# Smoking Cessation Programmes in Radon Affected Areas – Can they make a Significant Contribution to Reducing Radon-induced Lung Cancers?

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**Abstract.** Domestic radon levels in parts of the UK are sufficiently high to increase the risk of lung cancer in the occupants. Public health campaigns in Northamptonshire, a designated radon Affected Area with 6.3% of homes having average radon levels over the UK Action Level of 200 Bq m$^{-3}$, have encouraged householders to test for radon and then to carry out remediation in their homes, but have been only partially successful. Only 40% of Northamptonshire houses have been tested, and only 15% of householders finding raised levels proceed to remediate. Of those who did remediate, only 9% smoked, compared to a countywide average of 28.8%. This is unfortunate, since radon and smoking combine to place the individual at higher risk by a factor of around 4, and suggests that current strategies to reduce domestic radon exposure are not reaching those most at risk. During 2004-5, the NHS Stop Smoking Services in Northamptonshire assisted 2,808 smokers to quit to the 4-week stage, with some 30% of 4-week quitters remaining quitters at 1 year. We consider whether smoking cessation campaigns make significant contributions to radon risk reduction on their own, by assessing individual occupants' risk of developing lung cancer from knowledge of their age, gender, and smoking habits, together with the radon level in their house. The results demonstrate that smoking cessation programmes have significant added value in radon affected areas, and contribute a greater health benefit than reducing radon levels in the smokers' homes, whilst they remain smokers. Additionally, results are presented from a questionnaire-based survey of quitters, addressing their reasons for seeking help in quitting smoking, and whether knowledge of radon risks influenced this decision. The impact of these findings on future public health campaigns to reduce the impact of radon and smoking are discussed.

***KEYWORDS: radon, smoking, cessation, remediation, economics***

## 1 Introduction

### 1.1 Radon and Lung Cancer

Radon, a naturally occurring radioactive gas with variable geographical occurrence, concentrates in the built environment, including within domestic properties, contributing 50% to the average background radiation dose to the United Kingdom (UK) population [1]. At high concentrations in uranium mines, radon has been shown to be associated with increased risk of lung cancers, and extrapolation from the miners' data suggests that residents of high-radon areas are similarly at increased risk from lung cancer [2]. Meta-analysis of eight national epidemiological studies [3], case-control study in South-West England [4] and collaborative analyses of data from 13 European case-control studies [5] and from 7 North American studies [6], all support this view. Apart from the results of limited *in vitro* and animal experiments, the principal evidence on the combined effects of radon and tobacco smoke comes from the miners studies [2], indicating a synergistic effect of exposures to the two agents, although whether the effect is sub-multiplicative or truly multiplicative remains to be determined definitively. Current scientific consensus [2], however, is that smokers are at least 4 times more at risk from radon levels than are non-smokers.

Responding to the health threat posed by radon in dwellings, the UK Health Protection Agency (HPA) established an Action Level of 200 Bq·m$^{-3}$ for domestic properties and designated Radon Affected Areas, geographical entities where more than 1% of the housing stock is predicted to have radon concentrations in excess of the Action Level [7]. Northamptonshire was declared a radon Affected

Area in 1992 [8], and estimates of the total number of affected houses derived from HPA data suggest that test and remediation programmes are justified in Northamptonshire. However, public response to radon risks has hitherto been limited, affecting the health benefits and cost-effectiveness achievable by a remediation programme [9].

Examining the proposition that radon remediation programmes can be justified by the resultant health benefits and cost effectiveness, the Northampton Radon Research Group initiated studies of implementation and outcomes of radon remediation programmes in Northamptonshire. These studies, addressing National Health Service (NHS) properties [10], schools [11], workplaces [12], and private homes [13,14,15,16], demonstrate that radon remediation programmes can be economically justified and that the domestic remediation programme in Northamptonshire, if completed, could be favourably compared to other health initiatives, such as the UK mammography screening programme for women aged 50 to 65 [14]. The majority of early studies applied population-average risks and average home occupancy, overlooking the facts that various sections of the exposed population spend differing proportions of their total life in the home environment and that the occupancy factor of any individual will be age-, gender- and career-dependent. The European Community Radon Software (ECRS) [17] addresses these issues, permitting assessment of the additional mortality risk associated with individual radon doses, using age, gender, smoking status and radon level as input parameters. Our recent studies using ECRS have confirmed that, in Northamptonshire at least, remediation programmes are achieving less total health benefit than would be achieved if a cross-section of the population had remediated, with the population groups most at risk, young families and smokers, identified less likely to remediate [18].

### 1.2 Smoking Cessation

The 1998 White Paper "Smoking Kills" [19] described a comprehensive 'Stop Smoking' Service available across the NHS in England, providing counselling and support to smokers wanting to quit, and complementing the use of Nicotine Replacement Therapy (NRT) and Bupropion (Zyban), the principal prescription smoking and over-the-counter cessation aids available in the UK. In Northamptonshire, the smoking cessation programme is offered through General Practitices and associated staff (GPs), Pharmacists and Stop-Smoking groups (with a customised programme for pregnant smokers), and the Government target of 1000 smokers quitting per year has been achieved. Prior to 2007, the town of Northampton was served by a single Primary Care Trust (PCT) the remainder of the county of Northamptonshire being covered by a further two PCTs. Although these PCTs have now merged into a single county-wide entity, the study reported here is based on the earlier situation. Criterion for quitting is assessment at 4 weeks, with attempted validation by Carbon Monoxide monitor, the current success rate being 60% (above the national average). Patients are asked by questionnaire whether they have reverted to smoking at 6 and 12 months; these statistics are less reliable, as the response is low and not validated by CO monitor. Published results suggest that 25% of those who quit continue not to smoke at 12 months, and that there is age/sex bias in this group. Costs of the Northamptonshire smoking cessation programme are around £400 per quitter (FY 2005-06, c.f. Table 6), and costs of similar programmes elsewhere have been published [20].

### 1.3 Radon and Smoking

The study reported here addressed the special situation of Smoking Cessation campaigns in Radon Affected Areas, with the objectives of evaluating the cost-effectiveness of such campaigns and comparing their outcomes with co-located radon remediation programmes. Using data on smokers quitting permanently, together with imputed domestic radon concentrations derived the individual quitter's home postcode, the European Community Radon Software (ECRS) tool [17] was used to model the reduced individual risk from lung cancer resulting from permanent cessation, using the accumulated data to project overall health-care cost-savings. Results from this study are reported here.

## 2 Method

### 2.1 Data-set construction

Input data for the study comprised selected personal details of 432 52-week confirmed quitters monitored by the Smoking Cessation programmes in Northamptonshire during the period 2004-05. Ethical approval was obtained for the use of this data, which was anonymised prior to transfer to the research team. Retained data comprised age and gender, together with Postcode Sector, acting as surrogate for mean annual domestic radon exposure. Although all subjects were assumed to have quit smoking 52 weeks before entry to the database, the scope of the database extends over a full 12-month period, so not all subjects quit smoking simultaneously. Unfortunately, the database did not include the age at which the subjects commenced smoking. This deficiency was managed by assuming that all subjects commenced smoking at age 14, on the grounds that at least one subject was aged 15.

UK postcodes are hierarchical, comprising two components, a typical Northamptonshire code being NN1 2AB. The initial component, the 'outward code', directs mail from the originating sorting office to the destination office, while the final component, the 'inward code', sorts mail into individual delivery rounds. In the Northamptonshire example, the leading letters of the outward code (NN) represent the Northampton Area; the following digit or digits represent the District (1, corresponding to the central area of Northampton town) within that area. The first digit of the inward code (2 in this example, representing part of the central business area) defines the Postcode Sector, which may contain between a few hundred and a few thousand individual addresses depending on the locality.

The HPA 2004 Radon Atlas for England and Wales [21] tabulates arithmetic and geometric radon concentration levels at Postcode Area, District and Sector level, excluding from the tabulation for confidentiality purposes all entities with less than 10 radon results. Using the Atlas, the arithmetic mean annual radon concentration for the Postcode Sector of residence, or where that was not available, the mean level for the next highest tabulated hierarchical unit, was added to the anonymised data for each subject.

### 2.2 ECRS

The European Commission Radon Software (ECRS) [17], a Windows-based tool for PCs, performs lung-cancer risk calculations specific to European populations for various individual or collective radon exposure profiles, and evaluates, in terms of risk reduction, the efficiency of various countermeasures in dwellings. The Individual Risk calculation module determines, for an individual of given age and gender, the excess risk for a given radon exposure (past or future) time-profile, using demographic data specific to the selected population. The Collective Risk module determines the excess risk for each occupant of a dwelling, for a radon exposure time-profile derived from data describing the dwelling and its occupancy. These calculations use either epidemiological or dosimetric approaches. In each case, the modifying effect of tobacco consumption on the risk is accommodated, as is the time-frame of tobacco use, although no provision exists made for introducing the actual level, i.e. daily cigarette rate, of tobacco consumption. The executable is configured around a protected database containing a number of datasets, including demographic data, aerosol, breathing and smoking parameters and age/gender occupancy profiles, together with epidemiological, somatic, dosimetric and smoking risk models. Principal indicators calculated are whole-life mortality risk and loss of life expectancy.

### 2.3 Occupancy

ECRS provides the option to consider all of the occupants of a home as a family group, simplifying data entry by permitting details of the dwelling and its radon environment to be entered only once per household. The software requires values for the average occupancy for each gender at ages of 3 months, 1, 5, 10 and 15 years, and for adults aged above 15 years, providing four default occupancy sets based on various studies. The present study utilised an integrated-occupancy model, developed previously [18], merging data from three independent sources:

- Occupancy survey for by school-children, students and adults in Northamptonshire [22] which unfortunately, did not distinguish between males and females.
- Survey of residents of radon-remediated houses, which provided gender-specific data for adults.
- The ECRS default 'living room 100%' set, with values for children aged 3 months, 1 and 5 years.

### 2.4 Data Analysis

To provide sufficient data to permit consideration of all possible combinations of radon and smoking status, the following protocol was adopted:

a. For each real-life 52-week quitter, generate a synthetic 'family group', three individuals of identical age, gender, residence but differing smoking status, smoker, ex-smoker, never-smoker.

b. Specify ECRS analysis mode as:

   1. Collective exposure (i.e. all three individuals experience the same radon exposure)
   2. Epidemiological Risk Calculation (based on calculations from studies on uranium miners, assuming lung-cancer risk proportional to total radon exposure).

Analysis was performed on a case-by-case basis, each case representing an individual 'family group'. In addition to full output data generated in the principal MS Access file, summary output from each case was stored as an individual MS Excel file, and a master Excel spreadsheet was constructed to access data from the 432 individual output spreadsheets. Identification of subjects by Postcode Sector defines the radon exposure experienced in the individual home as the average for that sector.

## 3 Results and Discussion

The study population comprised 434 individuals, 210 males and 224 females, resident in the areas covered by Heartlands (342), Daventry (54) and Northampton (38) PCTs.

### 3.1 Radon Exposure

Figure 1 shows the distribution of domestic radon concentrations among the study population, while Table 1 summarises the statistics of the distribution. Although all study subjects reside in a radon Affected Area, the maximum mean annual radon concentration found is only 75% (151 Bq·m$^{-3}$) of the Action Level, while the mean and median values are of the order of 25% or the action Level (65 and 58 Bq·m$^{-3}$ respectively). This apparent discrepancy is due to the lognormal distribution of results typically found in any extensive radon measurement set.

Figure 1: Distribution of Domestic Radon environment among study population.

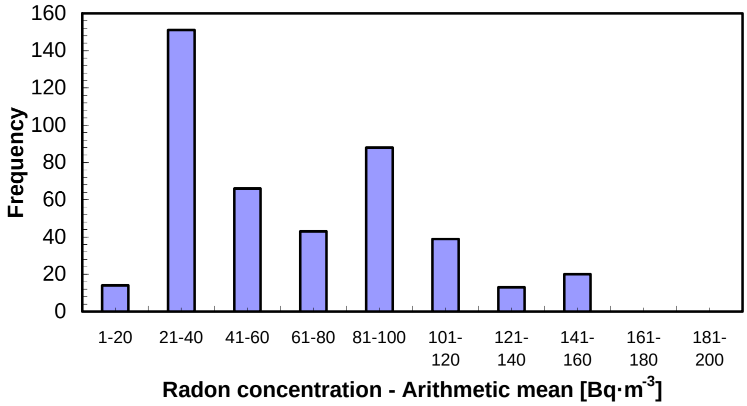


Table 1: Summary of Radon Distribution Statistics

| | Radon Concentration [$Bq.m^{-3}$] |
|---|---|
| Max | 151 |
| Median | 58 |
| Min | 15 |
| Mean | 65.23 (95% C.I. = 3.40) |
| St. Dev. | 36.08 |

Although around 6% of homes in Northamptonshire possess radon concentration levels in excess of the Action Level, the average for the area is strongly biased by the remaining 94% of homes with radon levels below the action Level. In the present study, the observed mean radon concentration, 65 $Bq.m^{-3}$, compares well with the arithmetic mean figure for the county as a whole, 70 $Bq.m^{-3}$, reported in the HPA Radon Atlas of England and Wales.

### 3.2 Demography

Figure 2 shows the age distributions for males and females, that for males being unimodal and moderately negatively skewed while that for females is arguably bimodal. Figure 3 sets the age distribution of the total population (males plus females) in context, comparing it with both the population distribution of Northamptonshire as a whole and the UK national incidence of smoking.

Figure 2: Age and Gender Distribution of Study Subjects.
Solid bars: Male Hatched bars: Female

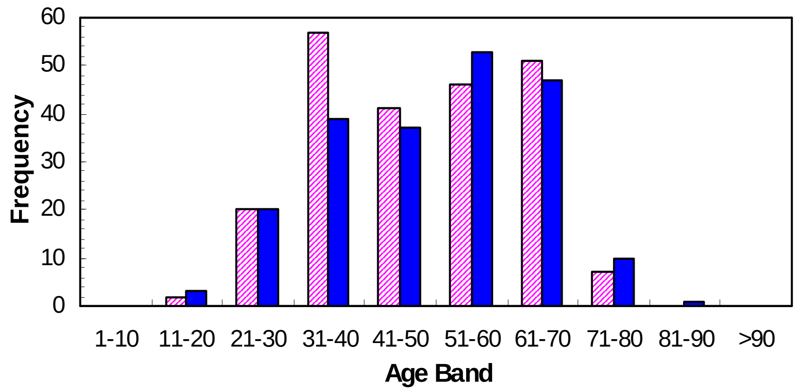
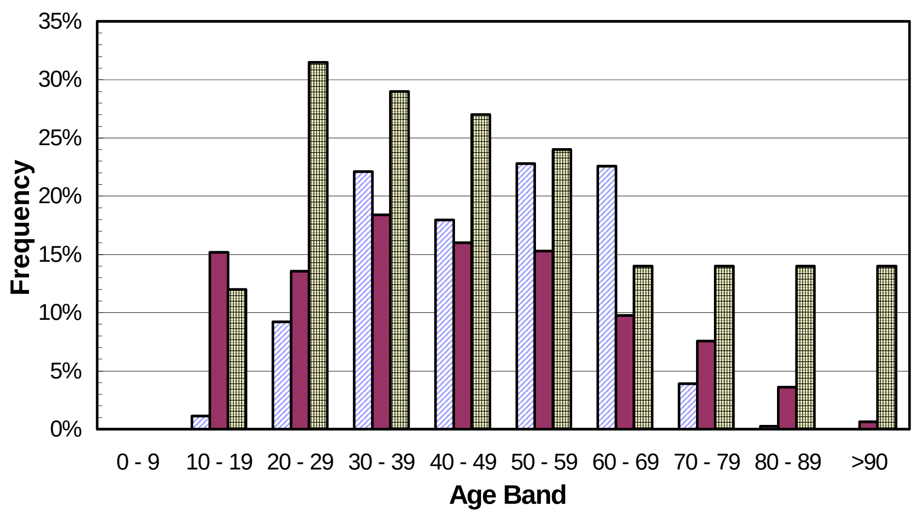



Figure 3: Age Distributions in Study and UK National Smoking Populations.
Diagonal hatch: Smoking Cessation Study
Solid: Northamptonshire (2001 Census): Cross-hatch: UK National Smoking Incidence



### 3.3 Mortality

ECRS calculates a number of mortality-related parameters.

- **Whole Life Lung Cancer Mortality**: the subject's lifetime risk of lung cancer, i.e. the lifetime probability of dying from lung cancer.
- **Whole Life Excess of Lung Cancer Mortality**: the subject's additional risk of lung cancer as induced by the subject's exposures, or the lifetime probability of dying from a lung cancer attributable to the exposure under consideration.
- **Whole Life Relative Excess of Lung Cancer Mortality**: the ratio of the whole life excess of lung cancer due to the subject's exposure and their baseline whole-life lung cancer mortality in the absence of exposure.

Table 2 reports Mean and 95% Confidence Interval (CI) data for these three parameters for the study population of 432 individuals, summarising the influence of exposure to radon, separately and jointly with smoking, for Never-Smokers, Ex-Smokers and Smokers. For Non-Smokers, with a baseline Whole-Life Lung-Cancer Mortality prediction of 1.17%, exposure to radon in Northamptonshire increases mortality to 1.37%. For Ex-Smokers and Smokers, mortality is 6.13% and 15.37% respectively in the absence of radon exposure, increasing to 6.78% and 16.73% respectively under radon exposure. Excess Mortality and Relative Excess Mortality naturally exhibit similar trends.

Table 2: Summary of Lung Cancer Mortality parameters for Non-Smoker, Ex-Smoker and Smoker Subject Populations (432 individuals)

| | **Baseline** | **Non-Smoker** | **Ex-Smoker** | | **Smoker** | |
|---|---|---|---|---|---|---|
| | No Exposure | Radon | Smoking | Radon + Smoking | Smoking | Radon + Smoking |
| ***Whole life Lung Cancer Mortality*** | | | | | | |
| Mean | 1.17% | 1.37% | 6.13% | 6.78% | 15.37% | 16.73% |
| 95% CI | 0.03% | 0.04% | 0.44% | 0.47% | 0.38% | 0.40% |
| ***Whole Life Excess of Lung Cancer Mortality*** | | | | | | |
| Mean | 0.00% | 0.20% | 5.00% | 0.69% | 14.33% | 1.59% |
| 95% CI | - | 0.01% | 0.44% | 0.05% | 0.35% | 0.09% |
| ***Whole Life Relative Excess of Lung Cancer Mortality*** | | | | | | |
| Mean | 0.00% | 16.83% | 444.88% | 13.98% | 1228.69% | 9.10% |
| 95% CI | - | 0.96% | 38.78% | 0.90% | 5.22% | 0.50% |

Figure 4: Mortality Profiles for Northants Population.
diamond: non-smoker, triangle: ex-smoker, circle: smoker, open symbol: radon exposure

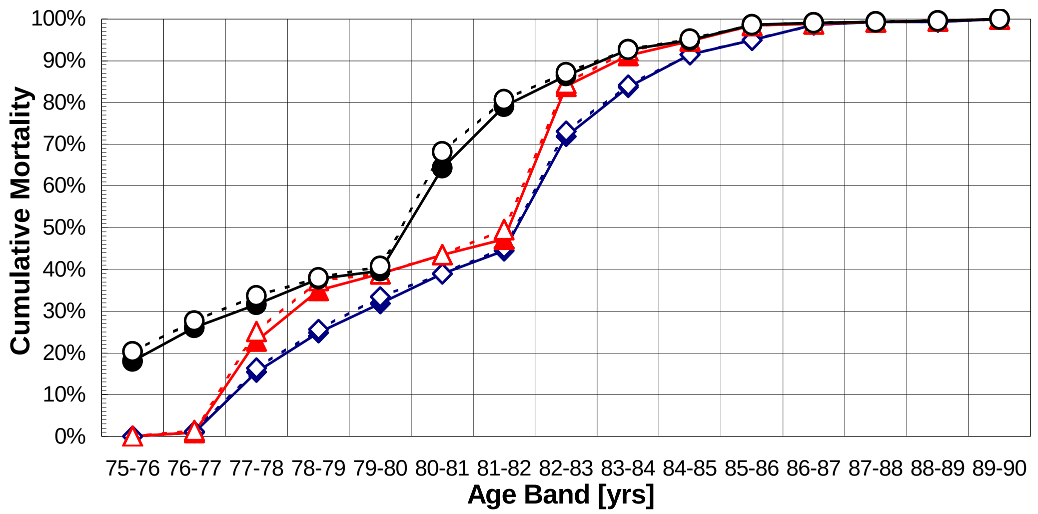


Figure 4 shows the effects of smoking and radon exposure on the cumulative mortality profile of the population studied resulting from this re-analysis. For non-smokers in the age-range 75 - 82 years, radon exposure increases mortality by about 1%. Above this range, there is little discernible effect.

For ex-smokers, the excess mortality caused by radon over the same age-range is of the order of 2%. For smokers in the age-range 75 - 82 years, excess mortality attributable to radon is between 2% and 5%. However, over most of the age-range plotted in the graph, the excess mortality directly attributable to smoking is in the range 15% - 20%. The effect of smoking on the mortality profile is considerably greater than the effect of radon, with minimal discernible difference in the details of the mortality profiles between non-smokers and ex-smokers exposed to radon and not exposed. More detailed calculations, not reported here, can be made for Males and Females separately. For lifetime smokers, however, the additional effect of radon exposure can be distinguished, and Table 3 shows the cumulative mortality at age 80 for the various classes of subject.

Table 3: Influence of Smoking and Radon Exposure on Cumulative Mortality at Age 80.

| | **Baseline** | **Non-Smoker** | **Ex-Smoker** | | **Smoker** | |
|---|---|---|---|---|---|---|
| | No Exposure | Radon | No Exposure | Radon | No Exposure | Radon |
| % Mortality at Age 80 | 38.7% | 38.7% | 43.3% | 43.3% | 64.3% | 68.2% |
| XS mortality attributed to smoking | 0.0% | 0.0% | 4.6% | 4.6% | 25.6% | 29.5% |
| XS Mortality attributed to Radon | | 0.0% | | 0.0% | | 3.9% |

### 3.4 Loss of Life Expectancy

Table 4 summarises loss of life expectancy following exposure to radon, tobacco and the two in combination, presenting mean and 95% C.I. results from the total population of 432 subjects. The effect of radon exposure on life expectancy among the study population is relatively low, with a maximum reduction of around 0.5 years. The impact of smoking is more severe, life reduction in the under-50 population exceeding 1.5 years for females 2.2 years for males. Summing the modelled results from the total population of 432 subjects, Table 5 indicates the full extent of the loss of life expectancy on a population-wide basis. Overall, exposure to radon is responsible for the loss of some 12 life-years among the population.

Table 4: Individual Loss of Life Expectancy

| | **Baseline** | **Non-Smoker** | **Ex-Smoker** | | | **Smoker** | | |
|---|---|---|---|---|---|---|---|---|
| | No Exposure | Radon | Smoking | Radon | Smoking + Radon | Smoking | Radon | Smoking + Radon |
| Individual Loss of Life Expectancy [years] | | | | | | | | |
| Mean | 0.00 | 0.03 | 0.62 | 0.10 | 0.72 | 1.72 | 0.21 | 1.93 |
| 95% CI | | 0.00 | 0.01 | 0.04 | | 0.00 | 0.00 | |
| Individual Relative Loss of Life Expectancy [years] | | | | | | | | |
| Mean | 0.00% | 0.09% | 3.16% | 0.44% | 3.60% | 6.34% | 0.77% | 7.11% |
| 95% CI | | 0.01% | 0.04% | 0.25% | | 0.00% | 0.00% | |

Table 5: Population Loss of Life Expectancy

| **Baseline** | **Non-Smoker** | **Ex-Smoker** | | | **Smoker** | | |
|---|---|---|---|---|---|---|---|
| No Exposure | Radon | Smoking | Radon | Smoking + Radon | Smoking | Radon | Smoking + Radon |
| Population Total Loss of Life Expectancy [years] | | | | | | | |
| 0.00 | 12.09 | 269.62 | 43.68 | 313.30 | 746.05 | 92.35 | 838.40 |

### 3.5 Cost-Effectiveness Studies

In the UK, treatment of smoking-related disease has been estimated to cost the NHS £1.4bn - £1.5bn per year (about 0.16% of the gross domestic product) [20]. The topic of smoking cessation cost-effectiveness, has received considerable attention nationally, and although the detailed numbers differ between studies based on the assumptions made, there is general consensus that smoking cessation can save years of life, at a low cost compared with alternative interventions [20].

For realistic comparison between the relative costs of saving one life-year from smoking cessation and radon remediation in Northamptonshire, it is necessary to derive realistic location-specific figures for these parameters. Table 6 summarises smoking cessation costs for the PCTs covering Northamptonshire, together with averaged figures for the County. Costs presented here include the PCT budget for Smoking Cessation services, together with relevant medication, but do not take account of costs incurred at the GP practice level, principally GP and Practice Nurse time.

Table 6: Smoking Cessation Costs for Northants, 2005-06

| PCT | No. of 4-week Quitters | Service Budget 2005/06 | NRT/Zyban Costs 2005/06 | Cost per 4-week Quitter |
|---|---|---|---|---|
| Heartlands | 1451 | £269,613 | £303,279 | £394.83 |
| Daventry & S. Northants. | 518 | £81,918 | £101,318 | £353.74 |
| Northampton | 1051 | £202,000 | £198,386 | £380.96 |
| Total | 3020 | £553,531 | £602,983 | £382.95 |

Note, however, that the criterion for successful quitting applicable to these costs is based on abstinence from tobacco for a period of 4 weeks, validated by CO monitoring, whereas the mortality results reported above are based on self-reported and unvalidated 52-week abstinence. Table 7 shows an indicative provisional cost-effectiveness analysis based on these figures, together with some comparative values from the literature. The figure of £750 for remediation of a dwelling is an average value representing recent experience of a single contractor remediating homes in Northamptonshire and operating to the UK Radon Council Code of Practice [23]. Undiscounted costs per life-year saved from smoking cessation range from £159 to £658, depending on the level of intervention [20]; the figure of £500 represents an estimate, while a further estimate of 25% of 4-week quitters remaining tobacco-free after 12 months is applied to generate the final column of the table.

Table 7: Provisional Cost-Effectiveness Analysis - Assumptions Still to be Validated

| | | Per Quitter | Per Home | Total | Cost per Life-Year saved |
|---|---|---|---|---|---|
| Cost of remediation | | | *£750* | *£324,000* | *£2,187* |
| Cost per Quitter | National | *£500* | | *£216,000* | *£850* |
| | Northants | *£500* | | *£216,000* | *£850* |

Direct comparison of the costs per life-year saved or radon remediation and smoking cessation programmes is complicated, firstly by the fact that the cost per life-year saved varies so significantly with the mode of intervention, and also by the fact that remediation of a home directly affects all of its residents, whereas smoking cessation is intrinsically a personal experience. For this, and other reasons, the results presented here require further validation and justification, both from published national statistics and from analyses of local costs and outcomes.

### 3.6 Attitudes to Radon and Smoking in Northamptonshire

To clarify understanding of the population's knowledge of and attitude to domestic radon risks, a questionnaire-based postal survey was administered to a cohort of 317 quitters counselled by the Northamptonshire Smoking Cessation Service. This questionnaire was sent, with their consent, to all patients counselled within the period July – September 2006, following their 12-month review contact in the Autumn of 2007. In addition to collecting anonymised demographic data, the questionnaire explored 23 factors influencing the decision to stop smoking, among them the prospect of developing bronchitis, lung cancer and other cancers, pregnancy, the effect of an individual's smoking habit on family, friends and colleagues, legislative measures and the perceived risk from radon gas. 103 clients (32%) responded, of whom 66 remain quit at 12 months. Respondents were asked to rank each reason for quitting as having major, minor or zero influence in informing their decision to quit smoking, and a weighted average was generated for each of the 23 proposed reasons. Respondents were classified as residing in localities of high, medium or low radon risk, using as classification tool the projected percentage of homes with mean annual radon concentrations above the HPA Action Level of 200 $Bq\cdot m^{-3}$, using data presented in the HPS Radon Atlas [21], results being shown in Table 8.

Table 8: Knowledge of the Risks of Radon as a Factor Influencing Smoking Cessation

| Radon Risk | % Homes > A.L. | Replies | Radon Risk Rank (of 23) | Respondents Ranking Radon | | | | Weighted Ranking | Relative Weighted Ranking |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Major | Minor | Zero | Blank | | |
| Low | 0 - 4.9% | 85 | 21 | 6 | 8 | 45 | 26 | 79/190 | 0.61 |
| Medium | 5.0 - 9.9 | 13 | 21 | 0 | 2 | 10 | 1 | 14/35 | 0.40 |
| High | >10.0 | 5 | 22 | 0 | 0 | 3 | 2 | 3/13 | 0.23 |
| Total | | 103 | | 6 | 10 | 58 | 29 | | |

While respondents, almost unanimously, regarded risk of developing bronchitis as a significant reason for giving up smoking, knowledge that the presence of radon gas in the home increases health risk was regarded as a significant decision factor by very few respondents, only 16 of the total of 103 regarding radon as a risk of any magnitude.

## 4 Conclusions

Overall, these studies confirm that individual and population mortality increases with both smoking status and radon exposure, with smoking accounting for 5 to 8 times more life-years lost than radon in the study population. Smoking cessation programmes have quantifiable added value in radon affected areas, and contribute a greater overall health benefit than that achieved by reducing radon levels in smokers' homes whilst they remain smokers. An even greater effect is achieved from smoking cessation and radon reduction in combination, but the health impacts are disproportionate. In high radon areas, it is therefore potentially more cost-effective (£ per life-year saved) to target smoking-cessation rather than radon-remediation, the individual benefits to smokers massively outweighing the benefits gained from remediating their homes. Other, ongoing, studies indicate that even in a high-radon area, the lung cancer risk from radon is not perceived as a reason for smoking cessation, and the question therefore arises as to whether increased publicity of the multiplicative nature of the risks from smoking and radon would increase the uptake or smoking cessation services.

A number of issues remain, in particular ensuring that any comparison actually compares equivalent data. Current estimates for cost per life-year saved from remediation area based on a "per-house" basis while smoking cessation costs are, intrinsically, calculated on an individual basis. 'People per house' occupancy data is available for all regions of the UK, and could be factored into comparison calculations, although it is probably not possible to do this in the retrospective situation considered here as the available data contains no information concerning subjects' household composition.

## 5 References


[1] DARBY, S., HILL, D., DOLL, R. Radon – a likely carcinogen at all exposures. Annals of Oncology 12 (2001) 1341.

[2] BEIR VI (Committee on Health Risks of Exposure to Radon). Health Risks of Exposure to Radon. Washington DC, USA: National Academy Press (1999).

[3] LUBIN, J., BOICE, J. Lung Cancer Risk from Residential Radon: Meta-Analysis of Eight Epidemiological Studies. J. Nat. Cancer Inst. 89 (1997) 49.

[4] DARBY, S. et al. Risk of lung cancer associated with residential radon exposure in south-west England: a case-control study. Brit. J. Cancer 78 (1998) 394.

[5] DARBY, S et al. Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case-control studies. BMJ 330 (2005) 223.

[6] KREWSKI, D. et al. Residential radon and risk of lung cancer: a combined analysis of 7 North American case-control studies. Epidemiology 16 (2005) 137.

[7] O'RIORDAN, M. Human exposure to radon in homes: recommendations for the practical application of the Board's statement. Docs. NRPB 1 (1990) 17.

[8] MILES, J., GREEN, B., LOMAS, P. Radon affected areas: Derbyshire, Northamptonshire and Somerset. Docs. NRPB 3 (1992) 19.

[9] COSKERAN, T. et al. A cost-effectiveness analysis of domestic radon remediation in four primary care trusts located in Northamptonshire, UK. Health Policy 71 (2005) 43.

[10] DENMAN, A. et al. The health benefits and cost effectiveness of the radon mitigation programme in NHS properties in Northamptonshire. J. Radiol. Prot. 17 (1997) 253.

[11] DENMAN, A., PHILLIPS, P. The cost-effectiveness of radon mitigation in schools in Northamptonshire. J. Radiol. Prot. 18 (1998) 203.

[12] DENMAN, A., PHILLIPS, P. Workplace radon in Northamptonshire. Env. Management and Health 9 (1998) 194.

[13] DENMAN, A., PHILLIPS, P. A review of the cost-effectiveness of radon mitigation in domestic properties in Northamptonshire. J. Radiol. Prot. 18 (1998) 119.

[14] KENNEDY, C. et al. A cost effectiveness analysis of a residential radon remediation programme in the United Kingdom. Brit. J. Cancer 81 (1999) 1243.

[15] DENMAN, A., PHILLIPS, P., TORNBERG, R. A comparison of the costs and benefits of radon remediation programmes in new and existing houses in Northamptonshire. J. Environ. Management, 59 (2000) 21.

[16] COSKERAN, T., DENMAN, A., PHILLIPS, P. The costs of radon mitigation in domestic properties. Health Policy 57 (2001) 97.

[17] DEGRANGE, J. et al. European Commission software tool for radon risk calculation and evaluation of countermeasures. Proc. $10^{th}$ Int.Congr. IRPA, Hiroshima, Japan (2000).

[18] DENMAN, A. et al. Assessment of individual health benefits accruing from a domestic radon remediation programme. J. Radiol. Prot. 24 (2004) 83.

[19] HM GOVERNMENT. Smoking kills: a White Paper on tobacco. CM4177. London: The Stationery Office (1998).

[20] PARROTT, S., GODFREY, C. ABC of smoking cessation. Brit. M. J. 328 (2007) 947.

[21] GREEN, B. et al. Radon Atlas of England and Wales. Chilton, National Radiological Protection Board (2002).

[22] BRIGGS, D. et al. Time-activity modelling of domestic exposures to radon. J. Env. Man. 67 (2003) 107.

[23] KENNEDY, C. et al. The cost-effectiveness of residential radon remediation programmes: assumptions about benefits stream profiles over time. J. Env. Rad. 59 (2002) 19.