RADPAR WP 7:

Cost-effectiveness

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Final Report:

Analysis of cost effectiveness and health benefits of radon control strategies

Version 3

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Introduction

All strategies to reduce the health impact of radon across the EU involve a balance of costs and benefits: the costs mainly involve radon measurement and testing and prevention or remediation actions on new and existing buildings, while the benefits are primarily the reduced risk of lung cancer to present and future inhabitants of the affected buildings. When deciding which policies to implement, it therefore is important to consider the costs and benefits simultaneously: failure to do so could result in the resources that have been committed to radon actions being used inefficiently.

Work Package 7 of the RADPAR project is concerned with economic evaluation. Specifically, WP7 has two main objectives:

1) "V: The assessment of the cost-effectiveness of existing and potential radon prevention and remediation strategies in the EU"
2) "VI: The improvement of the effectiveness of radon control strategies through the design and use of training courses for radon measurement, prevention, remediation and cost-effectiveness analysis."

Objective 2 was addressed by developing a two-day training course attended by 16 people from 9 countries participating in RADPAR. During the course, the group was familiarised with a spreadsheet-based cost-effectiveness model for new and existing homes.This RADPAR cost-effectiveness workbook was prepared for the RADPAR project, to facilitate the calculation of the cost-effectiveness of radon interventions in different EU countries and regions. The model is based on work undertaken in the UK and published in the BMJ in 2009 (Gray A, Read S, McGale P, Darby S. Lung cancer deaths from indoor radon and the cost effectiveness and potential of policies to reduce them. BMJ 2009; 338:215-218.) Full details of the main assumptions and methods can be found there.

During the course, participants also discussed data sources, general options for evaluation, specific national policies, and timescales for undertaking evaluations in their own countries. A manual setting out the rationale for the model and practical information on its use was subsequently prepared and constitutes deliverable D14 of the project, available from the RADPAR website.

At the training course it was also agreed that Objective 1 of WP7 - assessing the cost-effectiveness of existing and potential radon prevention and remediation strategies in the EU – could best be addressed by asking participating countries to use the cost-effectiveness model to look at:

1) The cost-effectiveness of incorporating basic radon prevention measures in all new houses

2) The cost-effectiveness of incorporating basic radon prevention measures in new houses in targeted areas, for example defined by average radon levels.

3) The cost-effectiveness of remediation programmes in existing houses in targeted areas, for example defined by average radon levels.

It was agreed that it would be important to assess these policies for different action or reference levels, and varying the assumptions concerning such things as test costs, radon risk, test invitation acceptance rates, and remediation effectiveness using sensitivity analyses.

It was also agreed that comparisons between countries would be clearer if certain parameters were held constant: in particular, it was agreed that:

- Discount rates for costs and outcomes should be set at 3% per annum for all countries.

- Quality of life values for the general population, used to calculate quality adjusted life years (QALYs), should be standardised in the main analyses using the UK values already on the model. Countries would be able if they wish to provide additional analyses using country-specific QALY values.

Following the course, five countries were able to undertake the agreed analyses:

- Czech Republic
- Finland
- Norway
- Ireland
- UK

This report describes in more detail the work of WP 7, the results of these analyses, and the recommendations arising.

Background

The cost-effectiveness approach

The fundamental premise of economics is that we live in a world of scarcity, where choices have to be made by individuals, organizations and governments about the allocation of scarce resources between competing ends. These allocative decisions can be influenced by many factors, and the results can be inconsistent or wasteful unless a decision rule or set of decision criteria are used. One such rule is cost-benefit analysis (CBA), which aims to place a monetary value on all the costs and benefits associated with a particular policy or action. If the estimated costs exceed the value of the benefits the decision would be to not go ahead, but if the benefits exceeded the costs the recommendation would be proceed. CBA has been used to evaluate many major investment decisions such as underground railway extensions, bridges, motorways and airports, and the adoption of road safety and environmental measures.

But it is very difficult to place agreed monetary values on things such as landscape views, species diversity, commuting time, or human lives, and this has limited the wider use of CBA. In particular, researchers interested in health interventions have instead recommended a more limited evaluative technique known as cost-effectiveness analysis. The cost-effectiveness approach is also based on the idea that resources are scarce, and that resource allocation decisions should therefore take into account the costs of an action or policy in relation to expected benefits. But in cost-effectiveness analysis no attempt is made to place a monetary valuation on these benefits. Instead, if we were interested in assessing the cost effectiveness of a new policy proposal, we would calculate the net costs of that policy (that is, all positive costs minus any savings) and compared this with the net costs of an alternative, such as the existing policy or a “do nothing” option. Similarly, the net health benefits of the new policy would be calculated (beneficial effects minus adverse consequences such as side effects), and compared with the benefits of the alternative or “comparator” policy.

Finally, the cost-effectiveness ratio would be calculated, which would take the form of the difference in costs divided by the difference in effects. The bigger the difference in costs between the new and existing policy the higher this ratio would be, but in like fashion the bigger the health benefits from the new compared to the existing policy, the lower the cost-effectiveness ratio would be. If similar cost-effectiveness ratios can be calculated for a range of different actions or policies, the result will be an index or set of information allowing different actions to be rank-ordered and prioritized.

Measuring health benefits

In principle, cost-effectiveness analysis can use any relevant measure of outcome or benefit: radon-affected houses detected, percentage reduction in radon levels, or lung cancer deaths averted. But we can only compare between actions or policies which have been evaluated using the same outcome measure: we cannot directly compare the cost-effectiveness of a policy measured in terms of the cost per radon-affected house detected with another policy measured in terms of the cost per lung cancer case avoided. To address this problem, economists working in this area have developed a composite outcome measure which includes quantity of life - survival, measured in life-years - but also quality of life, and this is referred to as the quality-adjusted life-year (QALY). Using the WQALY as the outcome measure, it should in principle be possible to make comparisons across any actions on policies that have an effect on health.

To illustrate the use of QALY, if a 70-year old woman person has an average quality of life, and we use a scale where full health-related quality of life is 1 and death is 0, her quality of life might be judged to be equal to 0.85: that is, each calendar year is equivalent to 0.85 quality adjusted life years. If she then has a stroke leaving her disabled and reducing her remaining life expectancy from 16 to 8 years, and reducing her quality of life to 60% of full health or 0.6, then her quality-adjusted life expectancy would have fallen from (16 x 0.85 =) 13.6 QALYs to (8 x 0.6 =) 4.8 QALYs, a loss of 8.8 QALYs which reflects shorter life expectancy *and* reduced quality of life.

If it is agreed that the QALY is a reasonable measure of health outcome, then the objective of cost-effectiveness analysis is to try to ensure that we get as many QALYs as possible with the money being spent in a particular policy area, such as radon prevention and remediation.

The perspective of the study

Many different kinds of cost could be included in a cost-effectiveness analysis, including costs incurred by different government agencies, private expenditures, and other costs such as losses of earnings as a result of morbidity or premature mortality. The results of the analysis could vary depending on the perspective adopted. Comprehensive analyses adopt a ”societal” perspective in which all costs are included, but agencies such as health departments may be mainly interested in the costs or savings falling directly on them.

Radon policies are interesting in this respect, as some costs are incurred by local and central government agencies in offering and providing tests, house-holders typically incur other costs in paying for preventive or remedial measures, and the health services may have to deal with fewer people with lung cancer but look after people living longer if lung cancer is prevented. Items such as social security payments and benefits are typically not included in cost-effectiveness analyses as they are considered “transfer” payments or money being moved around rather that genuine resource costs.

The RADPAR cost-effectiveness workbook allows users to evaluate cost-effectiveness results from more than one perspective.

The time horizon, and discounting

Cost-effectiveness analyses should adopt an analytic horizon that is long enough to capture all the main costs and benefits of the program being evaluated. For radon prevention and remediation this is likely to be a lifetime, as radon exposure affects the lifetime risk of lung cancer and hence life expectancy; the costs of maintaining and running active prevention and remediation measures will therefore have to be assessed over the same period. In the workbook, therefore, the default is to consider the costs and benefits of radon remediation over a period of 85 years.

When the costs and benefits of a program such as radon prevention is spread over time, it is necessary to express them in present values. But they cannot simply be summed over time. Individuals typically have positive time preference: that is, a preference for benefits now over benefits in the future, and a preference for costs deferred over costs incurred now. Discounting future costs and benefits using an approved annual discount rate is therefore recommended, so that costs and benefits occurring in the future are given less weight than costs and benefits incurred now. Discount rates vary from country to country, but are frequently around 3% per annum. The consequence of discounting is that, for example, a cancer case averted now is given substantially more weight than a case averted 50 years into the future, while costs incurred in the future are given less weight than costs incurred now.

The workbook permits the user to set their own discount rates for costs and for benefits.

Reporting uncertainty

It is important to appreciate that cost-effectiveness is not primarily concerned with testing hypotheses: it is mainly concerned with producing the best possible estimate. But cost-effectiveness results are likely to be subject to a considerable amount of uncertainty, for example due to lack of precision in input parameters. One way of dealing with this is to report the results of one-way sensitivity analyses, in which key input variables are varied across a plausible range to assess their impact on the results, holding all other variables constant.

A more comprehensive way of assessing uncertainty is to independently (or within some correlation structure) vary the input values of all parameters simultaneously and repeatedly around the central estimates, using random draws from specified distributions or ranges, with incremental costs, effects and cost-effectiveness recorded on each run. This is usually referred to as probabilistic sensitivity analysis or probabilistic uncertainty analysis.

In the cost-effectiveness workbook, one-way sensitivity analyses are automatically produced for a range of variables including the relative risk of lung cancer per 100 Bq/m^{3}increase, the percentage reduction obtained by remediation measures, initial prevention and remediation costs per household, running costs, health care costs of a lung cancer case, and health care costs of added life expectancy. Clearly many other uncertainties could be examined, such as the possible existence of some threshold or non-linear exposure-response relationship, or future changes in smoking rates, household size, life expectancy, and costs and effects of preventive/remedial technologies.

In line with the steps outlined above, the cost-effectiveness analysis reported here is based on a spreadsheet-based model, which is used to estimate the expected number of lung cancer deaths in a particular population in the presence and absence of radon prevention or remediation. These estimates are then combined with information on the costs of radon detection and prevention or remediation and of lung cancer treatment to calculate the incremental cost-effectiveness of a radon reduction program compared to no program. Cost-effectiveness is calculated as the ratio of net change in cost to net change in outcome, with outcome (lung cancer cases averted) expressed in terms of QALYs gained; this facilitates comparison of the cost-effectiveness of radon remediation with that of other public health and health care interventions.

Strategies and policies being analysed

As noted above, it was agreed between participating countries that analyses would focus on 1) the cost-effectiveness of incorporating basic radon prevention measures in all new houses; 2) the cost-effectiveness of incorporating basic radon prevention measures in new houses in targeted areas, for example defined by average radon levels, and 3) the cost-effectiveness of remediation programmes in existing houses in targeted areas, for example defined by average radon levels. These analyses are reported for all fivecountries, in each case against a comparator “do nothing” policy. In addition, two countries – Norway and Ireland – wished to explore the cost-effectiveness of a non-targeted remediation strategy across the whole country, and so these are reported also.

Data

Table 7.1 summarises the parameter inputs for basic preventive measures in all new homes, or preventive measures targeted in high radon areas.

Table 7.1: Parameter inputs for the cost-effectiveness analyses of a basic prevention strategy

	Whole country					High radon areas			
	Czech R.	**Finland**	**Norway**	**Ireland**	**UK**	**Finland**	**Norway**	**Ireland**	**UK**
Reference level, Bq/M^3	200.00	200	200	200	200	200	200	200	200
Arithmetic mean radon level in area of interest in Bq/M^3, adjusted for measurement error	126	117	77	79	21	228	226	135	52
Percent of homes over Reference Level	18.77%	17.2%	8.38%	8.46%	0.44%	48.3%	36.42%	20.60%	3.00%
Percentage reduction in radon from prevention measures	85%	57%	50%	50%	50%	57%	50%	50%	50%
Average household size	2.50	2.59	2.12	2.81	2.40	2.54	2.12	2.81	2.40
Cost of installing membrane/other basic measures	€ 300	€ 1,000	€ 900	€ 220	€ 250	€ 1,000	€ 900	€ 220	€ 250
Health Service annual per capita expenditure on all other health care during added life expectancy	€ 1,700	€ 7,817	€ 7,817	€ 4,000	€ 7,817	€ 7,817	€ 7,817	€ 4,000	€ 7,817
Mean Health Service/hospice treatment cost per lung cancer case	€ 14,000	€ 16,840	€ 16,840	€ 20,200	€ 16,840	€ 16,840	€ 16,840	€ 20,200	€ 16,840

Table 7.2 summarises the parameter inputs for the main remediation strategy: finding existing homes above the reference or action level and taking remedial measures where the homeowner agrees; inputs for the remediation strategy across the whole country are also given for Norway and Ireland. Appendix 1 gives further details of data sources.

Table 7.2: Parameter inputs for the cost-effectiveness analyses of a remediation strategy

	Whole country		High radon areas				
	Norway	**Ireland**	**Czech R.**	**Finland**	**Norway**	**Ireland**	**UK**
Reference level, Bq/M^3	200	200	400	400	200	200	200
Arithmetic mean radon level in Bq M-3, adjusted for measurement error	77	78	126	286	226	135	64
Percent of homes over Reference Level	8.4%	8.4%	4.7%	23.2%	36.42%	20.6%	5.0%
Percent of homes invited to test that accept	67%	2%	95%	4%	67%	2%	30%
Proportion of homes found over action level that decide to remediate	25%	25%	10%	55%	25%	25%	20%
Percentage reduction obtained by remediation measures	80%	92%	75%	52%	80%	92%	85%
Average household size	2.12	2.81	2.50	2.54	2.12	2.81	2.40
Unit cost of inviting households to test, per household	€ 1.00	€ 1.50	€ 6.00	€ 0.30	€ 1.00	€ 1.50	€ 1.65
Unit cost of measuring radon levels per household pre-remediation	€ 45	€ 54	€ 20	€ 33	€ 45	€ 54	€ 42
Remediation cost per household (initial)	€ 1,800	€ 1,150	€ 5,600	€ 2,000	€ 1,800	€ 1,150	€ 762
Replacement costs of electric fan	€ 200	€ 250	€ 400	€ 300	€ 200	€ 250	€ 200
Running & maintenance costs per annum	€ 50	€ 100	€ 80	€ 50	€ 50	€ 100	€ 60
Proportion of remediating homes with active measures	0.40	0.86	0.95	0.44	0.40	0.86	0.35
Remediation cost per household (100 years, with replacement every 15 years & running costs)	€ 2,568	€ 4,232	€ 8,650	€ 2,921	€ 2,568	€ 4,232	€ 1,545
Health Service annual per capita expenditure on all other health care during added life expectancy	€ 7,817	€ 4,000	€ 1,700	€ 7,817	€ 7,817	€ 4,000	€ 7,817
Mean Health Service/hospice treatment cost per lung cancer case	€ 16,840	€ 20,200	€ 14,000	€ 16,840	€ 16,840	€ 20,200	€ 16,840

Reference or Action levels

For the UK and Ireland the reference level or action level is set at 200 Bq/m^3, in line with existing policy when the analyses were conducted (2011). For Norway baseline analyses arealso reported at a reference level of 200 Bq/m^3: this corresponds to the Maximum Level in Norway where the Action level is defined as 100 Bq/m^3, but the maximum level in policy terms is more consistent with the reference level in the other countries included here. In the Czech Republic and Finland a level of 200 Bq/m^3 was used for the prevention strategy and a level of 400 Bq/m^3 for the remediation strategy, again in line with current policies. Further analyses were conducted at different reference levels.

Radon levels

In the Czech Republic the geometric mean measured radon concentration was reported at 84.3Bq/m^3, with a GSD of 2.5. In Finland, the geometric mean measured radon concentration in slab-on-ground houses with no radon prevention reported, based on a national random sampling survey conducted in 2006, was 92 Bq/m^3, with a GSD of 2.27. In the 6 areas with the highest radon levels the corresponding figures are 194 Bq/m^{3}and GSD of 2.06. In Norway radon levels are based on a series of municipal surveys conducted in 2000-2001 across 114 of the total of 435 municipalities, which reported a population weighted arithmetic mean radon concentrations of 77 Bq/m^3 in all dwellings with a GSD of 3.02. High radon areas in Norway are defined as the 38 municipalities with the highest proportion of homes over the maximum level, and the 7558 homes measured had a long-term eman radon level of 226 Bq/m^3. In Ireland the geometric mean measured radon concentration for the country as a whole was 48 Bq/m^3 with a GSD of 2.75, and in high radon areas was 81 Bq/m^3 with a GSD of 2.9. In the UK the arithmetic mean radon concentration across the country as a whole adjusted for measurement error was 21Bq/m^3 with a GSD of 3.15, and in higher radon areas in which remediation policies are targeted was 43.4 Bq/m^3 with a GSD of 2.5.

Average household size

Radon interventions benefit all inhabitants of the relevant house, and so calculations of benefit require information on the Average number of inhabitants in each house. This number changes over time, and in many countries has been falling. The cost-effectiveness model permits users to insert a time-trend value, but to simplify comparisons here it is assumed that current values are constant. In the Czech Republic the average was 2.5; in Finland was 2.59 in the country as a whole and 2.54 in high radon areas; in Norway was 2.12, in Ireland 2.81 and in the UK 2.4.

Proportions of homes accepting invitation to test, & agreeing to remediate if over the reference level

In the basic prevention strategy radon barriers are fitted to all homes, but in the remediation strategy directed at existing homes it is necessary to invite the householder to have their home tested. If the test is performed and radon levels are found to be over the reference level, the householder will then have to decide whether to take remedial action or not. These proportions have a significant effect on the cost-effectiveness of each strategy. In the Czech Republic, 95% of householders nationally accept invitations to have radon measured in their home, compared to 4% in Finland, 67% in Norway, 2% in Ireland and 30% in the UK. The proportions remediating when told that their home is over the reference level are 10%^ in the Czech Republic, 55% in Finland, 25% in Norway, 26% in Ireland and 20% in the UK.

Radon reduction from prevention and remediation measures

In Norway, Ireland and the UK the analyses are based on an estimated 50% reduction in radon levels following the installation of a membrane during construction of a new home; in Finland this reduction is estimated as 57% and in the Czech Republic as 85%. Remediation measures in existing homes are estimated on average to reduce radon levels by 95% in the Czech Republic, 52% in Finland, 80% in Norway, 92% in Ireland and 85% in the UK.

Cost of prevention and remediation measures

In practice the costs of installing preventive and remediation measures will vary substantially depending on the type of building and the severity of the radon problem, but as with the effectiveness estimates reported above, the costs of these measures are placed at average levels to facilitate analysis and comparison.

Radon test invitations and tests

The estimated cost of inviting households to have their home tested for radon is € 6.00 in the Czech Republic, € 0.30 in Finland, € 1.00 in Norway, € 1.46 in Ireland and € 1.65 in the UK. The unit cost of conducting a radon test using the standard methods employed in each country is € 20 in the Czech Republic, € 33 in Finland, € 45 in Norway, € 56 in Ireland and € 42 in the UK.

Basic prevention costs

In Finland the cost of installing a membrane and associated basic measures in a new home is estimated to be € 1,000, compared with € 900 in Norway, € 300 in the Czech Republic, € 220 in Ireland and € 250 in the UK.

Remediation costs

The typical costs of remediation measures in an existing home are not straightforward to calculate, as they will depend on the proportion of homes having active measures installed (such as electric fans), and the long-term costs of maintenance, running and replacement. Taking these factors into account, it is estimated that the lifetime cost of remediation measures is € 8,650 in the Czech Republic, € 2,921 in Finland, € 2,568 in Norway, € 4,232 in Ireland and € 1,545 in the UK.

Health care costs of lung cancer cases and of added life expectancy

Reducing lung cancer cases induced by radon will reduce the cost to health services of dealing with such cases, but will result in health service expenditure on other health problems during the additional life expectancy of those whose lung cancer has been averted. In Finland, Norway and the UK common figures were used, based on UK data sources, of € 16,840 saved for every lung cancer case averted, and € 7,817 incurred in other health care costs for each year of added life. In Ireland and the Czech Republic the relevant figures were estimated as €20,200 and € 14,000 respectively saved for every lung cancer case averted, and € 4,000 and €1,700 respectively incurred in other health care costs for each year of added life.

Smoking rates

The single most important influence on lung cancer rates is smoking behaviour.

Table 7.3: Proportions who are life-long non-smokers of any product, by age and sex

	Czech R.		Finland		Norway		Ireland		UK	
Age	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
<5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5-	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10-	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
15-	0.73	0.70	0.70	0.69	0.85	0.85	0.73	0.70	0.76	0.76
20-	0.58	0.61	0.70	0.69	0.80	0.80	0.58	0.61	0.68	0.64
25-	0.50	0.57	0.43	0.44	0.70	0.70	0.50	0.57	0.56	0.57
30-	0.54	0.56	0.43	0.44	0.70	0.70	0.54	0.56	0.56	0.57
35-	0.50	0.56	0.45	0.54	0.60	0.60	0.50	0.56	0.52	0.56
40-	0.50	0.56	0.45	0.54	0.55	0.55	0.50	0.56	0.52	0.56

45-	0.50	0.56	0.37	0.47	0.50	0.55	0.50	0.56	0.52	0.56
50-	0.37	0.51	0.37	0.47	0.50	0.55	0.37	0.51	0.50	0.57
55-	0.37	0.51	0.31	0.55	0.45	0.55	0.37	0.51	0.50	0.57
60-	0.31	0.58	0.31	0.55	0.40	0.60	0.31	0.58	0.40	0.57
65-	0.31	0.58	0.33	0.69	0.40	0.60	0.31	0.58	0.40	0.57
70-	0.31	0.58	0.37	0.77	0.40	0.60	0.31	0.58	0.40	0.57
75-	0.31	0.58	0.34	0.85	0.40	0.60	0.31	0.58	0.40	0.57
80-	0.31	0.58	0.42	0.85	0.40	0.65	0.31	0.58	0.40	0.57
85+	0.31	0.58	0.42	0.85	0.40	0.70	0.31	0.58	0.40	0.57

Table 7.3 shows the estimated proportion of males and females who are life-long non-smokers of any tobacco product. Norway has the highest proportions of never-smokers in most age-groups, but otherwise there are few clear differences.

Lung cancer rates

Table 7.4 shows lung cancer rates by age and sex, reflecting particularly the history of smoking in each country and age group. In the oldest age-groups these are typically highest in Ireland and the UK. In Finland in can be seen that overall lung cancer rates are slightly lower in the high radon areas than in the country as a whole, probably reflecting differences in smoking behaviour although only national data are available as seen in Table 7.3. In other countries it was not possible to produce accurate lung cancer rates specific to high radon areas.

Table 7.4: Lung cancer rates (per 100,000) by age and sex

	Czech R. – all		Finland – whole country		Finland – high radon areas		Norway - all		Ireland - all		UK - all	
Age-group	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
<5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0
5-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.1	0.1
15-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.7	0.2	0.1
20-	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3
25-	0.3	0.8	0.6	0.6	0.0	0.0	0.6	0.6	0.5	1.1	0.5	0.4
30-	0.4	0.7	0.6	0.6	0.0	0.0	1.2	0.6	1.1	1.1	1.3	1.0
35-	1.1	0.5	1.9	2.0	0.0	0.0	2.7	2.9	1.8	5.1	2.4	2.6
40-	5.5	2.0	3.9	3.5	2.4	2.5	5.3	5.6	8.6	6.7	6.7	6.6
45-	18.3	6.4	13.6	9.7	11.0	6.9	17.0	17.4	24.6	16.8	15.3	16.0
50-	48.8	20.8	34.1	18.7	33.4	22.6	39.1	40.7	32.1	40.0	39.4	34.0
55-	119.1	40.1	79.9	40.2	84.9	38.2	87.9	72.6	97.4	55.7	90.6	71.4
60-	236.8	70.8	123.3	48.9	116.7	44.9	151.0	112.6	156.2	100.9	150.3	111.4

65-	318.0	83.3	190.3	59.0	193.3	58.8	193.8	131.6	241.2	136.6	250.5	164.5
70-	388.4	106.7	281.8	77.4	267.4	67.1	319.4	194.4	375.0	214.0	351.8	220.4
75-	476.6	117.8	401.7	105.3	383.5	88.7	447.9	240.5	411.3	263.6	465.8	285.6
80-	415.6	123.0	385.8	101.4	390.2	87.9	430.0	185.0	538.6	243.8	555.9	308.5
85+	320.0	110.1	315.2	77.4	289.9	63.9	275.3	92.6	565.8	198.9	515.7	237.1

Results

Results are presented first using baseline values for all parameters for all four countries simultaneously for the prevention strategies and then for the remediation strategies. These are followed by sensitivity analyses for each country in which parameter values are varied systematically for the prevention strategies and then for the remediation strategies.

Prevention strategy- main results

Table 7.5 reports the main results for the prevention scenarios.First, the table shows the lifetime cumulative lung cancer risk before and preventive action is taken. The table then shows the equivalent figure after the preventive action has taken place.

For the whole country analyses, the preventive action, which on average reduces radon levels by around 50%, has the effect of averting between 3 (UK) and 17 (Czech R.) lung cancer cases per 1000 homes in which preventive measures have been installed. This can then be converted into life years gained and quality adjusted life years gained, and the equivalent figures can then be discounted to present values. On average, between 10 (UK) and 61(Czech R.) discounted QALYs are gained for every 1000 homes in which preventive actions are taken.

The prevention strategy incurs no testing or invitation costs, as it is assumed that all homes have measures installed, and in the baseline strategy it is also assumed that there is no testing after the preventive measures are installed. Hence the costs are purely those of the preventive measures themselves, ranging from € 220 in Ireland to € 1,447 in Czech Republic, some savings from lung cancer cases averted, ranging from €47(discounted) in UK to € 235 in Czech Republic, and the added costs of additional life expectancy, ranging from € 103 (discounted) in UK to € 385 in Finland. The net cost of all of these items then ranges from € 338 in the UK to € 1,520 in the Czech Republic.

From these results it is then possible to calculate the cost-effectiveness – that is the change in cost divided by the change in effect. The cost per Quality Adjusted Life Year (QALY) gained is € 25,080 in the Czech Republic, € 34,110 in Finland, €38,308 in Norway, € 9,382 in Ireland, and €32,666 in the UK.

When basic preventive strategies are focused in high radon areas only, the health benefits increase more than the costs per house, and so cost-effectiveness is improved, the cost per QALY gained typically falling by 30-50%.

Table 7.5: Baseline results for basic prevention measures in new homes

	Whole country					High radon areas			
	Czech R.	**Finland**	**Norway**	**Ireland**	**UK**	**Finland**	**Norway**	**Ireland**	**UK**
Lifetime cumulative lung cancer risk (%)									
Initial	4.82	4.46	6.53	6.15	7.46	4.22	7.87	6.62	7.81
Post-prevention	4.15	4.07	6.18	5.81	7.35	3.59	6.85	6.05	7.52
Health gain per 1000 households with preventive measures									
Lung cancer cases averted	16.8	10.1	7.4	9.4	2.8	16.0	21.5	16.1	7.0
Total life years gained	234.8	151.3	117.6	140.8	40.5	236.0	342.4	240.4	100.5
Total life years gained – discounted	76.4	49.2	38.3	45.8	13.2	76.8	111.5	78.2	32.7
Total QALYs gained	186.2	119.8	92.9	111.8	31.7	186.4	270.6	190.9	78.9
Total QALYs gained – discounted	60.6	39.0	30.2	36.4	10.3	60.7	88.1	62.1	25.7
Resource use and costs per household with preventive measures									
Number of invitations to test	0	0	0	0	0	0	0	0	0
Invitation costs	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0
Number of radon tests	0	0	0	0	0	0	0	0	0
Radon testing cost	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0
Radon prevention cost - discounted	€ 1,447	€ 1,000	€ 900	€ 220	€ 250	€ 1,000	€ 900	€ 220	€ 250
Sub-total: invitation, testing &prevention costs - discounted	€ 1,467	€ 1,000	€ 900	€ 220	€ 250	€ 1,000	€ 900	€ 220	€ 250
Health Service lung cancer treatment costs averted	€ 235	€ 171	€ 124	€ 191	€ 47	€ 270	€ 362	€ 325	€ 118
Health Service lung cancer treatment costs averted - discounted	€ 77	€ 55	€ 41	€ 62	€ 15	€ 88	€ 118	€ 106	€ 38
Other Health Service costs incurred during added life expectancy- discounted	€ 130	€ 385	€ 299	€ 183	€ 103	€ 601	€ 871	€ 313	€ 256
Net cost - discounted - Societal	€ 1,520	€ 1,329	€ 1,159	€ 341	€ 338	€ 1,513	€ 1,653	€ 427	€ 467
Net cost - discounted - Health Service	€ 53	€ 329	€ 259	€ 121	€ 88	€ 513	€ 753	€ 207	€ 217
Cost-effectiveness									
Incremental cost per life year gained - discounted	€ 19,894	€ 26,996	€ 30,271	€ 7,448	€ 25,625	€ 19,690	€ 14,834	€ 5,459	€ 14,286
Incremental cost per QALY gained - discounted - Societal	€ 25,080	€ 34,110	€ 38,308	€ 9,382	€ 32,666	€ 24,935	€ 18,772	€ 6,876	€ 18,211
Incremental cost per QALY gained - discounted - Health Service	€ 879	€ 8,453	€ 8,553	€ 3,334	€ 8,471	€ 8,450	€ 8,553	€ 3,334	€ 8,471

Prevention strategy- main results by smoking status

The results presented in Table 7.5 are for the whole population, but as noted previously the main cause of lung cancer is smoking. Therefore the results of a radon intervention will vary considerably depending on whether the inhabitants on a house are non-smokers or smokers. Table 7.6 shows the main results arranged in a similar way to Table 7.5, but for smokers and non-smokers.

Table 7.6: Baseline results for basic prevention measures in all new homes, by smoking status

	Whole country					High radon areas			
	Czech R.	**Finland**	**Norway**	**Ireland**	**UK**	**Finland**	**Norway**	**Ireland**	**UK**
Lifetime cumulative lung cancer risk (%):									
Initial									
Never smokers only	0.87	0.96	0.96	0.86	0.83	1.10	1.16	0.93	0.88
Current smokers only	23.35	26.30	27.03	24.17	25.78	26.42	31.79	25.84	26.85
Post-prevention									
Never smokers only	0.75	0.87	0.90	0.81	0.82	0.93	1.00	0.85	0.84
Current smokers only	20.38	24.26	25.75	22.98	25.42	22.89	28.21	23.84	25.96
Health gains per 1000 households with preventive measures									
Lung cancer cases averted:									
Never smokers only	3.1	2.2	1.1	1.4	0.3	4.2	3.2	2.3	0.8
Current smokers only	74.3	52.9	27.1	33.4	8.7	89.6	75.8	56.3	21.4
Total QALYs gained – discounted:									
Never smokers only	13.4	9.0	4.7	5.7	1.2	17.1	13.8	9.8	3.1
Current smokers only	217.2	145.9	78.4	97.2	22.2	241.5	219.3	163.9	54.7
Resource use and costs per household with preventive measures									
Net cost - discounted – Societal:									
Never smokers only	€ 1,476	€ 1,065	€ 933	€ 236	€ 260	€ 1,125	€ 997	€ 247	€ 274
Current smokers only	€ 1,491	€ 1,902	€ 1,372	€ 392	€ 402	€ 2,522	€ 2,221	€ 509	€ 624
Cost-effectiveness									
Incremental cost per QALY gained - discounted – Societal:									
Never smokers only	€ 109,870	€ 117,728	€ 198,659	€ 40,987	€ 209,704	€ 65,725	€ 72,354	€ 25,056	€ 88,934
Current smokers only	€ 6,867	€ 13,037	€ 17,511	€ 4,029	€ 18,109	€ 10,447	€ 10,131	€ 3,108	€ 11,414

It can be seen that lifetime cumulative risk is much higher in smokers: typically around 25%, compared with <1% for never smokers. As a result of the much higher risk of lung cancer amongst smokers, the number of lung cancer cases averted by the radon prevention intervention is also much higher: for example, in high radon areas of Finland, about 4 lung cancer cases would be averted per 1000 homes in which basic preventive measures are installed, assuming these homes were then occupied only by never smokers; in comparison, 90 lung cancer cases would be averted if these 1000 homes were to be occupied only by smokers. In consequence, cost-effectiveness ranges between € 3,108 (Ireland) and € 18,109 (UK) per QALY gained for smokers, whereas for non-smokers it is as high as € 209,704 in the UK and € 198,659 in Norway.

Remediation – main results

Table 7.7 reports the main results for the remediationscenarios.

Table 7.7: Baseline results for remediation of existing buildings in target areas

	Whole country		High radon areas				
	Norway	**Ireland**	**Czech R.**	**Finland**	**Norway**	**Ireland**	**UK**
Lifetime cumulative lung cancer risk (%) - all							
Initial	7.72	7.32	11.57	5.90	8.84	7.74	9.56
Post-remediation	6.22	5.62	5.98	4.46	6.44	5.66	7.58
Health gain per 1000 households remediating							
Lung cancer cases averted	31.9	47.7	139.8	36.5	50.8	58.5	47.4
Total life years gained	506.9	712.6	1951.8	537.6	808.9	873.0	681.5
Total life years gained – discounted	165.0	231.9	635.3	175.0	263.3	284.1	221.8
Total QALYs gained	400.6	565.8	1548.2	424.5	639.2	693.1	534.6
Total QALYs gained – discounted	130.4	184.1	503.9	138.2	208.0	225.6	174.0
Resource use and costs per household remediating							
Number of invitations to test	71	2390	222	195	16	971	333
Invitation costs	€ 71	€ 3,584	€ 1,334	€ 58	€ 16	€ 1,456	€ 550
Number of radon tests	48	48	211	8	11	19	100
Radon testing cost	€ 2,147	€ 2,581	€ 4,223	€ 257	€ 494	€ 1,048	€ 4,200
Radon remediation cost - discounted	€ 2,568	€ 4,232	€ 8,650	€ 2,921	€ 2,568	€ 4,232	€ 1,545
Sub-total: invitation, testing & remediation costs - discounted	€ 4,787	€ 10,397	€ 14,207	€ 3,236	€ 3,079	€ 6,737	€ 6,295
Health Service lung cancer treatment costs averted	€ 537	€ 964	€ 1,957	€ 615	€ 856	€ 1,181	€ 799
Health Service lung cancer treatment costs averted - discounted	€ 175	€ 314	€ 637	€ 200	€ 279	€ 384	€ 260
Other Health Service costs incurred during added life expectancy- discounted	€ 1,290	€ 928	€ 1,080	€ 1,368	€ 2,058	€ 1,137	€ 1,734
Net cost - discounted - Societal	€ 5,902	€ 11,011	€ 14,650	€ 4,404	€ 4,858	€ 7,489	€ 7,769
Net cost - discounted - Health Service	€ 1,115	€ 614	€ 443	€ 1,168	€ 1,779	€ 752	€ 1,474
Cost-effectiveness							
Incremental cost per life year gained - discounted	€ 35,773	€ 47,474	€ 23,062	€ 25,168	€ 18,454	€ 26,357	€ 35,026
Incremental cost per QALY gained - discounted - Societal	€ 45,270	€ 59,800	€ 29,073	€ 31,873	€ 23,353	€ 33,200	€ 44,650
Incremental cost per QALY gained - discounted - Health Service	€ 8,553	€ 3,334	€ 879	€ 8,450	€ 8,553	€ 3,334	€ 8,471

For the whole country policies in Norway and Ireland, the lifetime cumulative lung cancer risk before the remediation action is taken is 7.7% and 7.3% respectively. The table then shows the equivalent figure after remediation has taken place. The remediation action has the effect of averting 32 (Finland) and 48 (Ireland) lung cancer cases per 1000 homes in which remediation measures have been taken. This can then be converted into life years gained, quality adjusted life years gained, and the equivalent figures discounted to present values.

The remediation strategy incurs testing and invitation costs. Although the unit cost of invitations and tests is low, it may be necessary to issue large numbers of invitations and conduct many tests for every home that is identified as being above the reference level and eventually decides to remediate. In the whole country examples, it may be necessary to issue up to 2390 invitations (Ireland) and conduct radon tests in up to 48 homes for each home that is eventually remediated. Combining these costs with the actual remediation costs produces an average figure of between € 4,787 (Finland) and €10,397 (Ireland) per home eventually remediating. Taking into account the savings from lung cancer cases averted, and the added costs of additional life expectancy, the net discounted cost is € 5,902 in Finlandand €11,011 in Ireland.

From these results it is then possible to calculate the cost-effectiveness – that is the change in cost divided by the change in effect. The cost per Quality Adjusted Life Year (QALY) gained is € 45,270 in Finland as a whole and €59,800 in Ireland as a whole.

As expected, the cost-effectiveness of remediation strategies is considerably better when such policies are targeted on high radon areas: targeting reduces the costs of finding homes over the reference level and increases the health gain when they remediate. Consequently the cost per QALY gained of targeted remediation policies is € 29,073 in the Czech Republic, € 31,873 in Finland and € 33,200 in Ireland. In Norway the cost per QALY gained is €23,353 and in the UK is €44,650.

Remediation strategy- main results by smoking status

Table 7.8 shows the main remediation results as seen in Table 7.7, but for smokers and non-smokers. As in the analysis of preventive measures, it can be seen that the lifetime cumulative risk is much higher in smokers than in never smokers, resulting in a much higher number of lung cancer cases averted by radon remediation amongst smokers. In consequence, for whole country strategies, cost-effectiveness is €243,238 per QALY gained in Finland and € 358,685 per QALY gained in Ireland for never smokers, compared with €20,579 per QALY gained (Finland) and €23,268 per QALY gained in Ireland for smokers.

For the targeted remediation policies the difference is equally striking: cost-effectiveness ranges between € 89,472(Finland) and € 306,982(UK) per QALY gained for never smokers, whereas for smokers it is less than € 25,000 in all countries.

Table 7.8: Baseline results for remediation measures in target areas, by smoking status

	Whole country		High radon areas				
	Norway	**Ireland**	**Czech R.**	**Finland**	**Norway**	**Ireland**	**UK**
Lifetime cumulative lung cancer risk (%):							
Initial							
Never smokers only	1.13	1.03	2.16	1.55	1.30	1.09	1.08
Current smokers only	31.19	28.23	48.63	35.13	34.99	29.62	32.01
Post-prevention							
Never smokers only	0.91	0.79	1.08	1.16	0.94	0.79	0.85
Current smokers only	25.82	22.31	28.26	27.71	26.66	22.44	26.14
Health gains per 1000 households with preventive measures							
Lung cancer cases averted:							
Never smokers only	4.8	6.9	26.8	9.8	7.7	8.4	5.5
Current smokers only	113.7	166.2	509.1	188.5	176.7	202.0	140.8
Total QALYs gained – discounted:							
Never smokers only	20.3	29.2	116.4	39.4	32.5	35.8	21.0
Current smokers only	328.9	483.5	1488.8	507.9	511.1	587.6	360.1
Resource use and costs per household with preventive measures							
Net cost - discounted – Societal:							
Never smokers only	€ 4,929	€ 10,476	€ 14,289	€ 3,524	€ 3,308	€ 6,834	€ 6,460
Current smokers only	€ 6,769	€ 11,251	€ 14,374	€ 6,439	€ 6,159	€ 7,774	€ 8,758
Cost-effectiveness							
Incremental cost per QALY gained - discounted – Societal:							
Never smokers only	€ 243,238	€ 358,685	€ 122,727	€ 89,472	€ 101,761	€ 190,639	€ 306,982
Current smokers only	€ 20,579	€ 23,268	€ 9,655	€ 12,677	€ 12,050	€ 13,230	€ 24,319

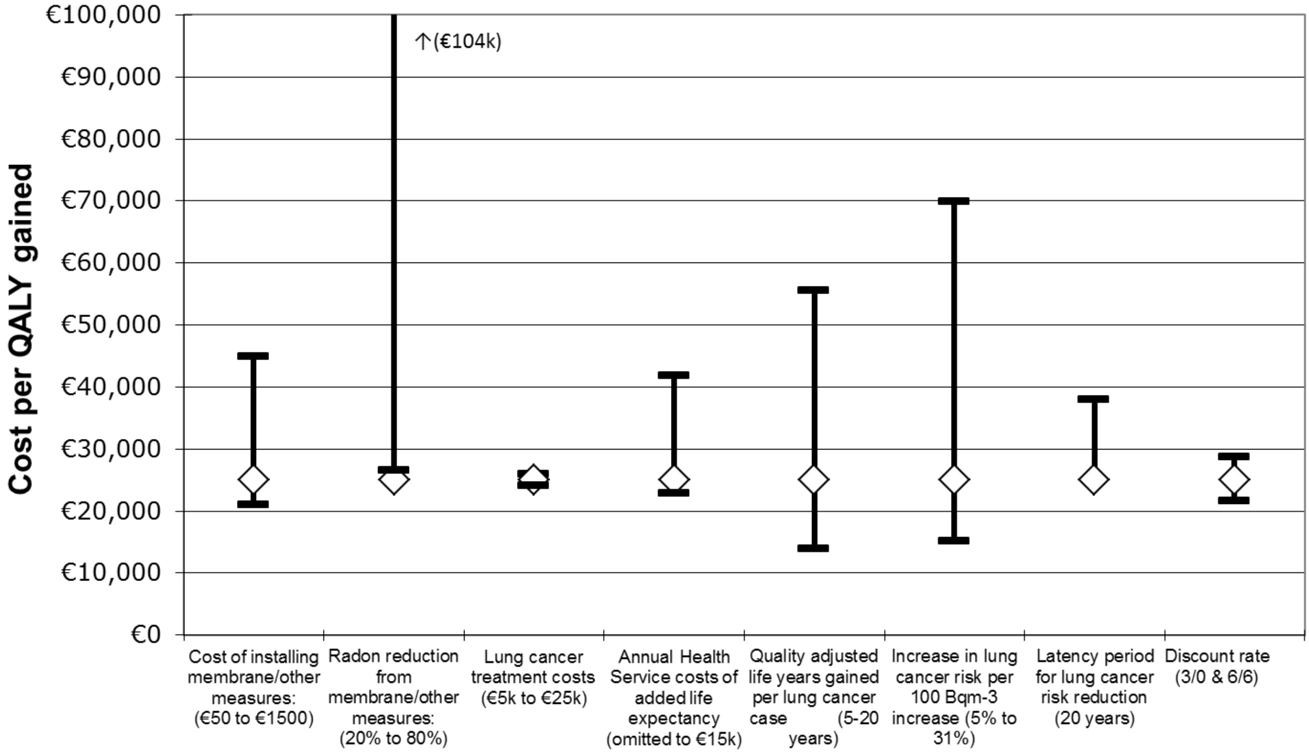
Prevention strategy- sensitivity analysis

In this section, the main parameter values used in the analyses are varied to assess the effects of changing them on the results. In particular, for the analyses of the prevention strategy, the cost of installing a membrane is varied between € 50 and €1500; the radon reduction obtained from fitting a membrane or other measures is varied from 20% to 80%; the costs of treating a lung cancer case are varied from €5k to €25k; the annual health service costs of added life expectancy are omitted completely or increased to €15k; the quality adjusted life years gained per lung cancer case are varied from 5 to 20 years; the increase in lung cancer risk per 100 Bqm-3 increase is varied between 5% and 31%); the latency period for lung cancer risk reduction is set to 20 years; and the discount rate is varied to 3% for costs and 0% for effects, or to 6% for costs and effects.

Czech Republic

Figure 7.1 shows the sensitivity analysis for the Czech Republic. The results are mainly affected by the size of the radon reduction obtained from installing a membrane, the QALYs gained per lung cancer case, and the lung cancer risk associated with radon.

Figure 7.1: Czech republic - sensitivity analysis of prevention strategies – all areas



Finland

Figures 7.2 and 7.3 show the sensitivity analysis for Finland. The results are mainly affected by the size of the radon reduction obtained from installing a membrane, the QALYs gained per lung cancer case, and the lung cancer risk associated with radon.

Figure 7.2: Finland - sensitivity analysis of prevention strategies – all areas

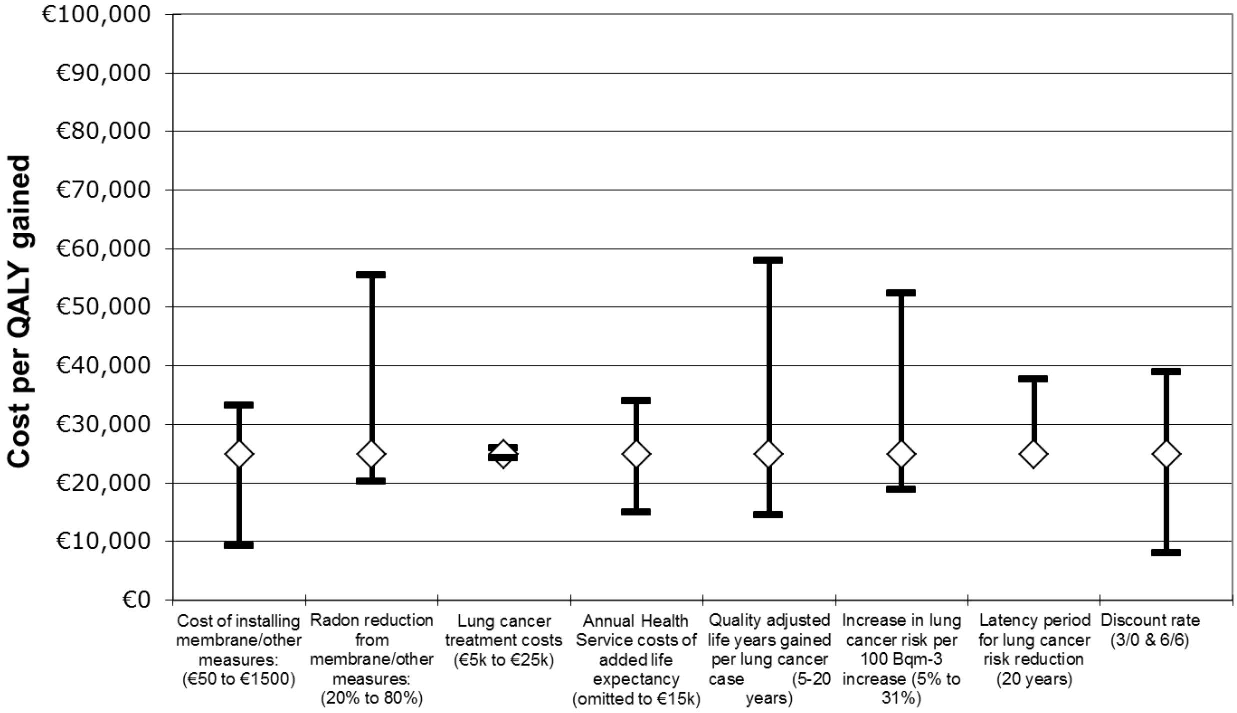
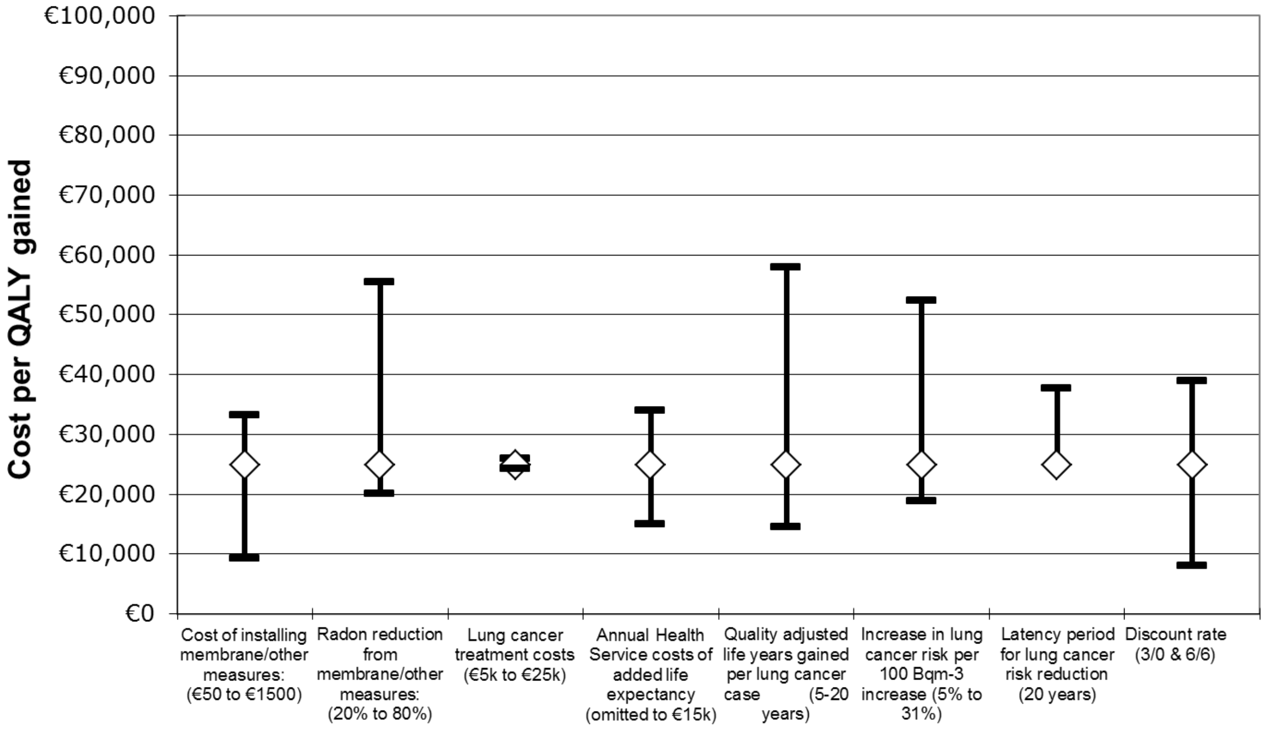


Figure 7.3: Finland - sensitivity analysis of prevention strategies – high radon areas



Norway

Figures 7.4 and 7.5 show the sensitivity analysis for Norway. The results are mainly affected by the cost of installing a membrane, the size of the radon reduction obtained from installing a membrane, the QALYs gained per lung cancer case, and the lung cancer risk associated with radon.

Figure 7.4: Norway - sensitivity analysis of prevention strategies – all areas

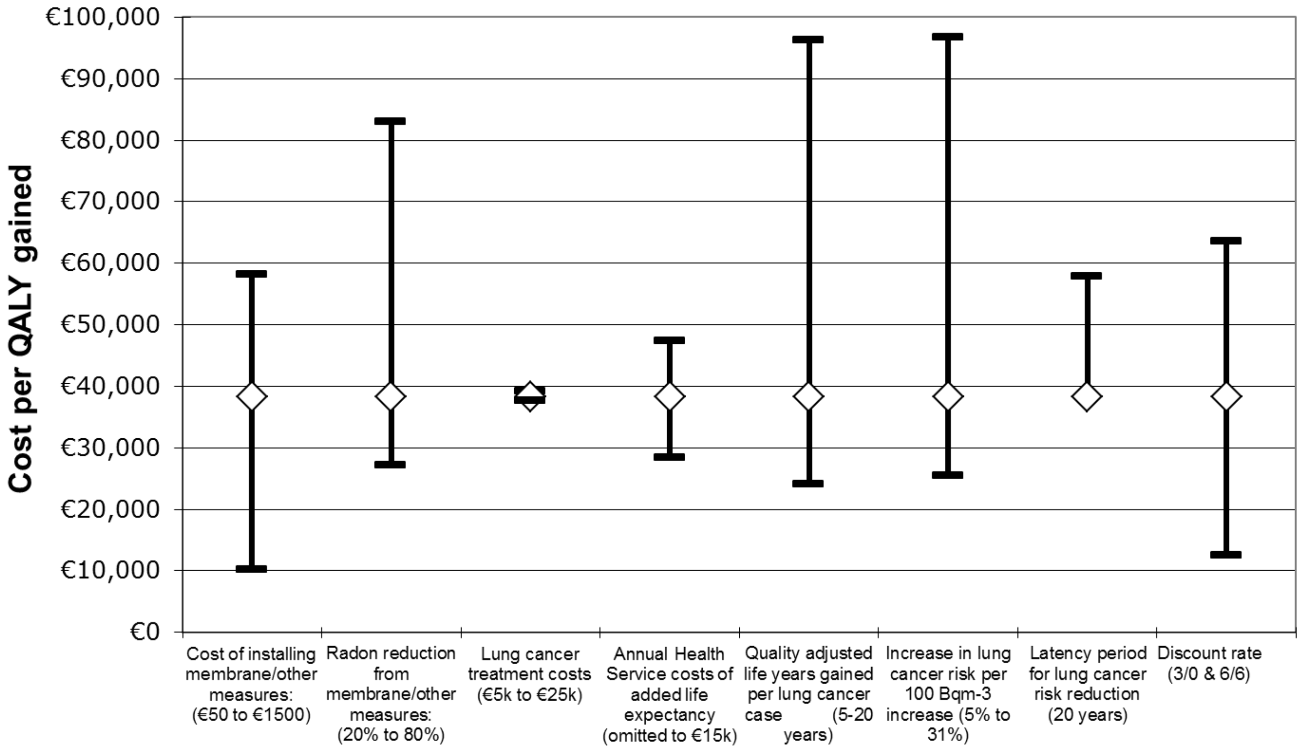
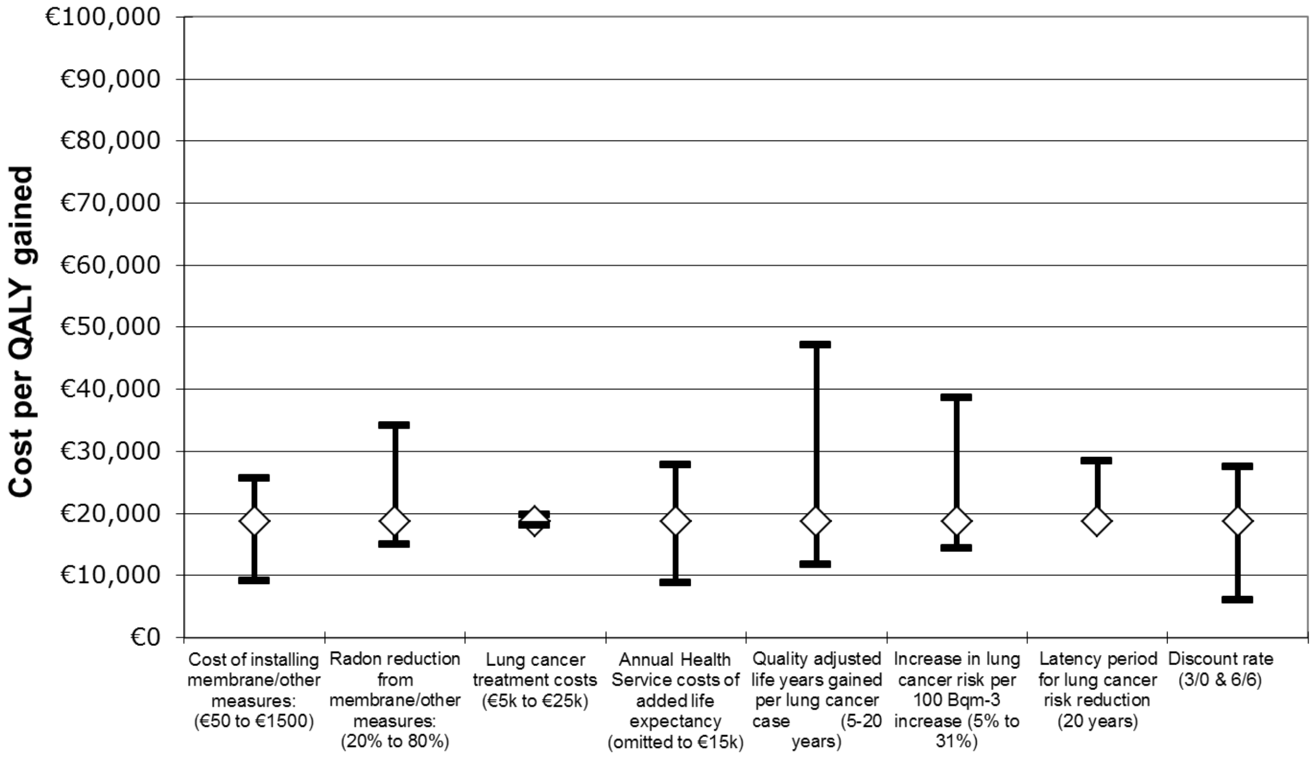


Figure 7.5: Norway - sensitivity analysis of prevention strategies – high radon areas



Ireland

Figures 7.6and 7.7show the sensitivity analyses for Ireland. The results are mainly affected by the cost of installing the membrane,the annual health service costs associated with added life expectancy, and the number of QALYs gained per lung cancer case.

Figure 7.6: Ireland - sensitivity analysis of prevention strategies – all areas

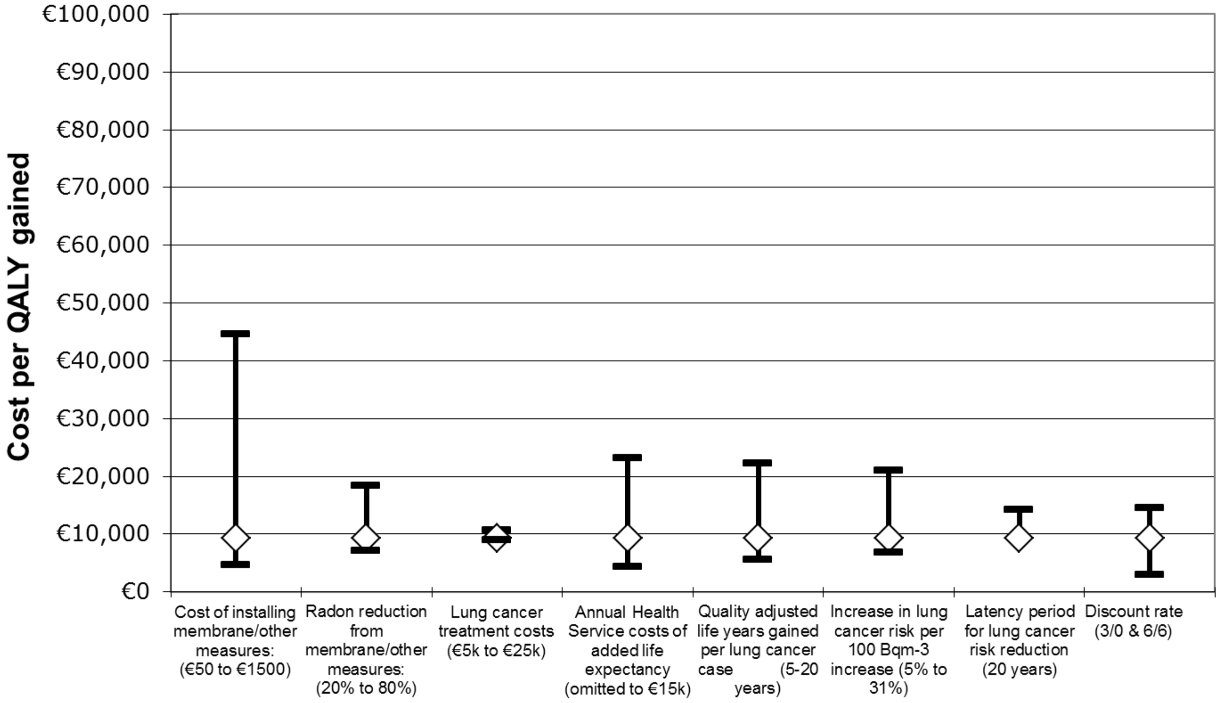
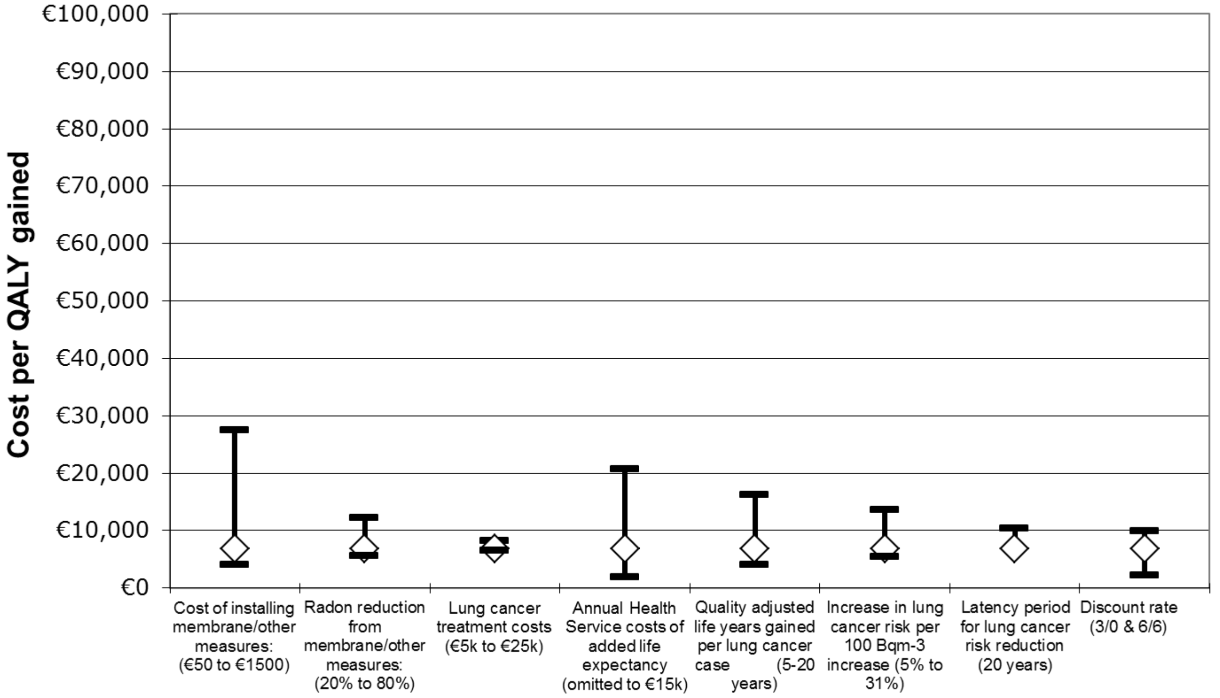


Figure 7.7: Ireland - sensitivity analysis of prevention strategies – high radon areas



UK

Figures 7.8and 7.9show the sensitivity analyses for the UK. The results are mainly affected by the cost of installing a membrane, quality adjusted life years gained for each lung cancer case averted, and the increased risk associated with radon.

Figure 7.8: UK- sensitivity analysis of prevention strategies – all areas

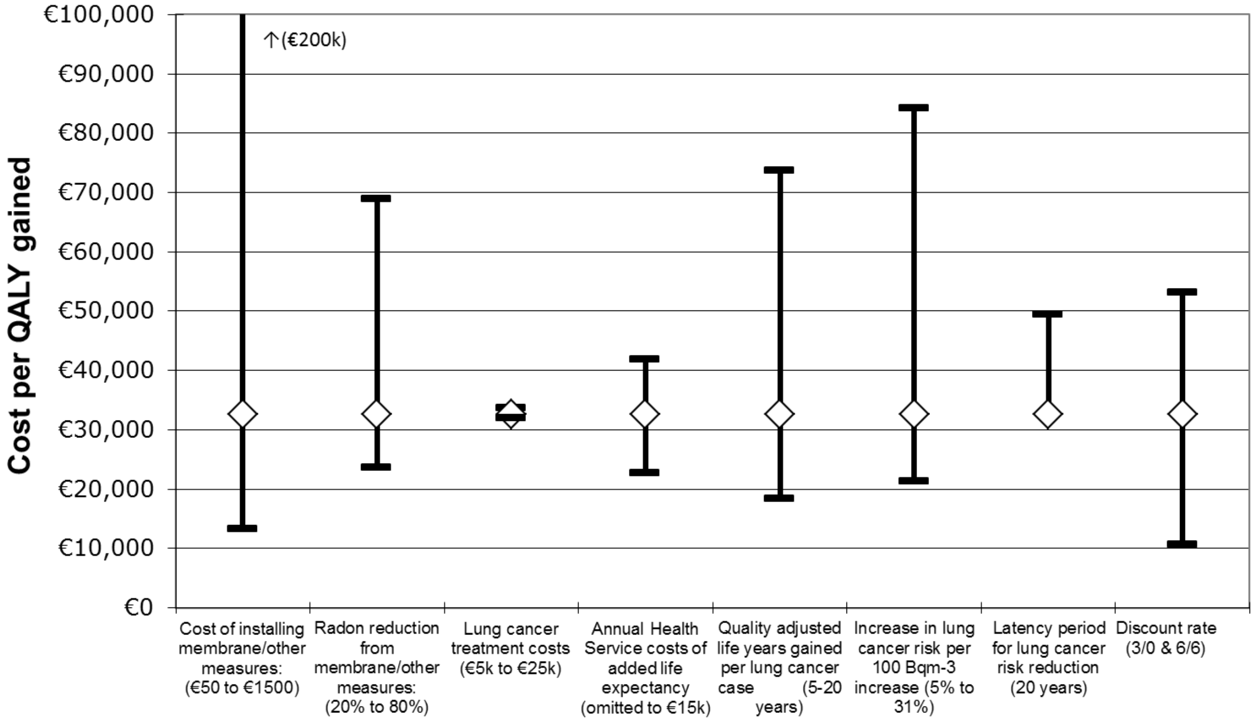
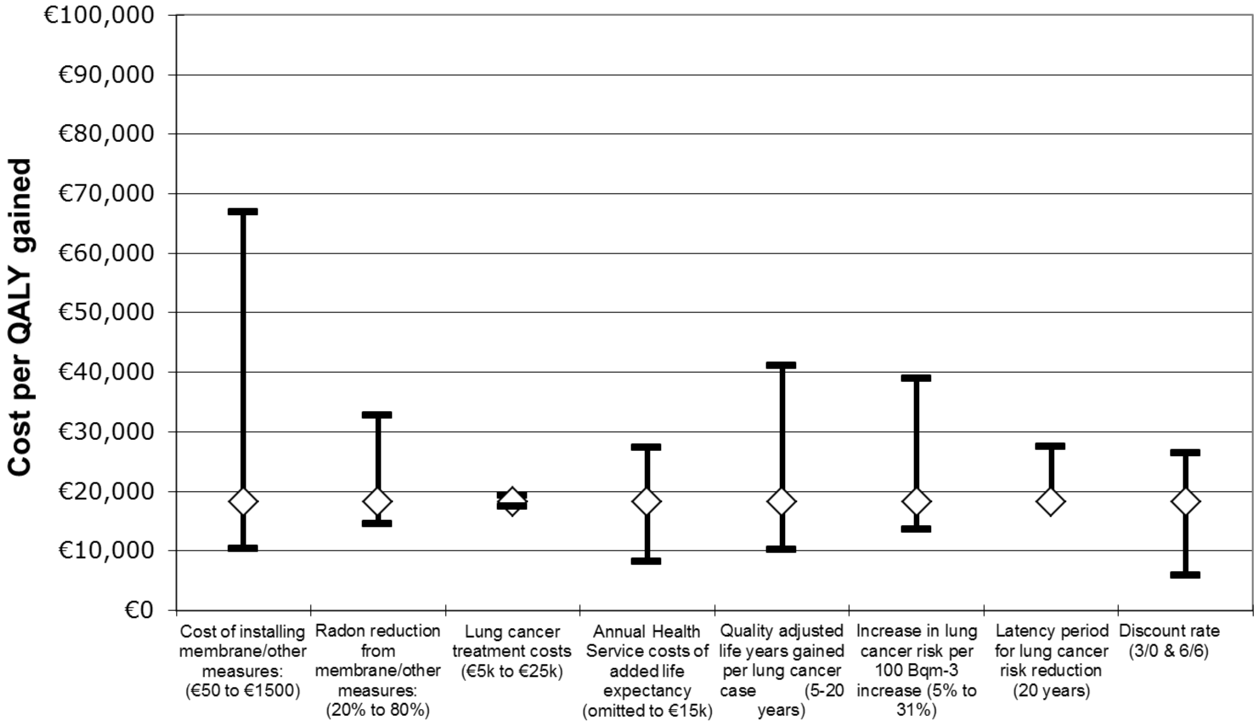


Figure 7.9: UK- sensitivity analysis of prevention strategies – high radon areas



Remediation strategy- sensitivity analysis

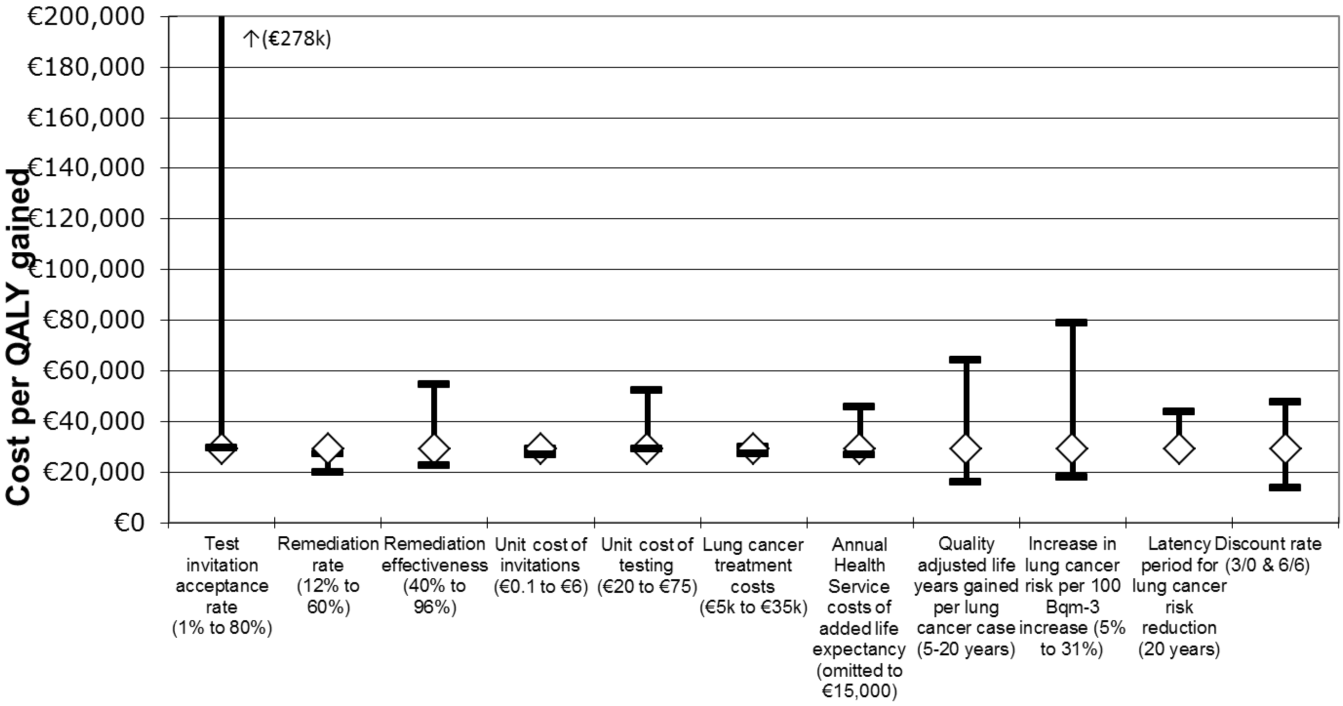
Similar sensitivity analyses were carried out for the remediation strategy: the main parameter values used were varied to assess the effects of changing them on the results. For the analyses of the remediation strategy, the test invitation acceptance rate was varied between 1% and 80%; the remediation rate was varied between 12% and 60%; the effectiveness of remediation measures was varied between a 40% and a 96% radon reduction; the unit cost of invitations was varied between €0.1 and €6; the unit cost of testing was varied between €20 and €75; lung cancer treatment costs were varied between €5k and €35k; annual health service costs of added life expectancy were omitted or increased to €15k; the number of quality adjusted life years gained per lung cancer case was varied between 5 and 20 years; the increase in lung cancer risk per 100 Bq/m^3 increase was varied between 5% and 31%; the latency period for lung cancer risk reduction is set to 20 years; and the discount rate is varied to 3% for costs and 0% for effects, or to 6% for costs and effects.

In addition, for the remediation strategy, the action level or reference level and average radon level in target areas were varied simultaneously.

Czech Republic

Figure 7.10 shows the sensitivity analysis for remediation in the Czech Republic. The cost-effectiveness results for remediation are most sensitive to the test invitation acceptance rate and the increase in lung cancer risk per 100 Bq/m^3 increase.

Figure 7.10: Czech Republic - sensitivity analysis of remediation strategies



In the analysis in which the action level and average radon level of target areas are simultaneously changed (Figure 7.11) it can be seen that the cost per QALY gained rises above €50k/QALY (shaded area) once the radon level in targetted areas falls below 87 Bq/m^3 at almost all action levelsincluding the current level of 400 Bq/m^3.

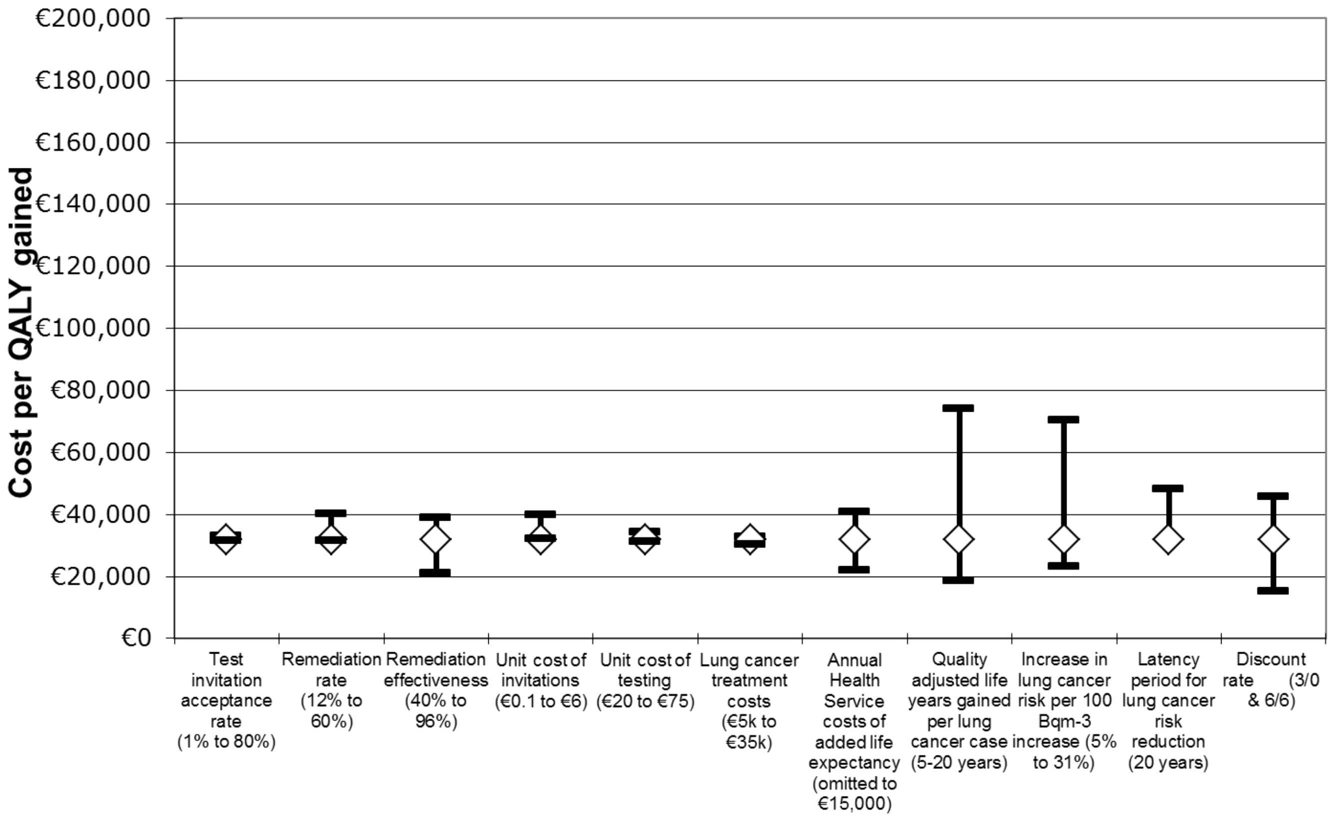
Figure 7.11: Czech Republic - sensitivity analysis of remediation strategies – different Action Levels and radon levels in target areas: Cost per QALY gained (€'000)

Areas targetted: (Long-term arithmetic mean Bq/m^3)	Action Level (Bq/m^3)				
	50	*100*	*200*	*300*	*400*
36	€ 105.0	€ 90.4	€ 152.5	€ 349.0	€ 765.0
64	€ 75.0	€ 57.3	€ 52.3	€ 66.9	€ 99.8
87	€ 61.6	€ 47.5	€ 38.4	€ 39.6	€ 47.6
100	€ 56.3	€ 44.0	€ 34.7	€ 33.7	€ 37.6
150	€ 42.1	€ 34.6	€ 26.8	€ 23.8	€ 23.0
200	€ 33.6	€ 28.9	€ 22.8	€ 19.8	€ 18.3
250	€ 28.0	€ 24.9	€ 20.2	€ 17.5	€ 15.9
300	€ 23.7	€ 21.7	€ 18.0	€ 15.7	€ 14.3

Finland

Figure 7.12shows the sensitivity analysis for the whole country strategy in Finland. The cost-effectiveness results for remediation are most sensitive to the number of quality adjusted life years gained per lung cancer case and the increase in lung cancer risk per 100 Bq/m^3 increase.

Figure 7.12: Finland - sensitivity analysis of remediation strategies – all areas



In the analysis in which the action level and average radon level of target areas are simultaneously changed (Figure 7.13) it can be seen that the cost per QALY gained rises above €50k/QALY (shaded area) once the radon level in targetted areas falls below 100 Bq/m^3 at the current action level of 400 Bq/m^3.

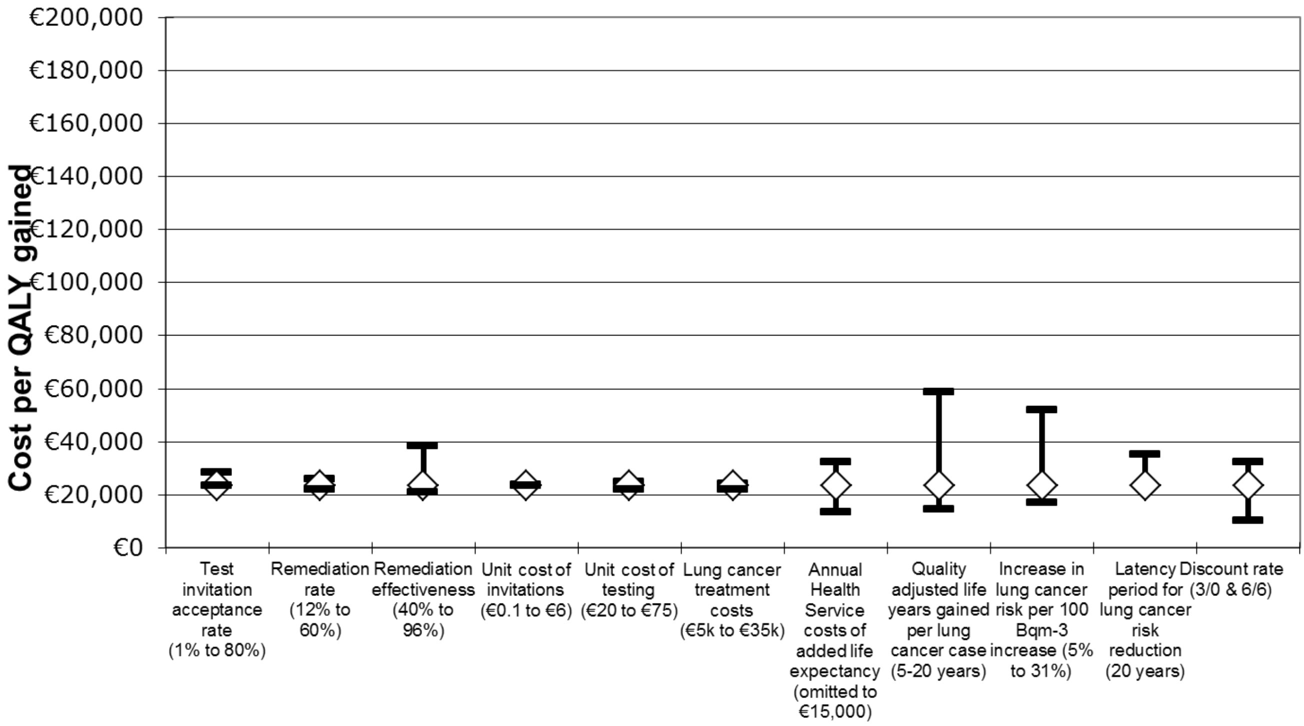
Figure 7.13: Finland - sensitivity analysis of remediation strategies – different Action Levels and radon levels in target areas: Cost per QALY gained (€'000)

Areas targetted: (Long-term arithmetic mean Bq/m^3)	Action Level (Bq/m^3)				
	50	*100*	*200*	*300*	*400*
36	€ 197.0	€ 160.4	€ 198.9	€ 335.3	€ 589.4
64	€ 139.8	€ 106.8	€ 89.6	€ 96.3	€ 118.2
87	€ 115.3	€ 89.7	€ 70.6	€ 66.7	€ 70.4
100	€ 105.8	€ 83.4	€ 65.0	€ 59.5	€ 60.0
150	€ 80.5	€ 66.8	€ 52.5	€ 46.0	€ 43.0
200	€ 65.5	€ 56.7	€ 45.7	€ 39.9	€ 36.6
250	€ 55.5	€ 49.6	€ 41.1	€ 36.1	€ 33.0
300	€ 48.0	€ 44.0	€ 37.4	€ 33.2	€ 30.4

Norway

Figure 7.14 shows the sensitivity analysis for Norway for remediation in the targeted high radon areas. The cost-effectiveness results are most sensitive to the remediation effectiveness, the number of quality adjusted life years gained per lung cancer case and the increase in lung cancer risk per 100 Bq/m^3 increase.

Figure 7.14: Norway - sensitivity analysis of remediation strategies – high radon areas



In the analysis in which the action level and average radon level of target areas are simultaneoulsy changed (Figure 7.15) it can be seen that the cost per QALY gained rises above €50k/QALY (shaded area) once the radon level in targetted areas falls below approximately 64 Bq/m^3 .

Figure 7.15: Norway - sensitivity analysis of remediation strategies – different Action Levels and radon levels in target areas: Cost per QALY gained (€'000)

Areas targetted: (Long-term arithmetic mean Bq/m³)	Action Level (Bq/m³)				
	50	*100*	*200*	*300*	*400*
36	€ 81.8	€ 92.4	€ 240.7	€ 663.6	€ 1,597.2
64	€ 56.5	€ 49.0	€ 58.9	€ 94.3	€ 163.0
87	€ 47.1	€ 39.8	€ 38.9	€ 48.1	€ 66.8
100	€ 43.5	€ 36.9	€ 34.3	€ 39.1	€ 49.9
150	€ 34.2	€ 29.9	€ 26.2	€ 25.8	€ 27.4
200	€ 28.8	€ 26.0	€ 22.8	€ 21.6	€ 21.5
250	€ 25.2	€ 23.4	€ 20.7	€ 19.4	€ 18.9
300	€ 22.5	€ 21.3	€ 19.2	€ 18.0	€ 17.4

Ireland

Figures 7.16and 7.17show the sensitivity analysis for remediation in Ireland across the whole country and in targeted areas respectively. The cost-effectiveness results for remediation are most sensitive to the effectiveness of remediation measures, the unit cost of issuing invitations to be tested, the number of quality adjusted life years gained per lung cancer case and the increase in lung cancer risk per 100 Bq/m^3 increase.

Figure 7.16: Ireland - sensitivity analysis of remediation strategies – whole country

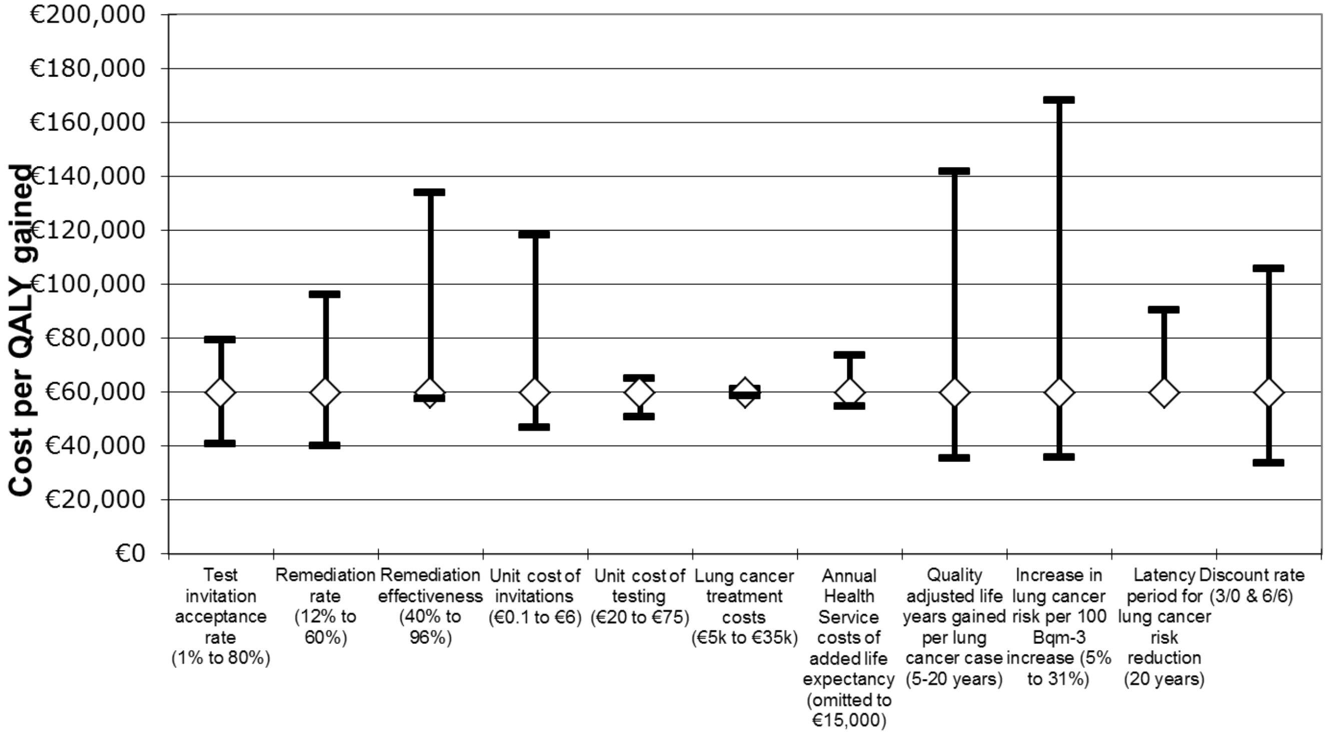
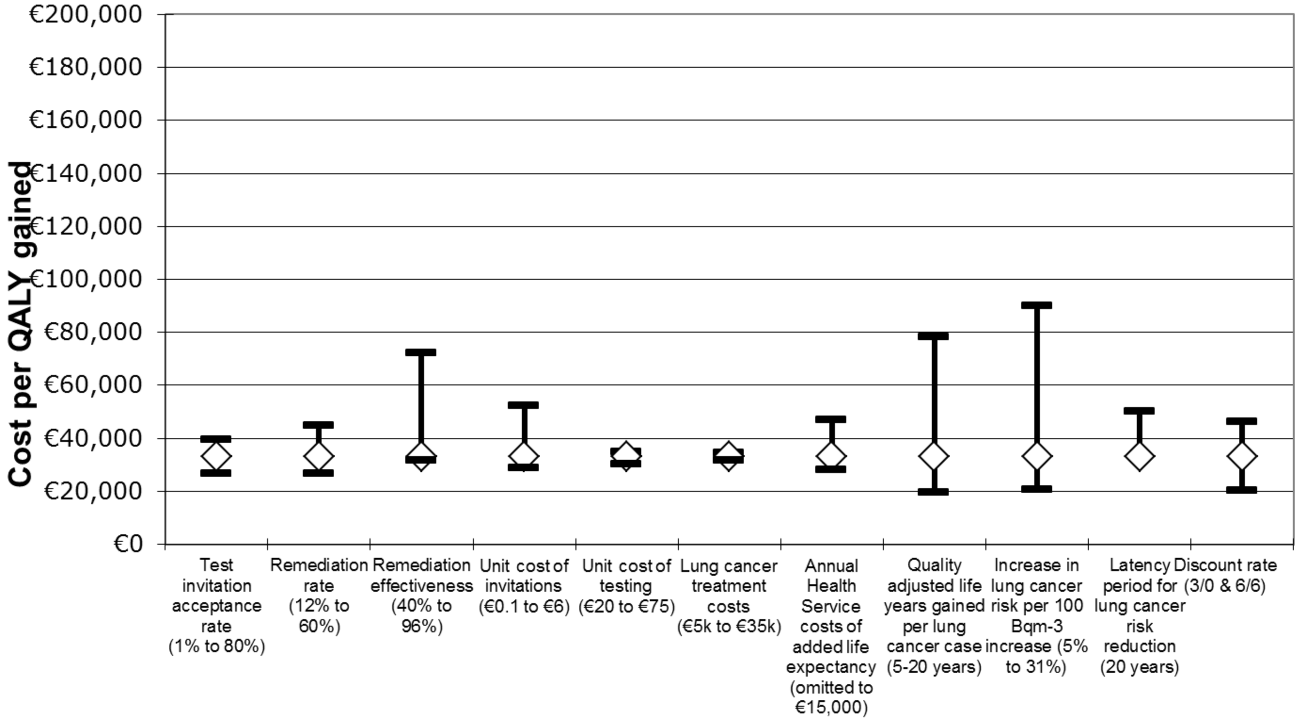


Figure 7.17: Ireland - sensitivity analysis of remediation strategies – high radon areas



In the analysis in which the action level and average radon level of target areas are simultaneoulsy changed (Figure 7.18) it can be seen that the cost per QALY gained remains above €50k/QALY (shaded area) unless the radon level in targetted areas is around 87 Bq/m^3 .

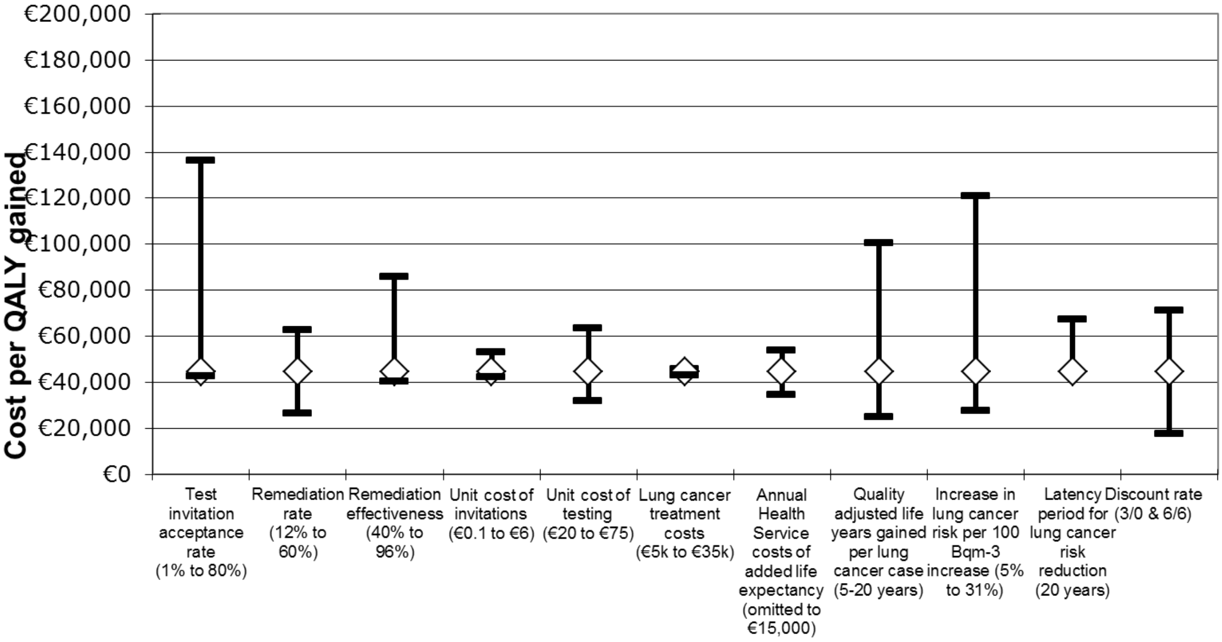
Figure 7.18: Ireland - sensitivity analysis of remediation strategies – different Action Levels and radon levels in target areas: Cost per QALY gained (€'000)

Areas targetted: (Long-term arithmetic mean Bq/m^3)	Action Level (Bq/m^3)				
	50	*100*	*200*	*300*	*400*
36	€ 103.3	€ 108.2	€ 186.9	€ 342.4	€ 589.9
64	€ 67.3	€ 58.2	€ 63.5	€ 83.6	€ 115.2
87	€ 54.1	€ 45.5	€ 43.1	€ 48.8	€ 59.3
100	€ 49.2	€ 41.4	€ 37.7	€ 40.5	€ 47.0
150	€ 36.7	€ 31.6	€ 27.2	€ 26.3	€ 27.2
200	€ 29.5	€ 26.2	€ 22.4	€ 20.9	€ 20.6
250	€ 24.8	€ 22.6	€ 19.6	€ 18.0	€ 17.3
300	€ 21.3	€ 19.9	€ 17.4	€ 16.0	€ 15.2

UK

Figure 7.19 shows the sensitivity analysis for the UK. The cost-effectiveness results for remediation are most sensitive to the test invitation acceptance rate, number of quality adjusted life years gained per lung cancer case, the increase in lung cancer risk per 100 Bq/m^3 increase, and the discount rates used.

Figure 7.19: UK - sensitivity analysis of remediation strategies – high radon areas



In the analysis in which the action level and average radon level of target areas are simultaneoulsy changed (Figure 7.20) it can be seen that the cost per QALY gained remains below €50k/QALY (shaded area) as long as the average radon level in targeted areas is at least 64 Bq/m^3 with an action level of 200 Bq/m^3 or lower.

Figure 7.20: UK - sensitivity analysis of remediation strategies – different Action Levels and radon levels in target areas: Cost per QALY gained (€'000)

Areas targetted: (Long-term arithmetic mean Bq/m^3)	Action Level (Bq/m^3)				
	50	*100*	*200*	*300*	*400*
36	€ 51.7	€ 68.8	€ 187.6	€ 482.4	€ 1,079.9
64	€ 33.8	€ 32.6	€ 44.7	€ 73.5	€ 124.2
87	€ 28.1	€ 25.8	€ 28.4	€ 37.2	€ 52.3
100	€ 26.2	€ 23.8	€ 24.7	€ 29.9	€ 39.1
150	€ 21.2	€ 19.5	€ 18.5	€ 19.3	€ 21.2
200	€ 18.5	€ 17.3	€ 16.2	€ 16.0	€ 16.6
250	€ 16.7	€ 15.9	€ 14.9	€ 14.5	€ 14.6
300	€ 15.4	€ 14.8	€ 14.0	€ 13.6	€ 13.5

Discussion

Radon concentrations are modifiable by a variety of preventive and remedial interventions, and there is therefore a need to evaluate radon control policies using the evaluative techniques that are increasingly used to assess other health interventions. In this exercise we have developed a cost-effectiveness tool, familiarized a number of participating EU countries in the use of the tool, and applied it in five countries using a set of agreed principles and parameter inputs to evaluate a standard prevention intervention and a standard remediation programme.

The results suggest that basic radon prevention measures, such as installing membranes in all new buildings, are likely to be cost-effective even in settings where the average radon level is quite low.

Concerning remediation measures in existing buildings, the results were less clear-cut, and indicated that cost-effectiveness is highly dependent on the radon level in target areas: such policies may therefore need to be carefully targeted. There was also evidence that the cost-effectiveness of such policies can be strongly influenced by the prevailing action level or reference level: at any average radon level in a particular area, cost-effectiveness typically falls as the action level is reduced before rising again when the action level falls below 100 or even 50 Bq/m^3. The likely reason for this is that remediation involves substantial search costs, and as the action level is reduced these are loaded onto an increasing number of homes over the action level: costs per house remediating fall more rapidly than does the benefit of remediation at lower radon levels. Eventually, however, this balance changes and the benefits fall faster than the costs at very low action levels.

The remediation analyses also illustrated very clearly that cost-effectiveness is strongly influenced by the characteristics of the inhabitants of homes that may be candidates for remediation. In particular, cost-effectiveness is much better for smokers, due to their much higher risk of lung cancer. Of course remediation policies are directed at houses, and the occupiers of any particular house may change over time, as may their modifiable characteristics such as smoking. Radon remediation policy therefore cannot focus too much on the smoking behavior of the current inhabitants, but needs to recognize that those most at risk and therefore most likely to benefit from remediation actions are likely to be smokers.

The analyses of remediation policies also showed large variations in such things as invitation acceptance rates, remediation rates in homes found to be over the action level, and the effectiveness and costs of remedial actions. These variations suggest that there are likely to be considerable gains from a better understanding of why they vary so much internationally. In some cases the variation may also reflect lack of information rather than genuine differences between countries, and the analyses presented here may help in determining areas in which better information is required to inform radon policies.

International comparisons of cost-effectiveness of this type are not common and can be complex to set up, undertake and interpret. To ease interpretation some of the parameter values used were held constant, but in further analyses it would be possible to obtain local inputs for a wider set of parameter values. It would also be possible to undertake more detailed analyses, such as the cost-effectiveness of installing more complex preventive measures during construction, the cost-effectiveness testing new homes after they have been occupied and undertaking further remedial work where necessary, and the cost-effectiveness of policies to increase invitation acceptance rates and remediation rates.

Appendices:

Czech Republic

Scenarios: New homes

According to Czech legislation everyone who intends to build a house with habitable rooms is obliged to measure the radon index of the building site. In case the radon index is medium or high or the floor heating is used in the contact construction, the preventive measures are obliged by the Czech Technical Standard 73 0601. We used the ratio of 0.75 for houses built with preventive measures. The cost of measurement per one house is about 200 Euro.

The membrane serving as the radon proof membrane additional cost is calculated as the average additional cost of verified radon proof membrane to standard damp proof membrane (2 Euro per m^2) multiplied by the average surface of contact construction as $150m^2$.

The number of new houses is taken as the sum of the houses build after 2005, when the Czech Technical Standards dealing with protection of radon and thermal protection of buildings were issued.

Scenarios: existing buildings

NRPI distributes the track detectors in the frame of National radon program. The price is around 20 Euro per two detectors (two rooms), mailing cost and evaluation. Near to 100% of people accept the measurement. If the average concentration of radon in the dwelling is higher than 1000 Bq/m^3, the remediation is recommended to the homeowner. In the case of houses built before 1991, it is possible to obtain the state subsidy of 6000 Euro for remedial action in the house. This was divided in to two parts 5600 Euro per remediation and 400 Euro per post remedial measurement. We estimated, that only 10 % of dwellings above the action level decide to remediate.

Population databy age-band and sex:

Czech Health Statistics Yearbook - 2010, *Institute of Health Information and Statistics of the Czech Republic, Palackehonamesti 4, P.O.BOX 60, 128 01 Prague 2, Czech Republic. Published in 2011, I*SSN 1210-9991, ISBN 978-80-7280-966-0. Table 1.1.1

Country or region annual number of live births, by sex (in '000s):

Demographic Yearbook of the CzechRepublic – year 2010, Czech statistical office, http://www.czso.cz/csu/2011edicniplan.nsf/engpubl/4019-11-eng_r_2011
Or
Czech Health Statistics Yearbook - 2010, *Institute of Health Information and Statistics of the Czech Republic, Palackehonamesti 4, P.O.BOX 60, 128 01 Prague 2, Czech Republic.Published in 2011, I*SSN 1210-9991, ISBN 978-80-7280-966-0. Table 1.4

Country or region total annual lung cancer cases, by age-band and sex:

Deaths 2010, *Institute of Health Information and Statistics of the Czech Republic, Palackehonamesti 4, P.O.BOX 60, 128 01 Prague 2, Czech Republic.Published in 2011,* ISSN: 1210-996, ISBN 978-80-7280-925-7, http://www.uzis.cz/en/publications/deaths-2010Table 4.2.

Country or region life-table data:

Life tables for the Czech Republic, Table 1 and Table 2
http://www.czso.cz/csu/2011edicniplan.nsf/engpubl/4002-11-eng_r_2011

Country or region life-table data:

Values not changed: used UK 2006

Population mean quality of life , by age-group and sex, for QALY adjustment:

Values not changed: used UK

Radon statistics in country

According to National Survey held in 1993/1994.
Literature: (1) Hulka, J., Thomas, J. (2004). National Radon Programme: 20 years of experience in Czech Republic. Proceedings of the 11th Congress of the International Radiation Protection Association (IRPA–11) Madrid, Spain 23–28 May.
(2) Thomas, J., Fojtíková, I., Hůlka, J. (2007). The regulatory role in the Czech Radon Programme. Proceedings of the IBC Global Conference RADON RISK, London, UK, 29-30 January

Mean Health Service/hospice treatment cost per lung cancer case

The expenditures for lung cancer treatment were discussed personally in the hospital Na Bulovce.

Health Service annual per capita expenditure on all other health care during added life expectancy

The per capita and year healthcare expenditures were taken as average for the age group from 40-100 from the bulletin Economic information on health care 2010, ISBN: 978-80-7280-969-1, Table 5.9

Finland

Scenario 1: All of Finland

Scenario 2 and 3: High-radon area of Finland. The six provinces with the highest radon levels: Etelä-Karjala (South Karelia), Kanta-Häme, Kymenlaakso, Pirkanmaa, Päijät-Häme and the former province of Itä-Uusimaa. There was 20 provinces in Finland until 1.1.2011. Itä-Uusimaa was incorporated with Uusimaa 1.1.2011. The original Uusimaa is outside the high-radon area.

Population data, by age-band and sex:

Source: as of 31.12.2010

Official Statistics of Finland (OSF): Population structure [e-publication].

ISSN=1797-5395. Helsinki: Statistics Finland [referred: 26.8.2011].

Access method: http://www.tilastokeskus.fi/til/vaerak/index_en.html.

Country or region annual number of live births, by sex (in '000s):

Source: as of 2010

Official Statistics of Finland (OSF): Births [e-publication].

ISSN=1798-2413. Helsinki: Statistics Finland [referred: 29.8.2011].

Access method: http://www.tilastokeskus.fi/til/synt/tau_en.html.

Country or region total annual lung cancer cases, by age-band and sex:

Finnish Cancer Registry, Cancer Statistics at www.cancerregistry.fi, updated on 15.08.2011

Mean annual numbers of new cancer cases in 2005-2009

Lung, trachea C33-34

Country or region life-table data:

National data is used also in the regional scenarios 2 and 3.

Life-table data   as of 2009

Source (qx, lx and ex):

Official Statistics of Finland (OSF): Deaths [e-publication].

ISSN=1798-2545. Helsinki: Statistics Finland [referred: 29.8.2011].

Access method: http://tilastokeskus.fi/til/kuol/meta_en.html

qx100 is not reported by OSF. Here qx100=1, mx100=0.5.

dx = qx * lx

mx = dx/(lx-0.5*dx)

Country or region smoking data, by age-group and sex

the proportion who are life-long non-smokers of any product

National data is used also in the regional scenarios 2 and 3.

Sources:SatuHelakorpi, ElinaLaitalainen, AnttiUutela. Health Behaviour and Health amongas of 2009the Finnish Adult Population, Spring 2009. National Institute for Health and Welfare (THL), Report 7/2010, 211 pages.Helsinki 2010.ISBN 978-952-245-231-3 (print), ISBN 978-952-245-232-0 (pdf):

http://www.thl.fi/thl-client/pdfs/ce5ee5c1-6df4-44c2-bcd7-c3b735019570

ElinaLaitalainen, SatuHelakorpi, AnttiUutela. Health Behaviour and Health among the Finnish Elderly, Spring 2009, with trends 1993–2009. National Institute for Health and Welfare (THL), Report 30/2010, 173 pages.Helsinki 2010.ISBN 978-952-245-325-9 (print); 978-952-245-326-6 (pdf):

http://www.thl.fi/thl-client/pdfs/12023db0-7521-4e22-a80c-cb1dbb27b55a

Values used are "Never smoked"+"Less than 100"

Q1: Have you ever smoked during entire lifetime?

Q2: Have you smoked during entire lifetime at least 100 times (cigarettes, cigars or pipefuls)?

Never smoked: Q1 = No (skip Q2)

Less than 100: Q1 = Yes, Q2 = No

Have smoked: Q1 = Yes, Q2 = Yes

Population mean quality of life , by age-group and sex, for QALY adjustment:

The UK values already in the model

Mean outdoor level of radon

0 Bq/m^3.(No comprehensive data available, obviously small compared to indoor radon levels).

Household characteristics

Source: Official Statistics of Finland (OSF): Dwellings and housing conditions [e-publication].

ISSN=1798-6761. Helsinki: Statistics Finland [referred: 30.8.2011].

Access method: http://tilastokeskus.fi/til/asas/meta_en.html.

Houses (flats not included) as of 31.12.2001, assuming household size = 8 for houses reported as "7+".

Household size change from 31.12.2001 to 31.12.2010.

Health Service annual per capita expenditure on all other health care during added life expectancy

UK values already in the model.

Mean Health Service/hospice treatment cost per lung cancer case

UK values already in the model.

SCENARIOS

1) The cost-effectiveness of incorporating basic radon prevention measures in all new houses.

Sealing the slab/footing gap with a bitumen felt + passive radon piping under the slab in all new slab-on-ground houses (64% of all the new houses). The remaining 36% of other types of houses are not included, as the same percentage reduction and/or prevention method does not apply.

Arithmetic mean radon level in Bq M-3, adjusted for measurement error

96 Bq/m^3.All dwellings (houses+flats).National random sampling survey 2006. Not adjusted for measurement error.

Percentage reduction: 57%.

Source: http://rpd.oxfordjournals.org/content/early/2011/05/31/rpd.ncr192.full

Cost of installing membrane/other basic measures: 1000€ (educated guess, no published source)

Initial radon concentration distribution:

GM = 92 Bq/m^3, GSD = 2.27, AM = 130 Bq/m^3

Slab-on-ground houses with no radon prevention reported. National random sampling survey 2006.

2) The cost-effectiveness of incorporating basic radon prevention measures in new houses in targeted areas, for example defined by average radon levels.

Same as 1) but only in the 6 out of 20 provinces having the highest average radon levels.

Arithmetic mean radon level in Bq M-3, adjusted for measurement error

201 Bq/m^3.All dwellings (houses+flats) in high-radon area.National random sampling survey 2006. Not adjusted for measurement error.

Initial radon concentration distribution: GM = 194 Bq/m^3, GSD = 2.06, AM = 248 Bq/m^3

Slab-on-ground houses with no radon prevention reported, located in the 6 high-radon provinces.National random sampling survey 2006.

3) The cost-effectiveness of remediation programmes in existing houses in targeted areas, for example defined by average radon levels.

Campaign in 6 provinces having the highest average radon levels. A brochure is sent to households in detached-house areas. They are offered a radon measurement in reduced price.

Arithmetic mean radon level in Bq M-3, adjusted for measurement error

201 Bq/m^3.All dwellings (houses+flats) in high-radon area.National random sampling survey 2006. Not adjusted for measurement error.

Percentage reduction: 52% (weighted average of different remediation methods)

Remediation cost: 2000€ (weighted average of different remediation methods)

Weighted averages calculated from:

	Sub-slab suction or radon well	Other methods	Source
Frequency	24%	31%	1
Percentage reduction	80%	30%	2
Estimated cost	3000€	1225€	2

Proportion of homes found over action level that decide to remediate: 55%

Sub-slab suction or radon well 24% + Other methods 31%. Source 1.

Sources:

1) Experience from the previous campaigns. Source in Finnish: Valmari et al., Ympäristö ja terveys 6-7:2011, p. 78-81.
2) http://www.stuk.fi/julkaisut_maaraykset/tiivistelmat/a_sarja/fi_FI/stuk-a229/
   The numbers concerning other methods are rough estimates due to heterogeneity of the other methods.

Replacement costs of electric fan: 300€ (source 2)

Running & maintenance costs per annum: 50€ (electricity: 60W; 0,095€/kWh)

Proportion of remediating homes with active measures: 44%

Sub-slab suction or radon well out of all the remediating homes = 24%/(24%+31%) = 44%

Initial radon concentration distribution: GM = 194 Bq/m^3, GSD = 2.69, AM = 324 Bq/m^3

Participants in previous campaigns in the 6 high-radon provinces, all the houses but no flats.

Unit cost of inviting households to test, per household: 0,30€

Radon campaigns by STUK and local municipalities in the season 2010-11:

Printing and posting 82 000 brochures	12 200€
Rough estimate of the costs of working hours by local municipalities and STUK	12 400€
Total	24 600€
Total per household (24 600€ / 82 000 households)	0,30€

Unit cost of measuring radon levels per household: 33€

Price per detector paid by a resident during the radon campaigns in the season 2010-11.

Percent of homes invited to test that accept: 4%

The percent during the last two seasons (2009-10 and 2010-11) in the radon campaigns organised in the high-radon area (9100 accepted/228000 invited).

Norway

As part of Work Package 7 in the EU project RADPAR participating countries will perform several agreed cost-effectiveness analyses for different radon strategies, using a model developed at the Health Economics Research Centre UK, to highlight possible differences between EU countries. This paper provides a description of the parameters used in the cost-effectiveness analyses performed for Norway. The strategies analysed reflect the options of prevention (new build) and remediation (existing dwellings) from elevated radon levels.

The input data includes population data, life-tables and lung cancer incidence for different age-intervals, radon levels in dwellings and average cost estimates for preventative and remedial measures. Some specific data are not readily available in some of the participating countries. Therefore, it was agreed at a WP7 meeting in July 2011 that all participating countries should keep some parameter values constant in order to be able to make comparisons between countries. For example, it was decided that all countries should use the same data for the *discount rate for cos*ts (3 % per annum) and the available UK data for *quality of life values*. The following cases were suggested at the meeting: 1) The cost-effectiveness of incorporating basic radon prevention measures in all new houses, 2) The cost-effectiveness of incorporating basic radon prevention measures in new houses in targeted or defined high-risk areas and 3) The cost-effectiveness of remediation programmes in existing houses in targeted or high risk areas.

In our analyses for Norway we have looked specifically at the following cases:

1) The whole country, reference level of 200 Bq/m^3, all existing and new homes, and mean radon level of 77Bq/m^3.

2) High radon areas, reference level of 200 Bq/m^3, and mean radon level of 226Bq/m^3.

In our analyses we have used radon data from two different surveys.

1) Municipal surveys 2000-2001 in 114 municipalities (of a total of 435 municipalities in Norway). This data has been compared with mean values for each municipality based on the nation-wide survey 1987-89. Based on this comparison population weighted mean radon concentrations of 77 Bq/m^3 in all dwellings and 90 Bq/m^3 in single family (detached) and terraced houses have been estimated.

2) 38 out of the 430 municipalities of Norway which had morethan 20% of the housing stock exceeding 200 Bq/m3 in municipalsurveys. The calculations are based on measurements in 7558 out of115,200 homes, and the total population is241,800 (5 % of the population in Norway). The arithmetic mean radonlevel was calculated to 226 Bq/m3.

The average costs and reduction effectiveness of preventative measures are based on information received from private companies who offer radon services, in combination with internationally published data. The average costs of remedial measures are based on data from a national project, partially funded by Norwegian authorities, where remedial measures were installed in 1100 homes.

Population data

Table 1 shows the population data (per 1 January 2011) from Statistics Norway[1]. The data are presented by age-intervals of 5 years and for both sexes.

Table 1: Population by age-interval and sex (SSB, 2011)

Age	Males	Females
0-5	158 452	150 374
5-9	151 952	145 827
10-14	161 656	153 448
15-19	167 124	156 500
20-24	162 253	156 765
25-29	158 849	154 261
30-34	163 689	156 786
35-39	182 137	173 902
40-44	189 756	179 727
45-49	176 233	166 258
50-54	163 750	157 085
55-59	151 389	147 453
60-64	147 642	144 766
65-69	111 996	114 771

[1]Statistics Norway is the official national statistics bureau (www.SSB.no)

70-74	77 335	86 441
75-79	57 161	72 770
80-84	43 952	64 879
>85	34 877	77 715
Total	**2 460 203**	**2 459 728**

Table 2 shows the number of live births recorded in 2010 from Statistics Norway. The number of recorded live births has been constant during the last 5 years (www.SSB.no).

Table 2: Annual number of live births (SSB, 2011)

	Males	**Females**
Annual number of live births	31 573	30 079

Lung cancer cases

The mean number of lung cancer cases in the period 2005-2009, recorded for 5 year age-intervals among males and females are shown in Table 3. These data are from The Cancer Registry of Norway[2]. The incidence rate of new lung cancers in the Norwegian male population increased significantly from 1960 to the late 1980s and has recently flattened out, whilst the lung cancer rate for females has continued to increase up to the present time (though at a lower incidence compared to males). Lung cancer incidence for both sexes is predicted to decline in the future mainly due to the decrease in the number of smokers in the population, though population aging may partially offset this decline.

Table 3: Mean annual number of lung cancer cases in the period 2005-2009, by age-interval and sex.

Age	**Males**	**Females**
0-4	0	0
5-9	0	0
10-14	0	0
15-19	0	0
20-24	0	0
25-29	1	1
30-34	2	1
35-39	5	5
40-44	10	10
45-49	30	29
50-54	64	64
55-59	133	107
60-64	223	163
65-69	217	151
70-74	247	168
75-79	256	175
80-84	189	120
>85	96	72
Total	**1473**	**1046**

[2] http://www.kreftregisteret.no/Global/Publikasjoner%20og%20rapporter/Cancer%20in%20Norway/Cancer_in_Norway_2009_and_Special_Issue.pdf

Life-table data

The life-tables (for 2010) for both males and females used in our analyses are taken from Statistics Norway[3]. These are in a standard format and data is given for one-year intervals from 0 to 100 years of age.

Smoking data

The proportion of smokers in the Norwegian population has significantly decreased in the period from the beginning of the 1990s to 2010, and is still declining. Table 4 shows that the reduction for all males has been from 37 % to 20 % in this 20-year period, and the corresponding data for all females is from 33 % to 20 % in the same period. However, the number of lung cancers among females has increased significantly more than for males due to the increase in the proportion of smokers among females compared to males in the 70s and 80s (Figure 1). Data for never-smokers is not available in Norway and there are difficulties in using earlier smoking data to estimate the proportion of never-smokers in different age groups in the population. Official UK statistics show that the proportion of smokers in the Norwegian and UK populations are very close, while to the total consumption of cigarettes per person is significantly higher in UK than in Norway[4] (1108 for UK, 578 for Norway).

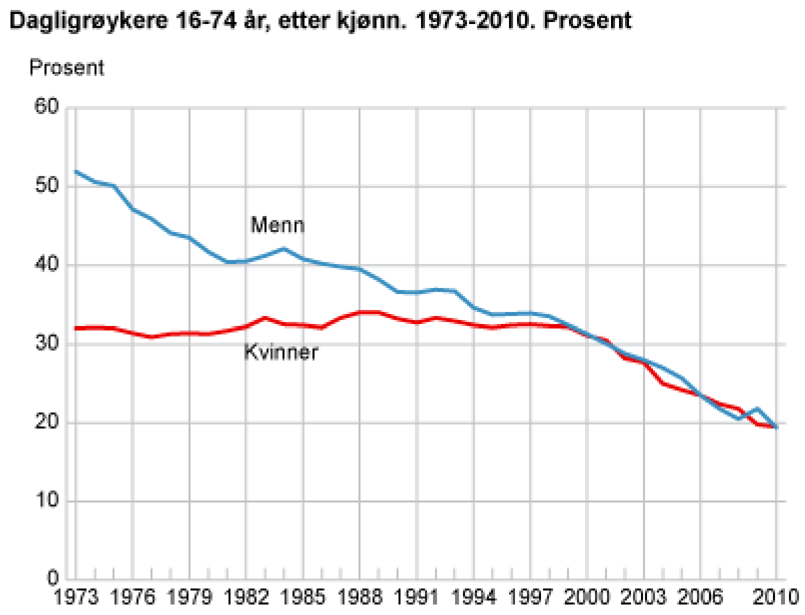
[3] Life-tables for Norway: http://www.ssb.no/dode_en/arkiv/tab-2010-04-15-05-en.html
[4]http://data.euro.who.int/tobacco/Default.aspx?TabID=2444

Table 4: Percentage of smokers in different age-intervals, males and females, 20-year period from 1991 to 2001.

Age\Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
All (16-74)	35	35	35	34	33	33	33	33	32	31	30	29	27	26	25	24	22	21	20	20
16-24	29	29	28	28	28	29	30	30	30	29	29	26	25	24	23	20	17	16	15	15
25-34	41	41	40	37	35	35	35	35	33	31	30	28	26	24	22	20	19	18	19	20
35-44	41	41	40	39	37	36	36	36	36	35	33	31	31	29	28	26	25	23	20	19
45-54	37	38	37	35	36	37	37	37	37	37	35	34	32	30	29	28	27	26	25	25
55-64	32	32	33	31	31	30	29	27	27	28	29	28	27	27	27	26	24	23	23	23
65-74	22	22	23	23	23	24	24	24	23	21	20	19	19	17	17	17	17	16	17	18
All men 16-74)	37	37	37	35	34	34	34	34	32	31	30	29	28	27	26	23	22	21	20	20
16-24	28	31	31	30	29	29	30	30	30	28	28	25	26	25	24	20	16	15	14	14
25-34	41	40	40	37	36	35	36	36	33	32	30	29	26	25	24	21	19	19	20	22
35-44	42	42	42	39	37	36	35	35	35	33	31	30	30	30	27	26	24	23	20	19
45-54	40	42	40	35	36	38	38	38	37	37	35	34	31	30	29	28	26	25	25	24
55-64	34	35	36	34	32	31	30	29	27	28	28	29	28	29	29	26	25	23	23	23
65-74	28	26	27	26	27	28	29	28	25	24	24	23	22	19	18	16	16	16	17	19
All women (16-74)	33	33	33	32	32	32	33	32	32	31	31	28	27	25	24	24	22	21	20	20
16-24	29	28	26	27	28	29	30	30	30	30	30	27	24	22	22	21	18	17	16	15
25-34	42	42	41	37	34	35	35	35	33	31	29	28	26	23	21	20	19	18	18	18
35-44	40	40	38	39	37	37	36	36	37	37	35	32	31	29	29	27	25	22	20	19
45-54	33	34	35	34	37	37	37	36	36	37	35	34	32	30	29	28	27	26	26	26
55-64	29	29	30	28	29	29	29	26	27	27	29	27	26	25	25	25	23	23	22	22
65-74	15	18	19	20	19	19	20	21	21	18	17	15	16	15	16	17	18	16	16	16

Based on Figure 1 it can be seen that between 1973 and 1997, 32 to 35 % of females were smokers. This number then decreased to 20 % during the period 1998 to 2010. In 1973 more than 50 % of adult males were smokers, and this has declined continuously to the same level as for females in 2010; 20 %.

Figure 1: The percentage proportion of smokers among adult men (Menn) and women (Kvinner) from 1993 to 2010.



The estimated proportion of life-long non-smokers in different age-groups presented in Table 5 is based on available statistics. Although there are large uncertainties in these estimates, these data are assumed to be more representative for Norway than the corresponding data from UK.

Table 5: Estimated proportion of the Norwegian men and women population who are life-long non-smokers.

Age	Males	Females
0-4	1,00	1,00
5-9	1,00	1,00
10-14	1,00	1,00
15-19	0,85	0,85
20-24	0,80	0,80
25-29	0,70	0,70
30-34	0,70	0,70
35-39	0,60	0,60
40-44	0,55	0,55
45-49	0,50	0,55
50-54	0,50	0,55
55-59	0,45	0,55
60-64	0,45	0,60
65-69	0,40	0,60
70-74	0,40	0,60
75-79	0,40	0,60
80-84	0,40	0,65
>85	0,40	0,70

Mean quality of life

Data used for *Population mean quality of life* is the same for all participating countries, i.e. from the UK.

Radon concentrations in Norwegian dwellings

Our analyses mainly use the results from the two latest nation-wide radon surveys:

Municipal survey 2000-2001

In the heating season from the beginning of October 2000 to the end of April 2001 measurements of radon were made in nearly 29,000 dwellings divided between 114 municipalities throughout the whole country. In each municipality measurements were performed in between 2 % and 10 % of the housing stock depending on the population size and the dwelling density. The measurements were made using CR-39 track-etch detectors, one in each dwelling. Each of the results was corrected to an annual mean value and the population weighted annual mean radon concentration was thereby calculated.

Table 6 shows the mean radon concentration in the different categories of dwellings in the survey in 2000-2001 as well as the percentage of the sample in the different categories. Population census data (2001) from Statistics Norway are also included in the table. The table shows that there is a considerable over-representation of detached single family houses in the radon survey 2000-2001 compared to data from the 2001 population census. In the radon survey 96 % of the dwellings measured are detached single family houses while the corresponding figure is 64 % in the 2001 population census. Only 0.2 % of the sample is in the category *blocks of flats and terrace apartments* in the radon survey 2000-2001while the 2001 census data shows that 13.4 % of the Norwegian population lives in this category of dwelling. By using the census data, and the mean levels in different dwelling categories in the survey 2000-2001, the corrected mean concentration in Norwegian dwellings is estimated to 77 Bq/m^3 while the population weighted mean radon concentration is estimated to 80 Bq/m^3. Data from earlier surveys are also shown for comparison.

Table 7 summarizes the results for different surveys and presents the values used in the cost-effectiveness analyses for Norway.

Table 6: Mean radon concentration for different categories of dwellings in the surveys 1987-89 (7526 dwellings), 1998-99 (1323 dwellings) and 2000-2001 (28,810 dwellings)

Category of dwelling	Census data			Radon survey 1987-89		Radon survey 1998-99		Radon survey 2000-2001	
	Distribution of dwellings (%)	Population distribution (%)	Number of residents per dwelling	Percentage of sample (%)	Mean radon concentration (Bq/m^3)	Percentage of sample (%)	Mean radon concentration (Bq/m^3)	Percentage of sample (%)	Mean radon concentration (Bq/m^3)
Detached houses and farm houses	57.1	63.8	2.6	67.3	58	74.5	67	96.0	90
Terraced and un-detached houses	12.7	13.2	2.4	11.2	56	11.0	65	2.1	72
Horizontally separated dwellings in two-family houses	8.5	7.2	1.9	4.7	45	2.4	39	1.0	73
Blocks of apartments and terrace apartments	18.4	13.4	1.7	15.4	41	11.5	30	0.2	42
Others	3.4	2.5	1.7	1.3	56	0.7	63	0.7	72

Census data 2001 from Statistics Norway (www.ssb.no).

Table 7: Corrected values for mean radon concentration in dwellings and population weighted mean radon concentration in the surveys 1987-89, 1989-99 and 2000-2001.

	Survey 1987-89	**Survey 1998-99**	**Survey 2000-2001**
Mean radon concentration as reported and not corrected for category of dwelling (Bq/m^3)	54	**62**[1]	89
Mean radon concentration in dwellings by correcting for category of dwelling (Bq/m^3)	54	58	**77**[1]
Population weighted mean radon concentration by correcting for category of dwelling (Bq/m^3)	55	60	80

[1)] The mean values used in the analyses for Norway.

Household size

In our analyses we use an average value of 2.2 persons per household. According to data from Statistics Norway, the average household size in Norway has remained almost constant over the last two decades.

Population (1.1.2011): 4 920 000
Number of households: 2 343 100

- Detached houses (single-family houses, farmhouses, etc): 1 233 483 (52.6%)
- Terraced houses: 271 304 (11.6%)
- Two-family houses (both vertically and horizontally separated): 213 937 (9.1%)

SUM: **1 718 724 (73.3%)**

- Apartments in blocks: 529 453 (22.6%)
- Apartments in commercial buildings: 61 696 (2.6%)
- Others (multi-dwelling units): 43 136 (1.8%)

Average household size – all dwellings): 2.1
Average household size – relevant to detached, terraced and two-family houses: 2.2

Remedial and preventative measures

In principle, the measures in existing and new buildings are similar, but both the challenges of technical installation and the costs incurred will be significantly lower for new buildings. Active measures which include a duct fan or ventilation systems will include significant running and maintenance costs, while passive measures are generally less expensive and the maintenance costs can be neglected. In the cost-effectiveness analysis the costs of preventative measures – simple measures in all homes – is represented by an average value. Remedial measures in existing homes are considered to be less expensive at moderately enhanced levels (100 – 200 Bq/m^3) since low cost measures which are simpler and cheaper are the preferred alternatives in most cases. Such measures will often have lower reduction effect (percentage reduction) than more expensive and comprehensive measures.

Remedial measures (existing buildings)

It is estimated that remedial measures have been undertaken in about 5000 existing Norwegian dwellings, most of these have been completed privately and no national database exists that includes costs and effectiveness assessments of these remedial measures. As part of a national health initiative against cancer (*Nasjonalkreftplan* 1999-2003) the government funded remedial measures for radon, carried out in about 1100 dwellings that had an identified radon problem. The average cost for these remedial measures was about 35.000 NOK (€4460 at present exchange rate), an amount that is considered to be somewhat high compared to more controlled remedial programmes. Some of the "remedial" actions included quite extensive structural and cosmetic changes to the affected buildings, not necessarily directly related to reducing radon levels, which will detrimentally affect the average cost estimate. The choice of remedial action may well also have been biased due to the fact that the owner did not have to foot the bill e.g., several homeowners opted for quite expensive ventilation systems where different cheaper remedial options would probably have been at least as adequate. The remedial action that showed the best effectiveness compared to costs of installation and maintenance was an indoor radon sump with/without active suction, combined with sealing of identified entry routes. This agrees well with observations made in many other countries where this type of solution is deemed very effective for about ¾ of dwellings. Dependent on the type of dwelling the installation of this type of remedial measure will vary, giving costs estimated at between 10 000 and 50 000 NOK (approximately €1275-6400). For the purposes of the cost effectiveness analyses, the average cost for this type of remedial action is estimated to 19 000 NOK (€2400) for detached and undetached houses. In general it is assumed that the radon sump option is most applicable to dwellings with over 200 Bq/m^3.

The effectiveness of remedial measures undertaken as part of the government initiative varied greatly; the average reduction in radon levels was calculated as 64 %.

In dwellings where the radon level is between 100 and 200 Bq/m^3 simpler remedial measures may often suffice e.g., sealing identified entry routes, sealing interior walls that have contact with the surrounding ground (basement walls) and where possible improving an existing ventilation system (e.g. cleaning/opening air vents in a basement). Based on the available information, for the purposes of the cost-effectiveness analyses, the average cost for these types of remedial action is estimated 9 000 kroner (€1150).

Based on the above, a simple estimate for the average costs of all remedial measures undertaken for radon levels over 100 Bq/m^3 is 14.000 kroner (~ €1800).

Accounting for the expected case where more complex remedial measures will be required, the mean costs for remedial measures with a mean radon level over 200 Bq/m3 is estimated to be €2400. These cost values are considerably higher than for UK, but agree with values given in the WHO Handbook on Indoor Radon (page 51).

Prevention measures (new buildings)

Costs of prevention measures in new constructions is on average lower than remedial measures in existing buildings and their effectiveness is often better than remedial measures since they are implemented in the construction process. The cost of preventative measures in new single family and terraced homes varies between €300 (low cost membranes) to more than €2000 (radon resistant membranes in combination with soil depressurization systems). The costs could be reduced significantly by choosing cheaper materials to be used as membranes and by standardizing specifications. Membranes used in Norway as per today are expensive (between €700 and €1200 per house) and in combination with active or passive soil depressurization systems the total costs per building are considerable. A systematic survey of the costs of preventive measures in new buildings in Norway has not been carried out, but based on available information from construction companies and the national research institute SINTEF Byggforsk[5], the average cost is estimated to €900. Table 8 presents a summary of average costs used in the Analyses for Norway.

Table 8: Mean costs for remedial measures (existing buildings) and preventative measures (new buildings) in Norwegian dwellings.

	Existing buildings	New buildings
100 Bq/m^3	€1800[1]	€900
200 Bq/m^3	€2400	€900

[1]Taken into account that measures levels between 100 and 200 Bq/m3, on average, are slightly cheaper than the 200 Bq/m^3.

The mean per annum running (electricity etc.) and maintenance cost for active measures is assumed to be €50, while the replacement cost of electric fan (every ten years) is assumed to be the same as in the UK (i.e. €200).

Post-remediation levels (existing dwellings)

The total reduction in the survey 2000-2003 which included remedial measures in 1100 dwellings was 60 %. However, the reduction for active measures such as sub-slab depressurization (indoor radon sumps) and

[5] http://www.sintef.no/home/

outdoor radon wells (soil depressurization) is assumed to be significantly higher – provided that these are installed according to standard technical descriptions. In our calculations the mean reduction is assumed to be 70 % which is assumed to be more realistic than the UK value of 85 %.

Health service and treatment costs

According to the SINTEF Report 2011-05-11, the mean treatment cost for lung cancer (per five-year prevalence and per capita) in the Nordic countries is €16 718 which is very close to the UK figure of €16 840.

There are no data available on "health service annual per capita expenditure on all other health care during added life expectancy" and we therefore use the value of €7817 (from UK) in our analyses.

Ireland

(Sources of information for inputs to the Cost Effectiveness model compiled by David Fenton, Radiological Protection Institute of Ireland.)

Data Inputs

Country Population by age-band and sex	M - 2,121,171 F – 2,118,677	CSO 2006 census www.cso.ie.
Country or region annual number of live births, by sex		CSO 2006 census www.cso.ie.
Insert Country or region total annual lung cancer cases, by age-band and sex.	Data obtained for 2006	NRCI, 2011. Personal Communication
Country or region life-table data:		CSO Life tables 2005-2007. www.cso.ie
Country or region smoking data, by age-group and sex		Data quoted is that of the UK

Common Parameters

Parameter	Value	Reference
Running & maintenance costs per annum	€100	RPII survey[6].
Health Service annual per capita expenditure on all other health care during added life expectancy	€4,000	Rounded up from €3,741 quoted by Dept of Health[7]
Mean Health Service/hospice treatment cost per lung cancer case	€20,208	WHO, 2009[8]
Remediation cost per household (initial)	€1150	RPII survey[1].
Replacement costs of electric fan	€250	Personal Communication with radon contractor[9]
Cost of installing membrane (meeting the specifications set out in TGD-C).	€220	RPII report for WP_2.2 of Dept of Environment National Radon Strategy group, 2012[10].
Cost of Standby Sump	€115	RPII report for WP_2.2 of Dept of Environment National Radon

[6] What is known about radon cost and remediation rates in Ireland. David Fenton RPII, National Radon Forum, Dublin, 2011. http://www.rpii.ie/RPII/files/8c/8ca1b1b6-9868-4370-a872-e81cab478c93.pdf.

[7] Department of Health and Children. Health in Ireland - Key Trends, 2011. http://www.dohc.ie/publications/pdf/key_trends_2011.pdf?direct=1.

[8] WHO Handbook on Indoor Radon – A Public Health Perspective. http://whqlibdoc.who.int/publications/2009/9789241547673_eng.pdf.

[10] Report compiled by David Fenton, RPII, January 2012.

		Strategy group, 2012[4].
Proportion of remediating homes with active measures	0.86	RPII survey[1].
Average household size	2.81	CSO, 2006
Fan lifetime	15 years	Gray et al., 2009[11]
Number of houses invited 1. New homes whole country 2. New homes – High Radon Areas 3. Existing homes – whole country 4. Existing homes – High Radon Areas	12,541 1,469,521 700,000	Average number of new homes completed in 2010 and 2011[12]. CSO, 2006[13] CSO, 2006[8]
Geometric mean measured radon concentration in High Radon Area, excluding outdoor	81.2	Derived from National Radon Survey data, 2002.
Geometric mean measured radon concentration in whole country, excluding outdoor	48.0	Derived from National Radon Survey data, 2002.
Geometric standard deviation High Radon Areas	2.9	Derived from National Radon Survey data, 2002.
Geometric standard deviation whole country	2.8	Derived from National Radon Survey data, 2002.
Mean outdoor level of radon	6 Bq/m^3	Fennell et al., 2002[14].
Reference level	200 Bq/m^3	www.rpii.ie
Discount rate on costs	3%	Agreed at RADPAR meeting in Oxford to use 3% to help comparison among RAPDAR partners
Discount rate on benefits	3%	Agreed at RADPAR meeting in

[11]Gray, A., Read, S., McGale, P. and Darby, S., 2009. Lung cancer deaths from indoor radon and the cost effectiveness and potential of policies to reduce them. British Medical Journal, BMJ 2009;338:a3110 doi:10.1136/bmj.a3110.

[12]http://www.cso.ie/px/Doehlg/Dialog/varval.asp?ma=HSM01&ti=House+Completions+(Number)+by+Month+and+State&path=../Database/DoEHLG/Housing Statistics/&lang=1.

[13]http://www.cso.ie/quicktables/GetQuickTables.aspx?FileName=CNA33.asp&TableName=Number+of+private+households+and+persons+in+private+households+in+each+Province+,+County+and+City&StatisticalProduct=DB_CN. Twelve counties were selected as being representative of the High Radon Areas. These counties are Mayo, Galway, Clare, Kerry, Waterford, Kilkenny, Wexford, Carlow, Cork, Wicklow, Louth, South Tipperary. High Radon Areas are defined in terms of individual 10km grid squares but it is not possible to obtain statistics by grid square. Data by county is readily available. Therefore data for these counties was used as a reasonable approximate for the High Radon Areas.

[14]Fennell, S.G., Mackin, G.M., Madden, J.S., McGarry, A.T., Duffy, J.T., O'Colmáin, M., Colgan, P.A. and Pollard, D., 2002. Radon in dwellings, the Irish national radon survey. RPII-02/1. Dublin: Radiological Protection Institute of Ireland. www.rpii.ie

		Oxford to use 3% to help comparison among RADPAR partners

Scenario specific parameters

Remediation of existing private houses		
Percent of homes invited to test that accept	2%	RPII – internal report 2011.
Proportion of homes found over action level that decide to remediate	25%	RPII survey[1]. Reported at Nation Radon Forum, 2011. www.rpii.ie.
Radon level in remediating homes as ratio of radon in all homes over AL	1	Gray et al., 2009[6]
Percentage reduction obtained by remediation measures	92%	RPII survey[1]
Unit cost of inviting households to test, per household	€1.50	RPII – internal report 2011
Unit cost of radon test	€54	Average of published prices of Radon measurement services in Ireland

Radon prevention in new buildings (in compliance with TGD C)		
Percent of homes invited to test that accept	100%	
Proportion of homes found over action level that decide to remediate	100%	
Percentage reduction obtained by remediation measures	50%	RPII survey report at National Radon Forum, Cork, 2010[15].
Unit cost of inviting households to test, per household	0	
Unit cost of radon test	0	

[15] Lessons learned from measuring 4,650 homes in Cork. Stephanie Long, National Radon Forum, Cork, 2010. http://www.rpii.ie/RPII/files/a4/a4cf2d35-42c1-4696-8b07-b51190db4b7f.pdf.

UK

Main input values used in cost-effectiveness analyses (costs in GBP £s in 2007 values, then uprated to 2010 €s)

	Baseline*	Source
Average number of occupants per house	2.4	National survey data for 2006.[1]
Average time spent in house	70%	Time use survey for 2005.[2]
Test invitation acceptance rate	30%	current DEFRA programmes and Department of the Environment, Transport and Regions pilot study in Derbyshire, Cherwell & Mendip.[3]
Proportion of homes testing over radon Action Level who decide to remediate	20%	NRPB Survey data.[4]
Radon reduction from installing basic measures in new home	50%	NRPB survey data.[5]
Radon reduction from installing active measures in new home	90%	Consensus value agreed by relevant agencies†; see reference[6] for further details.
Radon reduction from remediation measures in existing home.	85%	Average reduction reported in two samples of homes.[7, 8]
Cost of basic preventive measures such as sealed membranes in new home	£100	Consensus value agreed by relevant agencies†; see reference[6] for further details.
Cost of "Full preventive measures", consisting of basic preventive measures plus fitting a means of under-floor ventilation such as a radon sump and pipe, in new home	£200	Consensus value agreed by relevant agencies†; see reference[6] for further details.
Capital and installation cost of electric fan when sump/pipe already fitted	£300	Consensus value agreed by relevant agencies†; see reference[6] for further details.
Electric fan: replacement cost	£200	Consensus value agreed by relevant agencies†; see reference[6] for further details.
Electric fan: running cost per year	£60	Consensus value agreed by relevant agencies†; see reference[6] for further details.
Capital and installation cost of electric fan with retro-fitting of sump/pipe	£1,000	Consensus value agreed by relevant agencies†; see reference[6] for further details.

Invitation to measure	£1.65	Cost of invitation letter in colorectal cancer screening programme, updated to 2007 prices[9]
Measurement of radon: delivery, removal, reading and reporting from two track etch detectors in different rooms for three months	£42	HPA current price as of July 2008
Average remediation cost per household (initial)	£762	Reference [7], adjusted to 2007 prices using the Building Cost Index.
Lifetime remediation cost per household (discounted over 100 years, 35% with active measures requiring replacement every 15 years + running costs)	£1,987	Reference [7], and model. See reference[6] for further details.
NHS annual per capita expenditure on all other health care during added life expectancy	£7,817	Reference [10], using age-specific cost per person for Hospital and Community Health Services, & assuming other NHS expenditure is distributed similarly by age-group.
Mean NHS/hospice treatment cost per lung cancer case	£16,840	Reference [11], updated to 2007 prices using Hospital and Community Health Services cost Index, & increasing estimated in-patient palliative care costs to make approximate allowance for hospice care following discharge from hospital.

* Sensitivity analyses examined the effect of changing these values.

† Individuals from the Health Protection Agency, Department of Communities and Local Government & Building Research Establishment agreed the values listed in the table. See reference[6] for further details.

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