A COMPARISON OF CONTEMPORARY AND RETROSPECTIVE RADON GAS MEASUREMENTS IN HIGH RADON DWELLINGS IN IRELAND

Kelleher K. (1), McLaughlin J.P.(1), Fenton D.(2), Colgan P.A.(2)

(1) University College Dublin, Ireland.
(2) Radiological Protection Institute of Ireland, Dublin, Ireland

INTRODUCTION

In order to determine the risk of contracting lung cancer from radon gas in indoor air a number of different methods can and have been used. These include lung dosimetry modelling [1], miner epidemiological studies [2] and residential radon epidemiological studies (both ecological and case-control) [3, 4]. In case-control radon epidemiological studies the cumulative exposure to radon over the exposure period of interest must be determined in order to derive the risk associated with it. This cumulative exposure must take into account the amount of time spent indoors exposed to the gas and the average indoor radon gas concentration for the exposure period of interest.

The average indoor radon gas concentration for the exposure period of interest is probably the most difficult factor to determine. The most accurate way to determine this would be to continuously measure the radon gas concentrations an individual had been exposed to indoors but this is practically impossible in lung cancer studies as the exposure period of interest is the 5-35 years before the disease was first diagnosed. Instead surrogate measurements are usually made in order to estimate the radon gas concentrations.

The earliest case-control residential epidemiological studies relied upon house type, building materials and characteristics of the underlying geology as surrogate measurements of exposure [5] but more recently the majority of residential case-control studies have employed contemporary radon gas measurements as a surrogate. This method is passive, cheap and relatively easy to perform but, like all surrogates, it has numerous disadvantages. The main disadvantage is that the contemporary radon gas measurement does not take into consideration significant changes of the radon concentration over the exposure period of interest due to factors such as physical changes to the building, radon remediation and changes in the occupant's lifestyle.

An alternative surrogate measurement that has been used by Alavanja et al. [6] is to estimate radon gas retrospectively. Here the radon gas concentration that would have existed in the past is estimated using a ^{210}Po surface activity measurement on suitable glass objects in a dwelling and a modified Jacobi room-model and, unlike the contemporary radon gas measurement, it does take into account significant changes in the radon concentration in the past.

The work described here compares the retrospective radon gas estimates with contemporary radon gas measurements made in *domestic dwellings in the Republic of Ireland in order to determine the degree of correlation which may exist between them.*

MEASUREMENT TECHNIQUES

University College Dublin (UCD) first began investigating radon concentrations in Irish dwellings in the early 1980's and conducted the first national radon survey in the country between 1985 and 1989 [7]. Since then, UCD has also been actively involved in the development of a retrospective radon measurement technique known as the "CR-LR difference technique" [8]. In this technique, two pieces of CR-39 and one piece of LR-115 plastic are mounted on a flat, clean glass surface. The LR-115 plastic is sensitive to 1.2 - 4.8 MeV alpha particles and will not record the 5.3 MeV alpha particles emitted by the surface implanted ^{210}Po; instead it produces tracks proportional to the intrinsic alpha activity of the glass itself. However, the CR-39 track density records the tracks due to both the implanted ^{210}Po surface activity and the intrinsic activity of the glass. The ^{210}Po activity for a glass surface can be calculated using the formula:

$$P = \frac{CR - (B.LR)}{t.K}$$

Where P is the ^{210}Po surface activity in Bq m^{-2}, CR is the CR-39 net tracks per cm^2, LR is the LR-115 net tracks per cm^2, B is the intrinsic alpha activity track density ratio for unexposed glass, t is the detector exposure time in hours and K is the CR-39 sensitivity factor to ^{210}Po. This measurement technique has been validated in laboratory and field based intercomparison exercises with other passive ^{210}Po detectors and active (Surface barrier and Pulse Ionisation Chambers) detectors [9].
Using this ^{210}Po surface activity measurement and a modified Jacobi room model describing the behaviour of radon and its progeny in rooms [10], an estimate of the average radon concentration in the past can be made. This modified Jacobi room model takes into account the various room parameters that affect the deposition of radon progeny on surfaces in a room, including aerosol concentrations, ventilation rates and the rooms surface to volume ratio. These parameters are determined from a detailed questionnaire that is completed at the time of installation of the ^{210}Po surface activity monitor. This questionnaire records the factors affecting ventilation rates and aerosol concentrations in the room in the past and present as well as significant physical changes to the room that could affect the surface to volume ratio or radon concentration. A number of intercomparisons of this technique have been conducted [11, 12, 13]. Good correlation was found in previous studies where the retrospective radon estimate for a given room was compared with the radon concentration determined from a large number of individual contemporary radon gas measurements made over the exposure period of the glass object [14, 15].

The Radiological Protection Institute of Ireland (RPII) has been conducting contemporary radon gas measurements in the Republic of Ireland since the early 1990's and has, in that time, collected indoor radon data on over 27,000 domestic dwellings as well as conducting one of the most comprehensive national radon surveys to date [16]. The contemporary radon gas measurement technique uses the SSI type time-integrated passive radon detector comprising a polypropylene shell, that acts as a diffusion chamber, and a piece of alpha sensitive CR-39 plastic. A more detailed overview of this technique is described elsewhere [17]. The RPII radon measurement laboratory is accredited to ISO 17025.

DWELLING AND GLASS OBJECT SELECTION

The dwellings selected to participate in this study were taken from the RPII's residential radon database. The dwellings chosen contained rooms that, on the basis of previous contemporary radon gas measurements, were known to have a radon concentration greater than 1000 Bq m^{-3}. These were the rooms of interest in this study because, due to the high alpha track density, the contemporary radon gas measurement made in these rooms would have very small measurement uncertainties associated with them. In addition, if a room did contain a high radon concentration over a long period of time then the ^{210}Po surface activity associated with it would also be relatively high reducing the error on this measurement. Also, dwellings with high radon concentrations are those of most interest from a lung cancer risk perspective.

The ^{210}Po surface activity measurements were conducted on glass objects in the rooms matching the criteria outlined above. The glass objects chosen were those that had been brought into the room new, i.e. not exposed to radon in any other locations previously, and were located in the room of interest for a period of at least 10 years. Care was taken to ensure the glass object chosen was at a location where the radon progeny deposition rate would be close to the average radon progeny deposition rate for the room. This meant glass surfaces near heaters, electrical appliances, windows and doors were avoided. In addition, a detailed questionnaire was completed for each room of interest that recorded a number of other relevant factors relating to the aerosol concentration, ventilation rate and surface to volume ratio in the past and present. These details were then used in conjunction with the modified Jacobi room model in order to better estimate the average radon concentration the glass object was exposed to over its lifetime in the room.

The retrospective detectors were exposed in the summer of 2004 for an average period of 2 months in a total of 131 rooms in 66 different dwellings. The majority of these rooms were living rooms and bedrooms. Due to some detectors not being returned and others being unsuitable for analysis (due to incorrect removal and storage of the detectors by the homeowners or breakages in the post etc.) 93

measurements were compared with contemporary radon gas measurements.
In addition, during these investigations 46 of these rooms had another contemporary radon gas measurement made of at least three months duration. This contemporary radon gas measurement was made by UCD using the same CR-39 passive track-etch detector as the RPII. Rooms that had radon remediation work conducted since the previous measurements were exempt from this part of the study.

RESULTS AND DISCUSSION

The overall results from these 93 rooms are summarised in Table 1.

	UCD Retrospective Estimate (Bq m^{-3})	RPII Seasonally Adjusted Contemporary (Bq m^{-3})	UCD Seasonally Adjusted Contemporary (Bq m^{-3})
Min. radon Concentration	352	199	68
Max. radon Concentration	8678	7049	7580
Average radon Concentration	2268	1606	1765

Table 1. Summary of overall measurements from the 93 rooms
Note:the UCD seasonally adjusted contemporary radon measurement were only conducted in 44 rooms and were of 3 to 12 months duration, these seasonal adjustments were calculated in accordance with Wrixon et al. [17])

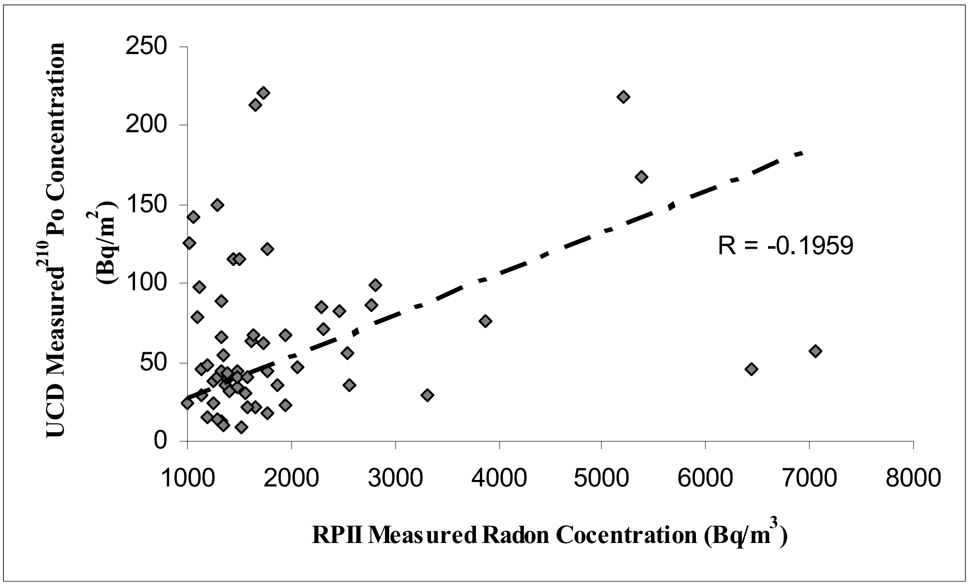

Figure 1. Comparison between the RPII contemporary radon gas measurement and UCD measured ^{210}Po surface activity measurements (normalised to 20 years)

The ^{210}Po surface activities normalised to 20 years for the 93 rooms were compared to the RPII contemporary radon gas measurements in *order to determine the degree of correlation that existed between the two and very little correlation was found (Figure 1).*

The retrospective radon concentrations were estimated for each of these rooms and plotted against the RPII's seasonally adjusted contemporary radon gas measurements.

The UCD estimated retrospective radon gas concentration did not correlate well with the RPII's seasonally adjusted contemporary radon gas concentration (Figure 2).

The results here indicate that there is little correlation between two measurement techniques that act as surrogates for cumulative exposure to radon gas. This would imply that choosing one technique over another would lead to two completely different estimates for cumulative radon exposure. However, these results cannot determine which technique is more suitable for epidemiological studies.

The contemporary radon gas measurements conducted by UCD in this study were then compared to the contemporary radon gas measurements made previously by the RPII to investigate any significant changes in the radon gas concentrations occurring between these two measurements.

The UCD measurements were seasonally adjusted using the same seasonal adjustment factors for Irish dwellings determined by the RPII. The average period between the two measurements was 12 years. Little correlation between the two contemporary radon gas concentrations made in the same room of the same dwelling is observed (Figure 3)

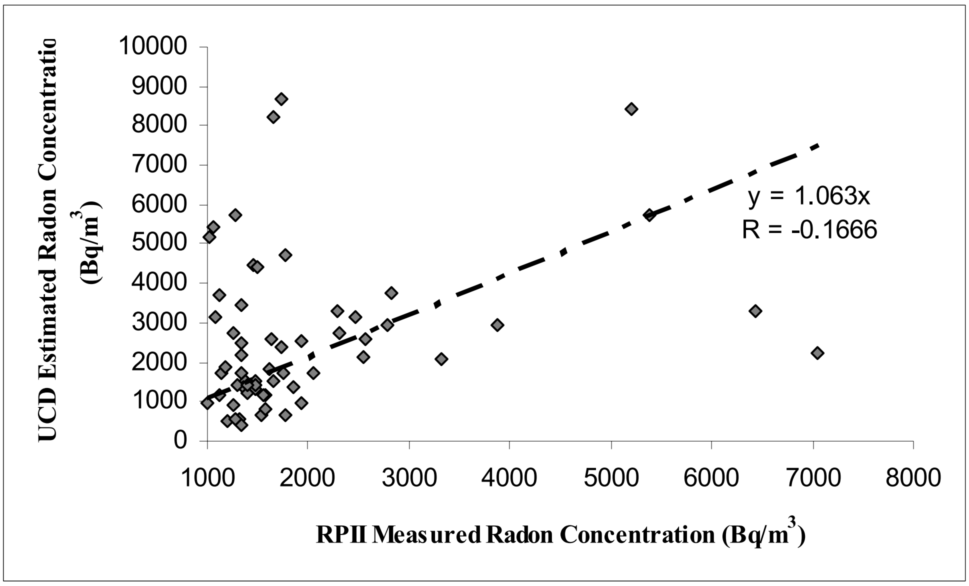

Figure 2. Comparison between RPII seasonally adjusted radon gas concentration and UCD estimated retrospective radon gas concentration.

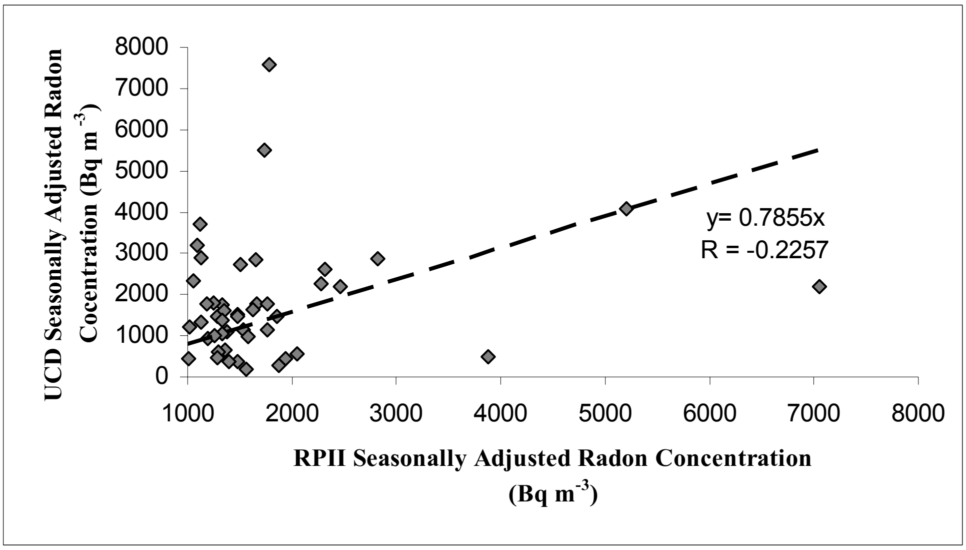

Figure 3. Comparison of UCD contemporary radon gas concentration to RPII contemporary radon gas concentration.

Further investigation of these contemporary radon gas measurements on a room-by-room basis found that some of the measurements have not changed significantly but in one room the measurement differed by a factor of twenty. The measured radon gas concentration in this room dropped from 1341 Bq m^{-3} to 68 Bq m^{-3}. However, this drop could be attributed to large scale building work that was carried out in the room in the intervening years. Omitting this room from the sample set, a large difference between the two contemporary radon gas measurements can still be seen in a number of rooms (Figure 4). The three largest changes in radon gas concentrations were seen in rooms 18, 37 and 44. All three rooms saw a drop in the radon gas concentrations from 3880 to 495 Bq m^{-3}, 1563 to 192 Bq m^{-3} and 1875 to 290 Bq m^{-3} respectively and the period between the two measurement period were 4, 5 and 10 years. Not one of these large drops over a relatively short time period could be explained or attributed to radon remediation, physical changes to the rooms in question or changes to the factors affecting ventilation rates in the rooms based on the questionnaire data.

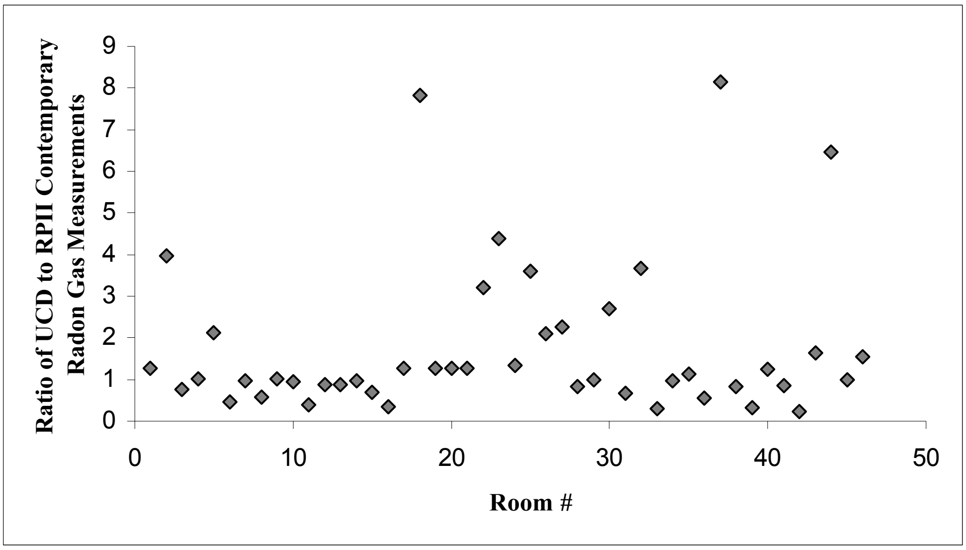

Figure 4. The ratio of the UCD contemporary radon gas concentration to the RPII contemporary radon concentration made in the past (both concentrations have been seasonally adjusted).

The mean of the two contemporary radon gas measurements were then calculated in order to get a crude estimate of the overall average radon concentration for the time between the contemporary radon gas measurements. This crude estimate was then compared to UCD's retrospectively estimated radon gas concentration. A weak correlation was found to exist between the two (Figure 6).

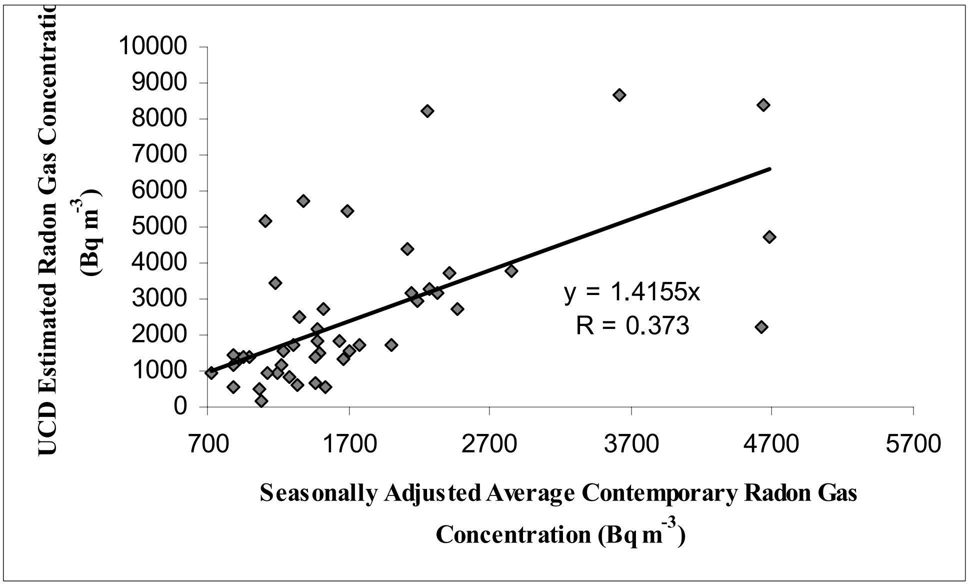

Figure 5. Comparison of UCD retrospective radon estimate and average seasonally adjusted contemporary radon gas concentrations.

CONCLUSIONS

Little correlation has been found between contemporary radon gas measurements made in the past and retrospective radon gas measurements in Irish dwellings. This would suggest that these two

techniques would result in two significantly different cumulative radon exposure estimates.
Contemporary radon gas measurements made a few years apart in the same room of a dwelling were found to be significantly different. None of these differences could be explained by known changes to the rooms themselves, such as ventilation or structural alterations to the room. This highlights the limitations of the contemporary radon gas measurement as a surrogate measurement for use in residential radon epidemiology.
The contemporary radon gas measurements made by the RPII and UCD do not cover the same exposure period as the retrospective estimates and so the accuracy of the retrospective measurements cannot be demonstrated. A weak correlation can be seen between the retrospective radon gas estimates and a combination of the two contemporary radon gas estimates. It is not unreasonable to expect improvement in the correlation if further contemporary radon gas measurements were made in these rooms.

REFERENCES

[1] ICRP (International Commission on Radiological Protection) 1994, "Human respiratory tract model for radiation protection", ICRP Publication 66, Annals of the ICRP 24(1-4), Pergamon Press, Oxford.

[2] NRC (National Research Council) 1999, "Health risks of radon and other internally deposited alpha-emitters", BEIR VI (Committee on Biological Effects of Ionising Radiations) Report, National Academy Press, Washington, D.C.

[3] Lubin J.H. and Boice J.D. 1997, "Lung cancer risk from residential radon: meta-analysis of eight epidemiologic studies", Journal of Nat. Cancer Inst. 89(1): 49-57.

[4] Darby S., Hill D., Auvinen A., Barros-Dios J.M., Baysson H., Bochicchio F., Deo H., Falk R., Forastiere F., Hakama M., Heid I., Kreienbrock L., Kreuzer M., Lagarde F., Mäkeläinen I., Muirhead C., Oberaigner W., Pershagen G., Ruano-Ravina A., Ruosteenoja E., Schaffrath Rosario A., Tirmarche M., Tomásek L., Whitley E., Wichmann H-E., Doll R,"Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case-control studies". BMJ, Jan 2005; 330: 223.

[5] Samet J.M. 1989, "Radon and lung-cancer", J Natl Cancer Inst 81:745-757

[6] Alavanja M.C.R., Lubin J.H., Mahaffey J.A. and Brownson R.C. 1999, "Residential radon exposure and risk of lung cancer in Missouri" Am. J. Pub. Health. 89:1042-1048.

[7] McLaughlin J.P. and Wasiolek P., 1988. "Radon Levels in Irish Dwellings", Radiation Protection Dosimetry. 24, (1/4): 383 – 386.

[8] McLaughlin J.P., 1998, "The Application of Techniques to Assess Radon Exposure Retrospectively". Radiation Protection Dosimetry, 78, No.1:1-6

[9] Walsh C.,1999, "Reconstruction of Historical Exposure to Radon : Techniques,Developments and Field Work", Ph.D Thesis, National University of Ireland (Dublin).

[10] Porstendörfer J., Wicke A., Schraub A., 1978. "The Influence of Exhalation, Ventilation and Deposition Processes upon the Concentration of Radon (222Rn) and Thoron (220Rn) and their Decay Products in Room Air". Health Physics, 34: 465 – 473.

[11] Mahaffey J.A., Parkhurst M.A., James A.C., Cross F.T., Alavanja M.C.R., Boice J.D., Ezrine S., Henderson P., Brownson R.C., 1993. "Estimating Past Exposure to Indoor Radon from Household Glass". Health Physics, 64(4): 381 – 391.

[12] Field R.W., Steck D.J., Parkhurst M.A., Mahaffey J.A., Alavanja M.C., 1999. "Intercomparison of retrospective Radon Detectors", Environmental Health Perspectives, 107 (11): 905 – 910.

[13] Steck D.J., Alavanja M.C.R., Field R.W., Parkhurst M.A., Bates D.J., Mahaffey J.A., 2002. "^{210}Po Implanted in Glass Surfaces by Long Term Exposure to Indoor Radon". Health Physics, 83(2): 261 – 271.

[14] Bochicchio F., McLaughlin J.P., Walsh C., 2003. "Comparison of Radon Exposure Assessment Results: ^{210}Po Surface Activity on Glass Objects Vs. Contemporary Air Radon Concentration". Radiation Measurements, 36: 211 – 215.

[15] Kelleher K., "Retrospective Exposure Assessment in Residential Radon Epidemiology". M.Sc Thesis, National University of Ireland (Dublin)

[16] Fennel S.G., Mackin G.M., Madden J.S., McGarry A.T., O'Colmáin M., Colgan P.A, Pollard D., 2002. "Radon in Dwellings - The National Radon Survey". RPII-02/1, Dublin: Radiological Protection Institute of Ireland.

[17] Wrixon A. D. et al., 1988. "Natural Radiation Exposure in UK Dwellings".UK, NRPB-R190. TSO.