Lung cancer risk from exposure to radon in the home - are policies in the United Kingdom appropriate to the risk?

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Abstract:

At present, residential exposure to radon gas and its radioactive decay particles is predicted to be a major cause of lung cancer. The degree of risk of lung cancer is predicted from models based largely on data from studies of underground miners. These cohorts of miners were exposed to radon at much higher levels than encountered in the majority of homes and as such, the projected risks may be overstated.

This is an area of public health policy over which there has been considerable scientific debate and on which there still remains disagreement and controversy. The controversial issues are examined and discussed and the evidence from residential studies of radon and lung cancer is reviewed.

Also considered are issues which affect the applicability of the present policy of encouraging remedial work in dwellings where the radon activity concentration exceeds the UK "action level" of 200 Bq m $^{-3}$.

The paper concludes that the current policies are inappropriate in many respects and recommends that they be reviewed following the reassessment and evaluation of :-

- *issues in relation to residential mobility*
- *the calculation of the true costs of radon remediation as a health intervention allowing for mobility*
- *re-evaluation of the numbers and locations of properties currently affected by higher than average levels of radon*
- *a comparison of the effects of radon remediation against smoking cessation as a means of lowering the prevalence of lung cancer*

Introduction

The ultimate consequences of failing to recognise a problem of public health importance are likely to manifest themselves in the form of increased morbidity, mortality and premature death. All of these have costs to society. The alternative scenario is incorrectly attributing a risk to the public health which involves unnecessary expenditure and thus opportunity costs.

In the UK and other developed countries there have been substantial moves towards basing public health policy on sound empirical evidence. Despite this, it is acknowledged that although scientific analysis of environmental problems plays an important role in determining public policy, there are instances where policy either appears to have been based on questionable evidence, or the interpretation of evidence is inappropriate.

One such area of public health policy on which there has been much debate in scientific circles, is the risk of lung cancer associated with residential exposure to naturally occurring radioactive radon gas.

The currently accepted paradigm is that there is an excess risk of lung cancer associated with exposure to ionising radiation in residential properties emanating from naturally occurring radon gas. The evidence for this paradigm is based largely on data extrapolated from studies of underground miners exposed to radon in their work.

Uncertainties in the evidence base and its applicability to residential exposures has lead to current risk estimates in the UK being based around a model developed in the USA by the Sixth Committee on the Biological Effects of Ionising Radiation of the National Research Council.[1] This risk model is based on data extrapolated from the miner studies assuming the linear no threshold theory (LNT). Using this theory, there is assumed to be no threshold below which carcinogenicity does not occur and it is also assumed that there is a linear relationship between radiation dose and lung cancer risk.

Background

Radon:

Radon is a naturally occurring radioactive gas formed as part of the decay chain of uranium. The radiation emitted by radon and it's decay products is "ionising" radiation, which is so called because it has sufficient energy to ionise material by removing electrons from atoms and molecules. The substantive part of the ionising radiation to which humans are exposed is as a result of radon.[2]

Radon gas and several of the solid elements into which it decays are alpha particle emitters which have a high linear energy transfer. These solid "daughter" particles when combined with moisture in the air are thought to form a radioactive aerosol which, when inhaled, results in radioactive daughter particles being deposited in the respiratory tract which are capable of irradiating sensitive lung tissues and resulting in DNA damage.

Radon in the home varies from dwelling to dwelling, both within and between areas as a result of numerous factors. The distribution of radon concentrations is heavily dependant on geological factors, with high radon concentrations generally, but not necessarily, associated with igneous rocks, especially granite. Whilst radon emanates from the underlying rock it permeates through soil and seeps into dwellings through cracks and/or gaps in floors and walls.

There is little doubt that exposure to radon gas and its daughter particles is associated with lung cancer at high level occupational exposures. Cohort studies of uranium and other hard rock miners having shown a dose response relationship with increasing exposure and increasing incidence of lung cancer.

In the 1980's fears began to be expressed both in the UK and elsewhere that exposure to radon in a residential situation would result in an increased risk of lung cancer.

Lung cancer:

Lung cancer is a disease which is largely though not completely preventable. Once contracted, however, survivability from lung cancer is very low.

In public health terms, clearly, lung cancer is of major importance. Current U.K. figures show that the disease resulted in 33,386 deaths in 2001 and is the most common cause of cancer death - 22% overall, 25% male, 18% female.

Of these deaths, tobacco smoking will be implicated in the vast majority, including between 1500 and 2000 deaths attributed to radon. Approximately 90% of all lung cancer cases are attributed to tobacco smoking. The largest single other causative factor attributed is exposure to the decay particles of radon gas. The interaction between smoking and radon in the incidence of lung cancer is not completely clear, however it seems likely that the effects of smoking are either multiplicative or sub-multiplicative rather than additive.

Currently, the National Radiological Protection Board (NRPB) estimates that residential radon is responsible for a total of between 2000 and 3300 lung cancer deaths per annum, of which between 500 and 1300 are in non-smokers.[3]

U.K. Policy in relation to radon in dwellings:

Since the 1980's, following advice from both the NRPB and the committee on medical aspects of radiation in the environment (COMARE), the policy of the UK government has been to control radon levels in houses with the highest concentrations. NRPB produced advice for the government on radon dose levels above which remedial action should be taken.

In 1987, the government accepted that precautionary action was advisable with an action level based on a dose equivalent of 20 mSv per annum in existing dwellings and that a design level of 5 mSv per annum was appropriate for new dwellings. Radon activity concentrations have subsequently been substituted for dose equivalent levels in relation to existing dwellings which equates to 200 Bq m^{-3} (at equilibrium equivalent radon concentration).

The key actions to fulfil this broad brush policy have been:-

- The identification of the problem dwellings where such action is needed by funding a substantial survey by the NRPB
- A no cost measurement service for occupiers who were living in areas where radon concentrations might have been above or near the action level, and
- In the remainder of the UK a measurement service at the expense of the householders concerned.

The provision of free radon measurements to selected households has until recently been a substantial focus of UK radon policy, with over 2 million invitations for free tests having been issued to residents in radon risk areas and about 400,000 people having had their homes tested. These tests have had a duality of purpose in firstly identifying individual dwellings where action levels are exceeded and secondly in providing additional data for the NRPB's mapping of radon affected areas.

In addition to radon testing, the government has produced numerous information leaflets and booklets with the aim of increasing awareness amongst the general public about the potential risks of radon and the possible remedial measures.

Recent changes in residential radon policy have now ended free tests in most areas and there has been a shift of emphasis towards greater remediation in existing dwellings and protection in new dwellings.

In existing dwellings, the pre-existing policy measures had been shown by survey to result in a comparatively low proportion of households undertaking remedial works (10-20%) where recommendations following tests had been given. In order to increase this percentage the government has now targeted remediation by a programme of information in cooperation with local authorities.

In the case of new dwellings, changes to the UK Building Regulations have also been introduced which generally require radon preventative measures to be incorporated into new dwellings in all areas identified as being at the greatest risk of having high radon levels.

Although government policy has been to identify and inform, the cost of all remediation of high radon levels has generally been borne by the dwelling owners. There have been calls by a number of organisations for government policy to be changed to include the cost of remediation by way of mandatory grants.

Reviewing the epidemiological evidence

The issue of whether or not an excess risk of lung cancer can be attributed to residential exposure to radon and its decay particles is the cause of much debate and disagreement in the scientific community. Whilst there appears to be general agreement that large doses have potentially harmful effects, disagreements have resulted in a number of controversies which essentially relate to risks at low doses.

There are two main issues of concern with the epidemiological evidence, firstly, the applicability of data from the miner cohorts to residential situations, and secondly, the findings of the direct evidence from residential studies.

In relation to the former, several questions have been asked to which there are as yet no satisfactory answers. These are:-

- Is the dose response curve predicted by LNT appropriate at low doses and in particular, has the role of biological defence mechanisms in preventing potential initiating events developing into cancers been properly considered?
- Is it appropriate to generalise occupational data from studies of miners to residential exposures when the variables encountered in that situation are considerably different from residential exposures which are for the most part at much lower levels?

With regards to the findings of direct evidence, the principal question being asked is whether the direct epidemiological evidence supports the current risk predictions. Residential radon studies have been of the ecological and case-control type. The results of both types have not shown consistency of trends and as such, have not provided definitive support for the risks which have been predicted.

There has been considerable controversy over the applicability of ecologic studies. Evidence from ecologic studies at a population level does not appear to show a correlation between high radon levels and an increase in the incidence of lung cancer. Limitations of the ecologic method in terms of its ability to link outcomes to exposures without unacceptable biases and misconceptions are generally accepted, and the use of the method is primarily for hypothesis generation. Rejection of population level data does, however, seem counterintuitive where population study does not show a correlation between the incidence of cancer and high residential radon levels.

A review of the direct evidence from case-control studies was reviewed critically in 1999.[4] The review elicited more questions than it provided answers for.

The studies reviewed all suffered from problems in one or more areas which limited their ability to provide direct evidence of an association between exposure to residential radon and lung cancer. In summary these problems appear to have been:-

- Inaccuracies in the measurement of exposure
- Inadequacies in the control of confounders, such as environmental tobacco smoke and occupational lung carcinogens
- Inaccuracy in accounting for factors affecting the calculation of radiation doses received by subjects
- Inadequate sample size and power to resolve with precision the anticipated increase in risk

Since carrying out the review, the results of a further three case control studies have been published, all of which suffer from one or more of the above problems.

Other methodological issues relating to the evidence base

The lack of unequivocal direct evidence from epidemiological study has resulted in the adoption of a risk model to determine estimates of risk and to develop policy. However, there are also a number of methodological issues which can be expected to have substantial effects on the currently predicted health outcomes based on the modelled risks.

Population mobility:

The estimation of radon induced lung cancer risks to populations does not appear to take account of the effects of residential mobility. Mobility in populations causes considerable difficulty in retrospective epidemiological studies in that radiation doses received over time in different dwellings cannot be measured with any degree of accuracy. Mobility has been demonstrated to have a substantial effect on individual level risk as opposed to population level risks that are calculated by the BEIR VI model.

Warner et al [5] simulated the effects of the mobility of the US population and concluded that knowledge of the radon level of an individual's present home is not necessarily a helpful guide to that individual's risk. They predict that the majority of health benefits resulting from radon remediation in a home would accrue to future occupiers of that home and that the remediation of high-radon level homes may have only small health benefits to those individuals choosing to carry out these works.

Whilst Warner estimated the overall level of mortality resulting from domestic radon using a mobile population model to be broadly the same as the predicted risks to a static population, the distributions of the exposure and mortality were substantially different between differing categories of home radon exposure. (Tables 1 and 2)

Table 1 - Lifetime lung cancer mortality attributable to radon in a cohort of 50,000 males and 50,000 females at age 30

	Radon, pCi/l				
	<=0.5	0.5-4	>4	>10	Total
No-mobility model	40 (8.7%)	277 (60.5%)	141 (30.8%)	47 (10.3%)	458 (100%)
Mobility model	158 (34.9%)	264 (58.3%)	31 (6.8%)	2 (0.4%)	453 (100%)

Table 2 - Annual U.S.lung cancer mortality attributable to radon in a typical year, by exposure at time of death					
	Radon, pCi/l				
	<=0.5	0.5-4	>4	>10	Total
No-mobility model	1,294 (9.8%)	7,990 (60.3%)	3,970 (29.9%)	1,232 (9.3%)	13,254 (100%)
Mobility model	4,379 (32.3%)	7,683 (56.7%)	1,495 (11.0%)	356 (2.6%)	13,557 (100%)

Source: Warner, et al (1995)

Along with the cross level biases and inadequate control of confounders, the findings of Warner may help in explaining the lack of associations found in ecological studies of residential radon exposure and lung cancer.

Radon mapping:

Maps showing radon concentrations in geographical areas are used not only to illustrate the scale of projected risk of exposure to residential radon, but also to assist in the implementation of policy in relation to radon control for new dwellings and remediation in existing dwellings by predicting the numbers of dwellings likely to be affected by higher than average radon levels. For this reason, mapping should be as accurate as possible.

In the UK, data forming the basis for the original radon mapping of higher risk areas was obtained from a representative national survey and a selective survey of regions where high radon concentrations were expected. The surveys were carried out in the early 1980's.[6]

Since that time data from the statistical surveys has been supplemented with data resulting from radon tests over the ensuing period and revised radon maps have been issued in England, Wales and Northern Ireland incorporating the additional data. Potential problems with response (or participation) bias are likely to have resulted and it is not clear how, if at all, the potential problems with bias have been handled by the NRPB.

News headlines such as "Radon danger is spreading" [7] suggest that remapping the data is highlighting areas that were not apparently classified as being at risk from the original representative sample and that bias might be responsible for those "new" areas at risk. Alternatively, changes made to dwellings since the 1980's may equally well have resulted in changes in radon concentrations.

Cost effectiveness of radon control programmes:

Several analyses of the cost effectiveness of radon remediation as a health intervention have been published. Although there is a general consensus that radon remediation in properties exceeding the US and UK action levels is economically viable, the analyses have all been carried out on the basis of risk modelling of static populations.

The effects of population mobility can be assumed to be likely to have a major bearing on the cost effectiveness of home radon remediation and this is acknowledged by Ford et al [8] who, referring to work by Warner et al, concluded that "Modelling a dynamic population is likely to produce different cost effectiveness estimates".

To date there appears to have been no clear comparison of the cost effectiveness of radon remediation considered against measures to reduce the prevalence of smoking. The benefits of smoking cessation as opposed to radon exposure cessation were demonstrated by Ennever [9], who by using the BEIR IV risk model showed that ceasing smoking is of considerably more benefit. Work by Warner, et al [10] also clearly demonstrates that this difference in benefit holds good using a mobile population model.

Discussion

Predictions of the risk of lung cancer resulting from residential radon exposure and quantitative estimates of the problem radon presents to public health both in the UK and elsewhere have been modelled from data extrapolated from the miner cohorts. Whilst the evidence from the miner cohorts is good in relation to high level occupational exposures, making inferences from one distinct type of exposure to another is often fraught with difficulties and is frequently incorrect.

Ecological studies have looked for geographical trends in exposure and effect. Whilst a limited number of studies have shown a relationship between population based trends, most have shown no association and a few have shown a negative association. It is clear that ecologic studies cannot be used to elucidate on risk on an individual level, however, if what appears to be happening at a population level does not show an elevated level of risk, is it a matter of public health concern?

Case-control epidemiological studies have been used in an attempt to confirm the association between residential radon exposure and lung cancer at an individual level and to provide direct quantitative evidence. The evidence review suggests that the studies to date have largely been unsuccessful at providing definitive evidence.

Assuming that there were no problems with the epidemiological evidence and that the quantification of risk associated with residential radon had been established with an acceptable degree of robustness, there still remains a problem as to how to minimise lung cancer risk in the residential population resulting from exposure to radon.

At present, the policy in the UK with regards to existing dwellings is to encourage owners of property with radon levels above the action level of 200 Bq m^{-3} to carry out remedial works to lower their level of exposure. The largest proportion of the UK dwelling stock is owner occupied. The present policy does not explain to owner occupiers of homes with high radon levels that the level of radon exposure in their previous homes will also have a bearing on the reduction of risks they are likely to achieve by remediating. Also it does not explain that if they move in the future to another home with high radon levels they will have to bear the same costs in order to continue to avoid risk. A one time cost for owner occupiers could only be achieved if 100% of owners of existing dwellings with high radon levels were to remediate and on present performance, there appears to be little chance of this happening. Put another way, we are asking the owner occupiers of existing property to spend their money on works to a dwelling which, when residential mobility is taken into account, are likely to be of more benefit to its future occupiers.

The argument has been proffered that the costs of remediation are not high and would be recovered on the sale of the property. However, as that argument takes no account of property values in more depressed parts of the country, some of which have the highest radon levels, it is by no means a certainty.

The situation with regards to rented dwellings is somewhat different in that any potential risks are not borne by the owner unless he or she is a resident landlord. However, the problems anticipated to result from residential mobility would also be expected to occur unless all rented radon prone homes were remediated. Potential exists in the rented sector for some form of statutory regulation of radon exposure which could compel remediation work.

One area where mobility tends to be low is amongst local authority tenants who tend to move infrequently. In these situations the degree of risk predicted to the individual tenant by a no mobility model relative to the radon level in the home is likely to be more accurate.

If radon proofing of existing dwellings is to remain a central tenet of UK radon policy, given that a large proportion of the population does generally move home both within and between areas, then the problem is one to be addressed at a public level and not at an individual level.

With regards to radon proofing new dwellings, the costs are much lower than the costs of remediation and even though the degree of risk is unknown, the fact that radon is a proven lung carcinogen in miners suggests that the present policy is a prudent one.

Economic arguments:

The health economics of the policy of radon remediation need to be considered further and in greater detail. Whilst it can be argued that the historical costs of the radon programme should not be included in the economic equation as those are no longer opportunity costs, clearly the ongoing costs of the programme should be included with the cost of remedial works and not merely the costs of the actual radon tests. It should also be borne in mind that the evaluation of radon remediation as a health intervention can only be valid if 100% of the dwelling stock affected by high radon levels is radon proofed, otherwise given the mobility of the residential population, the calculations of life years gained will regress in the same way that the degree of protection against radon risk offered regresses in a mobile population.

All the evidence relating to lung cancer shows that the major risk factor is smoking and the evidence points towards smoking cessation programs as being the most cost effective way in lowering lung cancer mortality. The BEIR VI committee concluded that "...deaths from radon-attributable lung cancer in smokers could most efficiently be reduced through tobacco control measures, in that most of the radon-related death among smokers would not have occurred if the victims had not smoked".

Radon mapping:

There appears to be some potential for unrepresentativeness in the current radon mapping as a result of bias in the method of collecting some of the data. The dataset could also be considered to be quite dated as it extends back nearly 25 years and major changes have been observed in the dwelling stock over this period which would be expected to have a considerable effect on internal radon levels.

Energy saving measures, typically the replacement of windows and doors with those incorporating draught-proofing, reduction of ventilation openings and the sealing up or removal of fireplaces have reduced the rate of air change in the typical dwelling and radon concentrations will be expected to have risen as a consequence.

Conclusions

The epidemiological evidence linking radon in the home to lung cancer is not robust. The difficulty this presents is that the precise public health impact of residential exposure is uncertain and may be lower than that predicted by models based largely on occupational exposures of underground miners. Until a more accurate method of determining the cumulative dose received by study subjects is available, case-control epidemiology is unlikely to offer the robustness required. The US Department of Energy invited grant applications in 1998 for research to support its cellular biology program to provide a better scientific basis for understanding risks to humans resulting from low level exposures to radiation, and in the future, molecular biology may provide epidemiologists with precision tools with which to work.

In addition to the lack of robustness of the epidemiological evidence, there are also significant uncertainties relating to the policy of radon control in existing dwellings. As a result, it is considered that there is insufficient evidence to regard the present UK policies as being in the best interests of protecting public health.

This is not meant to imply that radon control is not capable of conveying a health gain, merely that the potential for health gain has not been properly evaluated either on its own or more appropriately against other measures capable of improving the health of the public by reducing lung cancer mortality.

Recommendations

If risk assessment is to be used as the basis of policies intended to reduce lung cancer mortality, there needs to be an honest and open debate involving all stakeholders in which the potential benefits and disbenefits can be evaluated including technical issues, public values and economics. In order for this to happen, a number of issues need to be properly reassessed or evaluated, namely:-

- Further study specific to the UK population needs to be carried out to examine the extent to which residential mobility affects the risk to the public of lung cancer resulting from exposure to radon in the home
- The true costs of radon remediation as a health intervention need to be calculated, allowing for residential mobility.
- The numbers and locations of properties currently affected by higher than average levels of radon need to be re-evaluated
- An evaluation is needed comparing the effects of radon remediation against smoking cessation programmes as a means of lowering the prevalence of lung cancer.

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