voids the test. The use of such device obviously adds additional cost but the manufacturer has tried to design the system for minimal setup time.

8 - MOISTURE GAIN

The charcoal canisters that were used provided the weight gain of each canister. This information often showed a variation of the tampered canisters to the non-tampered canister. Since a primary method of tampering with a charcoal canister is by restricting the radon uptake and since it is difficult to detect, this abnormal weight gain change is

an interesting method of detecting tampering. If the radon is restricted from entering the canister, so is typically the moisture. Tampering by spraying the canister with hair spray or static guard can also be seen as an additional weight gain even though the spray may in fact be blocking the moisture uptake of the canister. The key to the use of this method is knowing what the expected weight gain should be. The manufacturer of the canister should be able to supply this information if the humidity and temperature of the test area are known and the exposure length is calculated in. A tester would then be required to measure the humidity and temperature of the test area at the placement and retrieval of the detector and then compare the final weight gain with the expected weight gain. A lab might also be able to have its computer predict the weight gain automatically if the humidity and test area temperature are also given.

9 - TEMPERATURE

Charcoal canisters are the only detector that are very sensitive to being heated. To detect being heated a small heat dot can be purchased that changes color when a specified temperature is reached. This could be located on the tamper box or placed on each canister that is used.

The temperature of the basement was recorded during almost every run. When the windows were opened the temperature would typically only fall a few degrees. The furnace appeared capable of maintaining the basement temperature even with large increases in the basement ventilation. If the outdoor temperature is mild then there is little hope of seeing changes in basement temperature due to ventilation. During run G3 the basement temperature dropped from an average of 72 degrees to 68 degrees. During run L4 when the outside average temperature was below freezing, the basement average dropped from the previous run average of 70 degrees to 63 degrees. If, however, only run L4 was viewed, this lower temperature would be inconclusive because 63 degrees is not an unusual basement temperature.

10 - HUMIDITY

Humidity measurements in the basement did not change enough to indicate tampering from ventilation changes. During run L3 and L4, which had very cold outside temperatures, the basement average humidity which had been 48% during run L1 and L2, dropped to 32% and 33%. The basement windows were only opened during run L4. During run B1 through B4, the basement humidity averages were 83%, 82%, 79% and 80%. The basement windows were opened during run B4 and CO2 levels indicated that there was at least a tripling of the ventilation rate and still the humidity did not change much. The outside average temperature was a mild 63 degrees during run B4. This lack of change combined with the fact that humidity measurements before or after the measurement period are not typically available for comparison make using humidity for tamper indicating very questionable.

11 - PRESSURE MEASUREMENTS

Pressure measurements are difficult to make. Small amounts of wind can play havoc with results. Data loggers tend to only make one measurement per time interval rather than collecting the average pressure reading for the interval. Since the pressure reading can be fluctuating wildly during any windy period, single measurements are always questionable. Basement to outdoor measurements are especially sensitive to any wind because the house

acts like a giant sail that creates pockets of pressure that vary not only with wind speed but with wind direction. Basement to sub-floor measurements are much more stable but their strength or correlation with basement to outdoor measurements is dependent upon the tightness of the basement slab and foundation in comparison to the soil porosity. In run L1 to L3 the basement to outside averages -.012" while the basement to sub-floor is only -.001". This indicates a leaky floor.

All this taken into consideration, the changes in the basement pressures produced by opening the windows can often be seen but only if the pressure has been measured for a reasonable period when the windows were closed. During run L1 to run L3 the basement to outside pressure average was -.012". When the windows were opened during run L4, the basement to outside pressure average decreased to -.005".

12 - EQUILIBRIUM MEASUREMENTS

The measurement of the equilibrium ratio between radon and radon decay products was thought to be a possible indicator of increased ventilation. This was not found to be the case during any of the runs when the basement or first floor windows were opened. Sometimes the EQR went up, other times it went down. The inability to see a correlation may also be due to the fact that so many instruments were sampling the air in the test rooms. Occasionally EML would also have numerous pieces of equipment taking air samples at the same time. Even during run J2 when the furnace fan was run continuously, the EQR ratio decreased some but not to the degree where it could be observed as tampering.

13 - CO2

CO2 measurements were made during the first eight house runs with a tank supplying a steady rate of CO2 so that the ventilation rate might be determined. The data obtained was difficult to interpret because of the many variables in each house. Ventilation changes could however be seen but occupancy in the test area complicated the analysis. During the last four house runs, the CO2 measurements were made without adding additional CO2 to the air. During run L1 and L2, three EML personnel were in the house and the average CO2 was 756 PPM. During run L3, without the three EML persons the CO2 level averaged 610 PPM. When the windows were opened during run L4 the average CO2 level fell to 447 PPM, which is a 27% reduction although considering that the outdoor CO2 level is about half this amount the ventilation change might be double this amount although the radon levels only decreased 37%. The decrease in radon levels can also be due to the reduced pressure difference between the basement and the sub-soil.

The CO2 measurement detectors do however appear to be fairly accurate and to have good precision. This sensitivity allows them to be more useful than pressure measurements even though they are affected by occupancy. The need to plot the results on a computer is a draw back but Femto-TECH has recently added an option of a CO2 monitor that prints its results along with the radon results.

Unfortunately the dramatic change in CO2 at the beginning and end of runs that have the basement windows open, such as L4 are partially due to the tester being in the test area at the beginning and end of the test period. More testing of this device as a measurement of ventilation changes is necessary to confirm its effectiveness.

III - GENERAL TAMPER RECOMMENDATIONS

In the EPA document "Protocols for Radon and Radon Decay Product Measurements in Homes" under section 3.4, Measurement Checklist, there is a bullet that states "The test should include method(s) to prevent or detect interference with testing conditions or with the testing device itself." The EPA is directing testers to take necessary steps to ensure that the test conditions are being maintained. To what degree should this be done? In many cases the tampering only reduced the result 10 to 20%. This would only be helpful if the radon levels were less than 5 pCi/l. In reality most houses that get mitigated in PA have radon levels that are greater than 10 pCi/l. A 10 pCi/l elevation would require a tamper technique that reduces the radon by 70%. If the radon levels are at 20 pCi/l then a technique that gives an 85% reduction is necessary.

Considering the limited cases that tampering takes place and is effective, a tester should consider only the minimum methods which are easily accomplished and effective. Each of us is, however, a creature of habit. That which would appear complicated to one person is easy for another who does it regularly. In the same manner that driving an auto with a stick shift can become an automatic process so should those procedures which simply and effectively ensure quality measurements. All the testing equipment for measuring the radon or RDP's and the non-interference controls will be referred to as the "testing system". These recommendations are not in any way meant to limit an individual from developing alternative methods, equipment and techniques that accomplish the same goals.

1 - INFORMING THE CLIENT

Tampering often takes place unknowingly because the client was not adequately informed about the necessary test conditions before the test was begun. The tester must make sure that he clearly communicates to the responsible person or person the necessary test conditions. To help ensure the information is fully understood a non-interference agreement should be signed by the responsible person. This agreement documents that the responsible person has indeed been instructed of the proper test conditions and that he agrees to abide by those test conditions.

2 - INSPECTION OF THE HOUSE

The tester must make a careful inspection of the home to be tested in order to locate the best test location, ensure that the necessary test conditions are being maintained, and to be able to document any important features such as the condition of crawl space vents or that the furnace fan is set on automatic operation.

3 - DETECTOR PLACEMENT & MOVEMENT

The minimum detector location is in the lowest level frequently used or if the test involves a real estate transaction then a detector needs to be in the lowest level that is suitable for occupancy without need of renovation. The location should be in the most frequently used room of the lowest level and be at least three feet from a window and 1 foot from any exterior walls. If the detector requires an electrical source, the tester should carry an extension cord so that the optimal test location is not limited by proximity to an outlet.

Often the proper test location does not have a piece of furniture in the room. To avoid haphazardly using what is available, the tester should have his own test stand. This stand should allow a caulk or tape seal to be attached from the stand to the floor so that both cannot be moved to a low radon environment. The weatherstrip caulk or the void tape are the recommended seals to use for this and other seal requirements. The testing system needs to be able to detect if the detector is moved. If the test equipment can determine by it electronics that it has been moved that should be adequate. If it cannot, then either a caulk or tape seal should be used between the detector and the test stand. An alternative, acceptable, approach would be to use the hanging strips and locking clips that are commercially available.

4 - OPENING WINDOWS AND/OR DOORS

In order to ensure that closed house conditions are being maintained, all the lowest level windows and doors should have a caulk or tape seal from the window to the window frame or over the window latch. The lowest level doors should also be sealed unless they are the primary entrance. If a primary entrance door is on the lowest level to be tested, then the detector should be located as far as possible from this door. The next level windows and doors need only be sealed if the tester feels that there is a likely chance they will be opened and they will significantly influence the test results.

5 - TURNING DETECTORS OFF OR CHANGING PUMP FLOW RATES

Testing equipment that only provides one average measurement can be susceptible to tampering if it can be turned off. This includes E-PERMs and RIPSUs. E-PERMs in the S-chamber should have a locking clip placed through the drilled hole in the plunger shaft. E-PERM electrets can be kept in their keeper cap and then installed into an E-PERM shell that has a locking clip attached to it so that new clips do not have to be used for every test. Keep in mind that additional equipment steps used in tamper methods may require extra steps for individual pieces of equipment. For example; E-PERM shells and electrets must be kept free of dust so that keeping them clean before the test may require wiping or blowing out any accumulated dust before assembling them.

RIPSU detectors that do not have a timing mechanism to record the power on time should include a tamper seal on all plugs, switches and circuit breakers that control power to the unit.

Most continuous WL monitors will have some indication that the power or the pump has been turned off. If the detector cannot determine that it has lost power or the flow rate of the pump has been changed, then a caulk seal should be used on the detector controls. It may be unlikely that a homeowner would tamper with an electronic device but if the adjustment would go undetected and it can be easily protected with a seal then it should be done.

6 - COVERING DETECTORS

There are two general types of detectors that are especially susceptible to being covered; charcoal canisters and WL monitors.

Charcoal detector results are easily reduced by covering the detector opening, spraying a solvent into the charcoal, or covering the whole detector. To prevent a charcoal canister, tamper box or WL monitor from having something placed directly on top of it, it should have either two double stick tapes that don't touch each other placed over the top of the canister, or have noodles protruding from the top or be in a tamper resistant box.

To prevent a canister, canister inside a tamper box or a continuous WL monitor from having a container placed over it, place testing equipment so that it extends over the edge of its stand. This makes it difficult to place any rigid container over the testing equipment and still get a seal. A person could however seal a plastic garbage bag over the above testing equipment. The double stick tape or noodles prevents the plastic bag from being used because the plastic bag would get caught on the tape or break the noodles. The double stick tape or noodles would also protect a tamper cage from being itself turned into a container by taping off its inlets.

Hair spray or similar solvents sprayed into a canister could be used as a method of reducing the canister result. It typically, however, takes a large amount of hair spray to reduce the result significantly. A change in the canister inlet appearance or with the tape seals, may be one method of detecting that spraying has been used. If a charcoal canister is chosen that provides the weight gain, one can learn from the manufacturer what typical weight gains are for different humidities, temperatures and exposures. The humidity and temperature would need to be measured at the placement and retrieval of the detector. Noting unusual low weight gains may also characterize a canister that has been covered.

7 - FILTERING INLETS

Filtering WL monitor inlets can be effective at reducing the final result. The proper filter, however, needs to be used. It is hopefully a rare case that a homeowner would know how to place a filter over the WL monitor inlet to accomplish this. The only method used to detect filtering of inlet air was to use caulk and sorba noodles protruding out. This is, however, a clumsy method.

8 - ALTERING EQUIPMENT PERFORMANCE

If equipment performance can be easily altered by adjusting a dial such as the flow rate without detection then it should have a caulk or tape seal or other form of non-interference control.

Charcoal canisters are susceptible to being heated with a hair dryer to reduce their response. A heat dot that changes color at 120 degrees, laid on top of the canister, could be reused until such time that someone tampers with the canister by heating it.

The owner could place a fan or filter in the same room as a WL monitor or turn a furnace fan to continuous on. A tape or caulk seal could be placed over the furnace fan control switch. The fan or filter in the test room is more difficult to detect. The only possible method of detecting such a method is to measure radon at the same time. The equilibrium could then be calculated to determine if it is unusually low.