Journal of Environmental Management 91 (2010) 2263–2274

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

The cost effectiveness of radon mitigation in existing German dwellings – A decision theoretic analysis

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ARTICLE INFO

Article history:
Received 9 November 2009
Received in revised form
18 May 2010
Accepted 11 June 2010

Keywords:
Radon
Cost effectiveness analysis
Legal regulations
QALY
Lung cancer
Natural radiation
Relative risk

ABSTRACT

Radon is a naturally occurring inert radioactive gas found in soils and rocks that can accumulate in dwellings, and is associated with an increased risk of lung cancer. This study aims to analyze the cost effectiveness of different intervention strategies to reduce radon concentrations in existing German dwellings. The cost effectiveness analysis (CEA) was conducted as a scenario analysis, where each scenario represents a specific regulatory regime. A decision theoretic model was developed, which reflects accepted recommendations for radon screening and mitigation and uses most up-to-date data on radon distribution and relative risks. The model was programmed to account for compliance with respect to the single steps of radon intervention, as well as data on the sensitivity/specificity of radon tests. A societal perspective was adopted to calculate costs and effects. All scenarios were calculated for different action levels. Cost effectiveness was measured in costs per averted case of lung cancer, costs per life year gained and costs per quality adjusted life year (QALY) gained. Univariate and multivariate deterministic and probabilistic sensitivity analyses (SA) were performed. Probabilistic sensitivity analyses were based on Monte Carlo simulations with 5000 model runs. The results show that legal regulations with mandatory screening and mitigation for indoor radon levels >100 Bq/m^3 are most cost effective. Incremental cost effectiveness compared to the no mitigation base case is 25,181 € (95% CI: 7371 €–90,593 €) per QALY gained. Other intervention strategies focussing primarily on the personal responsibility for screening and/or mitigative actions show considerably worse cost effectiveness ratios. However, targeting radon intervention to radon-prone areas is significantly more cost effective. Most of the uncertainty that surrounds the results can be ascribed to the relative risk of radon exposure. It can be concluded that in the light of international experience a legal regulation requiring radon screening and, if necessary, mitigation is justifiable under the terms of CEA.

1. Introduction

Radon is a naturally occurring inert radioactive gas found in soils and rocks, the decay products of which account for almost 30% of ionizing radiation not emitted from medical devices in most European countries (Guhr and Leißring, 2005). Depending on geological and geophysical conditions such as uranium/radium content and bedrock permeability, as well as the construction and current condition of an individual building, radon, which is particularly mobile as it does not form any chemical bonds, can migrate from the ground through leakages in the building structure and accumulate in dwellings. Indoor radon contamination is mostly measured in Becquerel per cubic metre of indoor air (Bq/m^3), where 1 Bq = 1 radioactive decay per second. Inside the dwelling, the atomic nucleus decays to a number of short-lived isotopes such as polonium and lead, which adsorb to aerosol particles in the indoor air and can deposit in the respiratory tract and alveoli when inhaled. By means of further decay processes, alpha particles are emitted that irradiate lung cells, thereby leading to a higher risk of lung cancer. Almost 1900 deaths each year may be caused by radon-induced lung cancer in Germany (Menzler et al., 2006). However, there is a set of mitigative actions by which indoor radon concentrations can be considerably reduced, modifying for example the basic structure of a building or the indoor air exchange. Despite significant epidemiological evidence, and contrary to most other European countries, there are no regulations in Germany yet considering indoor radon exposure.

This study aims to analyze the cost effectiveness of different intervention strategies to reduce radon concentrations in existing German dwellings. A decision theoretic model is developed to

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doi:10.1016/j.jenvman.2010.06.015

analyze the impact of different regulatory regimes for radon mitigation, which have been discussed for some time but thus far not introduced in Germany. To determine the cost effectiveness of such interventions, the latest epidemiological data on radon distribution in Germany, as well as the relative risk of radon exposure, were applied. Furthermore, detailed empirical data on compliance with international radon regulations and guidelines was implemented in the model, as well as sensitivity and specificity of screening devices, which have been neglected in most cost effectiveness analysis. In addition, the model was explicitly allowed to account for a potential need for further improvements with respect to mitigative measures after negative confirmatory test results. To overcome the problems of standard cost effectiveness decision rules also two relatively recent approaches (cost effectiveness acceptability curve (CEAC), cost effectiveness acceptability frontier (CEAF)) were transferred to the field of environmental health economics to quantify the uncertainty that surrounds the results.

2. Material and methods

The cost effectiveness analysis (CEA) of radon mitigation was conducted as a scenario analysis, where each scenario represents a specific regulatory regime to reduce radon exposure in the German population. Therefore, a decision theoretic model (decision tree) was developed, which allows for the comparison of different intervention strategies. Every scenario was calculated for different action levels (AL), for which mitigation is advised or mandatory. Cost effectiveness was measured in costs per averted case of lung cancer, costs per life year gained and costs per quality adjusted life year (QALY) gained. QALYs are common outcome parameters in CEA, considering not only the impact an intervention has on the estimated time of survival but also the quality of an individual's life. A societal perspective was adopted to calculate costs and effects of radon mitigation. All model parameters were determined by an extensive search of the literature in computerized databases, as well as publications of national and international institutions (complete search algorithms are available from the author). To validate the results, univariate and multivariate deterministic and probabilistic sensitivity analyses (SA) were performed. Probabilistic SA were based on Monte Carlo simulations with 5000 model runs. The model was programmed using a spreadsheet application (MS-Excel).

Fig. 1 illustrates the scheme for cost effectiveness analyses of radon mitigation described by Kennedy and Gray (2001), which is implemented in most current CEA (see for example Coskeran et al., 2006a,b; Denman et al., 2005; Stigum et al., 2003) and served as the basis for this study. The net costs of interventions are composed of the costs for the identification of buildings with radon concentrations exceeding the pre-defined action level (delivery, reading and reporting costs from the measurement devices), plus expenses for remedial work on buildings (installation, maintenance and running of mitigative measures) and other mitigation efforts that will be incurred over the defined time-horizon, minus any direct and indirect costs (treatment costs and productivity losses from lung cancer morbidity and mortality) that could be averted by reducing lung cancer incidence. The intervention effect measured in terms of averted lung cancer cases or (quality-adjusted) life years gained is calculated as the product of total dose reduction, time-horizon and risk measure, which defines the interrelation between exposure and disease. For this study the scheme was expanded to account for individual compliance concerning the purchase and execution of radon tests, as well as the willingness to mitigate after positive test results.

Net costs = Screening costs
+ Mitigation costs (partly discounted)
- Lung cancer costs averted (discounted)

Net outcome = Exposure reduction
* Risk measure
* Time horizon
* Average no. of life years / QALYs gained from lung cancer (discounted)

Cost effectiveness = Costs per lung cancer case (life year / QALY) averted (gained)

Fig. 1. Schematic presentation of cost effectiveness analyses for radon interventions. Source: modified from Kennedy and Gray (2001).

3. Model structure and scenarios

Fig. 2 depicts the basic structure of the decision theoretic model. The decision tree was developed in accordance with accepted recommendations for radon screening and mitigative actions from international institutions, such as the International Commission on Radiological Protection (ICRP, 1994) or the German Federal Office for Radiation Protection (BfS, 2005). The model was built and validated following the guidelines for decision-analytic modelling in health technology assessment suggested by Philips et al. (2006) and the German Institute for Quality and Efficiency in Health Care (Bastian et al., 2008). Within the model a total of three regulatory scenarios was analyzed, with each scenario defining the relevant paths of the basic model structure, the number of households affected and the probabilities of particular events at the specific chance nodes. Thereby, an approach to assessing different policy options was pursued similar to the one adopted by Coskeran et al. (2009) who analyzed several radon mitigation strategies in the UK. For every scenario incremental cost effectiveness ratios were calculated in comparison with the base case which reflects the reference situation, where no official thresholds or mitigation guidelines exist.

3.1. *Scenario 1 (S1): universal screening and mandatory mitigation*

Scenario 1 is modelled on a draft bill introduced by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) in 2005, which met with widespread disapproval from federal state governments. Due to a change of government in 2005, it expired automatically and has not been brought up ever since (Ettenhuber et al., 2005a). Within the so-called Radon protection law ("Radonschutzgesetz"), an indoor target value of 100 Bq/m^3 was intended for existing dwellings. In case of higher radon readings, mitigation measures were mandatory until the exposure level was reduced to less than the target value. However, S1 is somewhat more restrictive than the intended regulation, as radon screening and mitigation are mandatory without exceptions. As the effectiveness of radon interventions cannot be predicted properly *a priori*, a confirmatory test has to approve that radon exposure has been reduced to less than AL. If radon readings are still above AL after initial mitigation further remedial actions are obligatory.

3.2. *Scenario 2 (S2): universal screening and optional mitigation*

The second intervention scenario is modelled after a radon guideline planned on behalf of the Ministerial Conference for Construction in 2003, as well as the regulations of the energy performance certificate (EPC), which obliges homeowners in Germany to disclose energy consumption/energy demand of their buildings. However, in contrast to the radon guideline and EPC-regulations, in S2 radon levels have to be disclosed for every building without exceptions. If test results are above AL, it is the