Questions have been raised about the economic implications of the regulations governing radon gas level identification and remediation in buildings. Attempts to answer the economic questions related to proposed policy have been varied and criticised for lack of scope and comparability. It is imperative therefore that a general model for the evaluation of radon remediation programmes is adopted by participating interests to ensure the comparability and usefulness of ratios in decision making. This paper presents a general guideline for the use of cost-effectiveness analysis (CEA) as an economic appraisal tool in the evaluation of radon reduction and prevention programmes. The data requirements for a CEA of radon remediation programmes, include both costs and outcomes. These components are discussed in the materials and methods with consideration of the following factors: programme objectives, comparator choice, perspective, time horizon, discounting, uncertainty, and final ratios. These must be kept in mind at all stages of programme development in order that continuing and meaningful evaluation of radon remediation programmes will be possible. By evaluating the radon remediation programme in similar terms with other health interventions (lung cancer prevention interventions), comparisons can be made based on outcomes and costs per life year gained.

Keywords: radon-induced-lung-cancer, radon-remediation, cost-effectiveness-analysis, cost-effectiveness-ratio, economic-evaluation, health-intervention, economic-appraisal, regulation-evaluation, radon-screening, life-years-gained.

INTRODUCTION

Over the last two decades epidemiological and technical research on the association between radon and lung cancer has produced information which has enabled attentions to be turned to radon identification and remediation programmes in buildings (NRPB 1988; Hughes and O'Riordan 1993). Decision making about policy implementation has been an integral part of these programmes (BRE 1992; EC 1990) and questions have been raised about the economic implications of the regulations (NRPB 1988; EC 1990; Mossman and Sollitto 1991; Colgan and Guiterrez 1995; Ford et al 1999). Attempts to answer the economic questions related to proposed policy have been varied and criticised for lack of scope and comparability. This paper proposes a general guideline for the use of an economic appraisal tool in the evaluation of radon prevention programmes.

Cost-effectiveness analysis (CEA) is the economic appraisal tool to aid the decision making process in radon regulation explored in this paper. In this specific type of economic analysis we are interested in the systematic evaluation of health outcomes and resource costs of health interventions (Russell et al. 1996). The main goal of radon remediation programmes is a reduction in radiation exposure, and the corresponding decrease in the number of radon-induced lung cancers. This type of programme is a health prevention intervention and can be evaluated using the best available and most appropriate economic tools.
Information provided by cost-effectiveness analyses (CEA) of radon remediation programmes can be used by environmental or health planning and policy administrators to help to ensure that their decisions include consideration of the far reaching economic implications of proposed or existing policies and programmes, in particular the opportunity cost of investing in this area of disease prevention. CEA is not preferred as the sole basis for decision making: it should be used in conjunction with consideration of ethical and political issues (Gold et al 1996 p.7). Using CEA as an evaluative tool in radon remediation is an example of the application of interdisciplinary methods in study of human-environment interactions.

The strength of using CEA to evaluate health interventions or programmes lies in the comparability of the results with CE ratios of alternative proposals and other health interventions. It thus provides answers to questions concerning the best way of attaining an objective, given that the decision maker has already determined this objective(s) is worth pursuing. It therefore provides relative rather than absolute answers: not 'Is human life worth preserving?' but, 'Given that human life is worth preserving, what is the most efficient way of accomplishing it?'. Figure 1 is useful in describing the importance of comparability. The cost-effectiveness plane is used to compare the costs and effectiveness of alternative programmes or interventions.

A key to ensuring cross-study comparisons is the adoption of a general framework for cost-effectiveness analysis. This is a particularly important point in the case of radon remediation because few cost-effectiveness studies adhering to the methodological framework proposed for health interventions (Gold et al. 1996; Drummond et al. 1997), have been undertaken (Ford et al 1999; Kennedy et al 1999). A general framework for evaluation should be adopted, in order that the resources required to obtain health gain from radon mitigation can be systematically compared with equivalent data for other health interventions.

WHY CEA AND NOT JUST REPORT COSTS?

Reporting only the resource costs of the programme does not reflect the savings and costs of the resulting outcome. Several published studies of radon detection and remediation programmes in domestic properties have reported only estimated and actual programme costs, expressed in costs per lung cancer case averted: for Spain (Colgan and Gutierrez 1996), for Sweden (Snihs 1992), for Canada (Letourneau et al. 1992), for the United States (Marcinowski and Napolitano 1993) and for Northamptonshire (Denman and Phillips 1998). Mossman and Sollitto (1991) estimated benefit /cost ratios of residential radon policy proposals in the United States but did not include all direct costs (identification costs). The usefulness of these studies for decision making purposes is limited because of the lack of comparability of these studies with other health interventions: that is, they can only be compared with other ways of averting lung cancer cases.

Without being able to compare the CE ratios of alternative programmes, the decision maker will be able to make only very limited use of the reported costs information. It is imperative therefore that a general model for the economic evaluation of radon remediation programmes is adopted by participating interests to ensure the comparability of ratios.
The data requirements for a CEA must be kept in mind at all stages of programme development in order that continuing evaluation is possible. It is conceivable that whole programmes have been introduced and that subsequent questions about cost-effectiveness could not be answered because data on key parameters such as remedial work costs and number of building occupants exposed, were not systematically collected. The purpose of this paper is to specifically outline the data requirements of the CEA of radon building remediation programmes.

THE MATERIALS AND METHODS OF A CEA OF RADON REMEDIATION

This study is set in the context of UK residential radon remediation programmes, but can be expanded to encompass other settings.

Programme Objective(s):
The objective of most radon remediation programmes will be to reduce radon exposure and consequently decrease in the number of radon-induced lung cancer cases. These objectives then require framing from a particular perspective (Gold et al 1996).

Perspective(s):
The analytical perspective to adopt in respect of radon remediation programmes is potentially very complex, depending on the organisation and enforcement of policies or legislation. For the purposes of defining a base-case scenario, a societal perspective should be adopted wherever possible. This is where the analysis includes consideration of all those affected by the programme and all significant health outcomes and costs associated with these people (Gold et al 1996). All types of costs including medical and participant time are accounted for. This then allows for different interests to carry out secondary analyses to chart the magnitude of effects on each in turn. Outlining explicitly from whose viewpoint costs and outcomes will be defined is key in then deciding who incurs what costs and who benefits from what outcomes in the programme.

Choice of Comparator(s):
There are many incremental comparisons that can be made within any CEA (Gold et al 1996). In a CEA of radon remediation programmes the choice of different assumptions is large, and it is important to choose an appropriate comparator within and without a CEA. Ensure for example, that there is a distinction made between the CE ratio calculated from an opportunistic remediation programme and a post-systematic screening remediation programme. Before any conclusions can be drawn from any CE ratio calculated, a comparator must be specified.

Horizon:
The horizon over which benefits and costs are expected to arise varies between interventions. Preventive health interventions may have to be evaluated using longer horizons than for curative interventions (Haddix et al. 1996). The horizon chosen by Colgan and Gutierrez (1996) and Denman and Phillips (1998) studies is 40 years. Justification of this choice is not made explicit in these studies. However, it may be based on the anticipated life expectancy of the remediation measures or on the mean manifestation period, where full expression of pulmonary malignancy after initial exposure to Rn decay products is expected at 40 years (UNSCEAR 1977).
Discounting:
The costs and outcomes of a programme are spread over time, defined as noted above in the choice of time horizon. But individuals generally prefer receiving benefits today to receiving them 5 years in the future. Opportunity cost also enters into this: resources not used now can be invested at a real rate of return. To take account of these, we discount values of future costs or outcomes by a set rate so that future costs and outcomes are given less weight than present ones. The resultant present values reflect the time value of resources (Gold et al. 1996). It is generally accepted that pecuniary costs and outcomes be discounted according to the regional guidelines prescribed. In the UK, HM Treasury sets out the prescriptive rates for discounting in central government evaluations. The rate currently stands at 6% (HM Treasury 1997). Whether or not the non-pecuniary outcomes should be discounted is currently debated (Russell et al. 1996). It is suggested here that one rate be chosen and applied across all applicable future values (pecuniary and non-pecuniary). However, as long as the choice is made explicit and is consistently applied, by varying this assumption in the subsequent sensitivity analyses, it will not undermine the comparability of the analysis.

Uncertainty:
In any study involving stochastic data there are measures of uncertainty reported. In radon remediation programmes uncertainty surrounds the estimates of effectiveness, of costs and of outcomes. Policy makers need to be aware of how these sources of uncertainty and changes in assumptions may affect the cost-effectiveness ratios estimated (Weinstein et al. 1996). Sensitivity analysis is a technique for exploring and interpreting the consequences of uncertainty in the analysis.

There are three main forms of sensitivity analysis: one-way, multivariate and probabilistic (Briggs et al. 1994). Each requires a different degree of knowledge about the nature and magnitude of the uncertainty. The form requiring the least information about parameter estimates is one-way. The data requirements for a one-way sensitivity analysis are the standard deviations and distributions of each stochastic parameter estimate. For example, in Kennedy et al. (1999) the standard deviations were reported around treatment costs and key parameters were varied within plausible bounds. This is the most basic form of sensitivity analysis and can only answer questions of quantitative ratio changes. As the information regarding uncertainty around parameter estimates improves, and also consensus is reached on how best to carry out the sensitivity analysis, the other forms described above can be employed.

COSTS
Identification/Screening:
The first step in any radon remediation programme is the identification of buildings which are over the pre-defined reference level, these levels vary over regions and countries¹ (EC 1990). Unit costs of measuring radon levels per building or room should include delivery, reading and reporting costs from the devices chosen, even if there is no explicit charge made to the occupants (in economics costs are not synonymous with charges, prices fees or tariffs). The total identification costs must be allocated to

¹ For example, 200 Bq m⁻³ in UK homes, 400 Bq m⁻³ in workplaces, 148 Bq m⁻³ in United States homes, 800 Bq m⁻³ in Canada homes, and 20 Bq m⁻³ for homes in the Netherlands (EC 1990).
those buildings in a surveyed area which are ultimately remediated. The number of buildings or rooms
tested, and the percentages of those found to be over the reference level, must be known.

**Effectiveness measurement:**
In order to gauge the effectiveness of the remediation, follow-up radon tests must be made in those
buildings or rooms that were remediated. The follow-up test costs should be included and results noted.

**Remedial Work:**
Data on the costs of remediation work undertaken is clearly very important. Total capital costs
(physical) of remedial work must be combined with any maintenance and running costs associated with
the remediation that will be incurred over the horizon defined. Maintenance, running, and possibly
replacement costs will be incurred after the initial remediation outlay, and are therefore future costs
associated with the remediation. Future costs can be discounted to reflect the changing value of money
over time. Consideration of local taxes can be made on a region specific basis, as long as the
assumption taken is stated explicitly.

**Outcomes:**
The objective of remediation programmes was described above as reducing population exposure to
radon and therefore reducing the number of lung cancer cases which would be expected to result from
the radon exposure. Direct costs associated with the estimated outcome of number of lung cancer cases
can be measured and considered in the ratio calculation. Published country or region-specific costings
for the treatment of lung cancer are rare (Wolstenholme and Whynes 1999). However, this information
is needed if the costs of lung cancer cases averted are to be included in the analysis. Table 1 presents
some published lung cancer costings and their respective countries and regions of study.

**OUTCOMES**

**Risk Exposures:**
In order to calculate the number of lung cancers which would have been expected from an exposure of
the magnitude prevented by the remediation, epidemiologically-derived risk estimates must be
employed. Risk estimates for radon-induced lung cancer have been reported by the ICRP and other
national radiological associations in the world (ICRP 1987). Residential radon risk is debated but
recent studies have shed light on this area (Darby et al. 1998). Studies are currently underway to pool
European and North American indoor radon risk estimates for lung cancer, and a more precise and
useful estimate of risk is expected to result from these analyses, which are expected in early 2000
(Darby et al 1998). For the purposes of discussion in this paper the ICRP estimate is suggested. The
lifetime risk of lung cancer per working level month (WLM) as 3.5*10^-4 for each year of exposure
(ICRP 1987). The number of lung cancers averted can be calculated using this or similar risk estimates
with the radon exposure prevented.

**Life years gained per lung cancer case:**
To follow the framework for the CEA of health interventions presented in Gold and others (1996), a
denominator showing effectiveness is chosen. Ideally, a measure such as the number of quality adjusted
life years gained by the reduction of lung cancer cases could be used. However, no measures of this
could be found that could be used on an aggregate level (ie: from small and non-small cancers, and
over all ages), the closest available estimates are for chronic bronchitis (Fryback et al 1993). Using local cancer mortality data, the average number of life years gained from a lung cancer case can be easily calculated. These calculations will not be shown here, details can be found in any basic epidemiology textbook (eg: Petitti 1994 pp138-142).

To get the denominator for the ratio, simply multiply the number of life years per lung cancer case with the calculated number of lung cancer cases averted by the prevention programme. This can be considered as a future benefit accruing from the programme and therefore discounted so that the present value of those years today reflects the time preference for the years. The choice of discount rate for this outcome will have been decided prior to the analysis (see discounting paragraph above).

RESULTS

Net costs and net outcomes are brought together to produce the cost-effectiveness ratio. For example see Table ii. The net outcomes and net costs are calculated. Alternatives can be compared. In the case of radon remediation programmes, the comparator ratio may be from a no programme or a different identification procedure situation. Therefore, the incremental cost-effectiveness ratio will be the ratio calculated from the net costs and outcomes. Reporting ratios from several different perspectives may be useful for radon remediation programme evaluation. Concerns over the incidence of costs (who pays) or the decision maker (who decides) may affect the overall decision making process.

FUTURE DIRECTIONS AND INTERPRETATION

By evaluating the radon remediation programme in similar terms to other health interventions, comparisons can be made based on outcomes and costs per life year gained. The cost-effectiveness ratios calculated can then be compared to the results from all other cost-effectiveness ratios reported in published studies of health care interventions in the country or region of interest. For example Briggs and Gray (1999) collate the results for all cost-effectiveness of health intervention studies in the United Kingdom before 1996.

Assessing the cost-effectiveness of a particular intervention is complicated by the absence of any explicit "ceiling" ratio in health care sectors. As the CEA tool is used in more public health intervention evaluations, the value of the ratios, their comparability, will increase.

Adherence to accepted methodological techniques in future evaluations of prevention programmes will facilitate comparison in the future. This paper highlights the need for the evaluation of other radon-induced lung cancer prevention programmes in other countries using comparable methodological techniques. It is imperative therefore that a general model for the economic evaluation of radon remediation programmes is adopted by participating interests to ensure the comparability of ratios. This paper has outlined such a general model and has discussed the data requirements for a CEA. These must be kept in mind at all stages of programme development in order that continuing and meaningful evaluation of radon remediation programmes will be possible.
REFERENCES


Table i: Lung Cancer Treatment Cost Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Costs (1998£)</th>
<th>Country or Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wolstenholme and Whynes 1999</td>
<td>£7,303</td>
<td>UK, Trent</td>
</tr>
<tr>
<td>Kennedy et al. 1999</td>
<td>£6,873</td>
<td>UK, Trent and SH</td>
</tr>
<tr>
<td>Evans et al 1995</td>
<td>£16,404</td>
<td>Canada, Ontario</td>
</tr>
<tr>
<td>Sanderson et al. 1992</td>
<td>£6,137</td>
<td>UK, Southampton</td>
</tr>
<tr>
<td>Rosenthal et al.1992</td>
<td>£10,157</td>
<td>Australia (small cell)</td>
</tr>
<tr>
<td>Baker et al.1991</td>
<td>£13,861</td>
<td>US</td>
</tr>
</tbody>
</table>

Table ii: Example A Cost-effectiveness Ratio Calculation

Net costs = identification costs + remedial work (partially discounted) - lung cancer treatment costs averted (discounted)

\[ £331,000 = £305,000 + £60,000 - £34,000 \]

Net outcomes = (total dose reduction) \times (risk measure) \times (horizon) \times (discounted average number of life years gained from lung cancer case)

\[ = 25 \text{ life years} \]

Cost-effectiveness Ratio = \[\frac{£331,000}{25 \text{ life years}} = £13,250 \text{ per life year gained} \]
Figure 1: Cost-effectiveness Plane