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CURRENT CONCEPTS IN RADON RISK MANAGEMENT FOR MEMBERS OF THE PUBLIC

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ABSTRACT

Radon risk management addresses data collection, risk assessment, risk control and risk communication. The different stages of development of these management-components are discussed with a global perspective.

1. INTRODUCTION

Risk management is generally understood as the comprehensive scientific-technical/socio-political procedure during which alternative options (operational, financial, regulatory issues) are evaluated and finally selected among them. With regard to radon risk management significant efforts are currently undertaken on an international scale, ranging from the conduct of national surveys to derive at "radon-risk potential maps" to professionally designed radon risk communication programmes. Globally over 55 Member States of the United Nations in all five continents have requested technical assistance from the International Atomic Energy Agency (IAEA, Vienna, Austria) with different radon programmes and that number is still growing. In the following some of the major developments in the management of the risk due to the radon exposure of man are discussed, comprising the individual microrisk-, as well as the complementary approach of the macrorisk management.

Risk is defined as the potential that a substance will produce harm under specified conditions. The risk from radon inhalation follows a probability distribution over all possible consequences of cumulative exposure to radon and its decay products which can have an adverse effect on the health of the exposed person.

Only a few years ago a heated discussion was going on in the scientific community whether radon exposure at environmental levels actually represented a health risk at all, e.g. at the international conference entitled ".Indoor radon and lung cancer: reality or myth?" (CR 92). In the meantime progress has been made in answering at least partly this hypothetical question. In fact, since then new questions have been raised about additional types of potential health effects other than lung cancer.

2.1. Radon-induced lung cancer

In 1988 the International Agency for Research on Cancer (IARC, Lyon, France) of the World Health Organization (WHO) has classified radon as a human carcinogen. This classification was based on a review of all available data on the lung cancer risk of miners and supported by animal inhalation studies. In 1993 the WHO-Working Group on Indoor Air Quality updated this review to include also the latest findings of ecological and analytical epidemiological studies on residential exposure situations (WH 93). It concluded that the exposure to radon in mines and homes results in an increased lung cancer risk, thereby representing a public health risk.

Over the past 40 years several studies have investigated the radon-induced lung cancer risk for miners. Occupational radon exposure with cumulative exposures ≥ 50 WLM is clearly associated with an increased lung cancer incidence (Tab.1). It is emphasized that this level of exposure is only about a factor 2 to 5 higher than the indoor radon exposure resulting from 70 years of residence in a typical dwelling. The excess relative risk (RR) coefficient [% per WLM] ranges from 0.2 to 3.9. With a centre value of RR about 1 % per WLM, derived from over 3500 lung cancer cases, it is evident that miners are at elevated lung cancer risk due to radon exposure, irrespective whether they are working in a uranium- or non-uranium mine.

Basically due to the lower radon levels in dwellings epidemiological studies of inhabitants living in "normal" dwellings require a large number of cases and matching controls in order to obtain statistically significant results. Such epidemiological studies should preferably be of the analytical type (case-control, cohort) because of inherent methodological deficiencies of ecological studies. Tab 2. shows a summary of results from recently conducted analytical epidemiological studies. Most researchers were able to demonstrate a statistically significant trend of increasing lung cancer risk with increasing radon exposure. Based on over 3500 cases and more than 6000 controls relative risk values found in different studies range from 1.1 to 2.4, with a centre value of about 1.6. Typically results are statistically significant for long term-exposure to radon concentration values ≥ 400 Bq/m³.

Over the years a multiplicity of risk models has been developed, projecting the radon-induced lung cancer risk. A resently published summary of such estimates by different authors for lifetime exposure to radon decay products covers a range of a factor 5 (NA 90). As an example the internationally currently favoured model, i.e. the "Time-since-exposure" (TSE)-model (NA 88), is applied to different exoposure scenarios. In Fig. 1 the lifetime risks are given for the widely used limit for uranium miners and US-family living in a "typical" dwelling, i.e. parents and child. This uses also the results of the comprehensive US-study on the exposure-dose relation for mining and home environments (NA 91). It shows the close proximity of the magnitude of the lung cancer risks for involuntarily exposed member of the public (particularly small children) and that of occupationally exposed underground uranium miners.

In summary, using the risk projections developed by different committees and organisations (ICRP 1987, BEIR IV 1988, EPA 1992) a convergence towards a "centre value" emerges, i.e. the lifetime probability of fatal lung cancer due to lifetime inhalation of radon decay products is about 270 lung cancer deaths per WLM in a population of 10^6 persons. In Western industrialized countries this represents typically ≤ 5 % of the total number of annual lung cancer deaths.

By 1996 the analysis of at least another 9 major epidemiological studies on radon induced lung cancer in domestic environments will have been completed in Belgium, France, Germany, United Kingdom and USA. The data will include 4900 lung cancer cases and 9250 controls, with the German contribution representing over 40% of the total data (DE 91). Although the investigative strategies of these studies are more comprehensive than most of those conducted over the past 25 years, it is unclear whether the intended pooled analysis will be able to reduce the present uncertainties associated with the lung cancer risk factors for low level radon exposure.

2.2. Other effects

Although the major focus has been on radon-induced lung cancer, several researchers have also found increased mortality from cancers at sites other than the respiratory tract (Tab.3).

Sites affected among miners were skin, stomach, liver and gallbladder. Non-mining populations exposed to high radon levels showed increased incidence of leukemia and mutation frequency in blood lymphocytes. Although the incidence of these effects is partly significantly higher than in the corresponding controls, the causal relationship with other carcinogens present in the environment or socio-economic factors cannot be excluded at this time.

Particular attention has been paid to the possible age-specific leukemia rate from radon. Using a modified relative risk model and assuming the conditions of a chronic population exposure at low dose rate (equivalent dose to the red bone marrow of 1.5 mSv/year), it is concluded that about 20 - 30 % of the total observed leukemia rate in children and youths is contributed by the background radiation (JA 93). Since the inhalation of radon (Rn 222, Rn 220) and decay products represent about 20 % of the total bone marrow dose from natural sources, an estimated $\leq$ 5 % of the total leukemia rate in this population group with a known elevated radiation-sensitivity as compared to adults may be due to radon exposure.

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3. THE RESPONSE BY SOCIETY

Hazard, danger, or any chance of harmful consequences associated with exposure usually trigger a reaction in society, aiming finally to eliminate this risk or at least reduce it to an acceptable level. In the case of radon exposure it is impossible to eliminate radon exposure altogether, since everywhere everybody is exposed to radon at any given time. Therefore only the exposure reduction to a certain level can be considered feasible. The ultimate goal is theoretically the radon level outdoors, a costly objective that so far has only been adopted by the US-society. If the basic ICRP-principles applicable to general radiation protection are accepted also for radon exposure indoors, the ALARA-principle ("as low as reasonably achievable") should be followed to arrive at the desired lower level, taking into account socio-economic factors. However, in the case of of the indoor radon issue some members of the professional community have had difficulties in the past in accepting that "radiation is radiation is radiation", i.e. by using arguments, such as apparent uncontrollability or hormesis effects, indoor radon was frequently excluded a priori from regulatory efforts. Thereby it was overlooked that the biological target "lung cell" cannot differentiate between an energy deposition due to an alpha particle originating from inhaled Pu in a nuclear establishment or radon decay product in a living room.. Consequently considerable and largely successful efforts have been made to control exposure from man-made radiation sources for the past six decades, while exposure control from natural sources is only gradually being perceived as at least partly controllable as well. It should be remembered that "controllable" changes its definition with time as our understanding of the processes involved improves. For example, radon mitigation techniques, successfully applied as a routine today, would have been neither possible nor feasible in 1956, when HULTQUIST pointed out the elevated doses for some of the inhabitants of Swedish dwellings.

3.1. Activities by the scientific community

In the 1990's in the **industrialized countries** large national indoor radon surveys have either been completed already (e.g. Sweden, Germany), or they are currently ongoing. Relatively few data have emerged so far from the former USSR, although some areas reportedly have significant problems, e.g. in Kazhachstan, Kyrgzstan and Uzbekistan. The general objective of such surveys is to identify population groups living in dwellings at unacceptably high lung cancer risk. In addition, several countries are also establishing radon risk-potential maps (e.g. Czech Republik, Austria, Sweden) in order to ensure that the area-specific radon conditions are appropriately taken into account for new constructions.
In this context four major issues are still awaiting optimum solutions:

a) the development of a fast and cost-effective method to identify an individual "radon-problem" dwelling located in an area with otherwise "normal" indoor radon levels in the surrounding dwellings;

b) provision of techniques ensuring the long-term effectiveness of radon mitigation in existing dwellings, resp. of radon-barries in new "radon-proof" buildings;

c) successful verification of computer-aided model predictions, forecasting the indoor radon values to be expected in existing dwellings after mitigation, resp. in new structures for a given architectural style and ground geology.

d) in several regions (e.g. Japan) it has been discovered that the contribution from Rn 220 (thoron) and its decay products cannot be neglected, since its dose contribution is comparable to that from radon. However, there is a pronounced lack of suitable, low-cost integrating detection devices for the dose-determining decay product ThB (Pb 212), for detailed discussion, see ref. (ST 93).

In the **developing countries** radon surveys are mostly in the planning- or pilot phase. A common problem is the lack of suitable infrastructure, such as communication- and transport problems or insufficient statistical data, while generally the technical means for the use of low-cost integrating radon detectors are available. Encouraging first results have been reported from several such countries already within the framework of the IAEA-Co-ordinated Research Programme "Radon in the Human Environment", the largest of its kind, e.g. Brazil, China, Ecuador, Egypt, Ghana, Iran, Syria and Vietnam. In many cases this will provide first data on the natural radiation environment and enlarge the global data base of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).

In the subject areas "Dosimetry and Epidemiology" considerable progress has been made in refining the respective methodology, e.g. the new ICRP- Lung Model has been completed, resp. mega-analysis of pooled epidemiological studies is being developed. Unfortunately the results obtained by the two disciplines are at issue with each other at present. Further analysis is needed in order to resolve the apparent discrepancy in the lung cancer risk factors derived from each discipline.

Extensive international efforts are currently being made in order to ensure comparability of the large amount of radon data forthcoming worldwide over the next decade. It is essential to coordinate Quality Assurance Programmes among all groups envolved. The

IAEA, within the framework of the International Radon Metrology Evaluation Programme (IRMEP) and with the logistical assistance of the US-EPA, has embarked on an ambitious initiative in this respect. This initiative foresees a system of four primary calibration centres in Australia, Europe and the US, together with four regional coordinating centres (South America, Africa, Europe and Australia) and technical support centres in Canada and USA. Furthermore, an IAEA Radon Database has been developed, jointly with the US-EPA, for subsequent use by scientists, industry and regulatory agencies.

3.2. Activities by regulatory bodies

In 1993 the ICRP has completed its evaluation process of exposure of the public from radon (BE 93). In summary ICRP has taken the following position:

a) in existing dwellings potentially necessary improvements should be achieved by modifications to the dwelling or the behaviour of the occupants

b) in new dwellings codes should be established to ensure that exposures in these dwellings will be below some previously chosen reference level

c) the choice of an action level should take into account - besides the level of radon exposure - also the likely scale of action and its economic implications

d) the issue of radon mitigation in dwellings represents a case of intervention. Therefore dose limits for practices, intended for the control of sources, are not applicable

e) on the basis of risk considerations for a reference population (lung cancer base line rate: 2.6%) an action level of 400 Bq/m^3 radon gas is recommended for homes

f) if exposures at above ground work places are above an action level of 1000 Bq/m^3 radon gas they are to be treated as occupational exposure.

A different approach to radon control was taken by the Commission of the European Community (EC) in 1990. Both EC-reference levels for existing and future dwellings were defined in terms of effective dose. Thereby the direct conversion to radon concentration values in air is subject to change, depending on the results of dosimetric modelling. The currently EC-applied exposure dose conversion factor (EDF) yields a radon reference level for existing dwellings equal to 400 Bq/m^3. The use of the new ICRP-lung model will lower this value significantly. This situation is illustrated in Fig. 2, showing the different EDF-values used.

The third example originates from Sweden which has always been on the forefront of radon-related actions. A scheme has been developed to classify the ground in accordance with the radon concentration in the soil gas, taking into account the uranium content and the soil permeability. This classification determines the type of building code applicable, specifying the type of protective technical and architectural countermeasures to be taken to ensure an acceptable level of radon indoors (AK 87).

In 1993 the WHO-Working Group on Indoor Air Quality issued a summary- and technical report, which contains a comprehensive set of 22 recommendations. The areas addressed are risks to health, risk management and risk communmication (WH 93). Summarizing the panel recommended a risk-based approach. Where individual risks exceeded 10^{-3} per year this should always be considered severe and actions should always be taken. When individual risks are lower, further risk reduction must be sought based on optimization and evaluation of available control techniques. Risks from radon should be considered preferably within a more integrated framework of all environmental risks; a three-step management scheme was proposed. A summary of numerical values is shown in Table 4.

3.3. Activities by the public

Up to about 1980 the general public in the industrialized countries in the West was largely unaware of the radon issue. Scandinavia and the US had to develop first concepts on communicating the radon-induced lung cancer risk identified by science to the individual. The reaction of the public was guarded: apart from an initial, often media-stimulated concern over a "new" cancer threat, relatively little reaction was obtained. Therefore it became evident that a rationale had to be developed, addressing the content of the message to be delivered as well as the method by which the information was transmitted. Sometimes a problematic balance had to be struck between rather effective emotionally-based appeals and the scientific credibility of the message conveyed. In this effort risk comparison was found to be a useful mechanism, stressing the significance of social equity in reading comparative risk conclusions.

Since radon is of concern as an indoor air carcinogen, the following comparison addresses the risk from chemicals in indoor air (Tab. 5; TA 89). Altogether 52 chemicals of different carcinogenic potency, were determined in US- and Dutch homes. The total risk is considerably greater than 10^{-6}/life, i.e. indoor air pollution in general warrants more attention by the public than outdoor pollution. It also shows that the total risk from non-radiological pollutants is still lower than the risk from radon indoors.

Communicating this kind of information to the public has to overcome three major difficulties:

a) signal strength vs. "noise":

in industrial countries approximately 250 individuals of every 1000 persons are likely to die from cancer. The addition of ≤ 10 cancer cases due to air pollution, food additives, etc. will be extremely costly and difficult to detect;

b) ~~preparation~~ perception of cancer risk:

the cancer risks from chemical contamination of work places and the environment is generally viewed erroneously as the major contributors to the total cancer risk. Really significant components, however, such as smoking or dietary habits, are often disregarded.

c) economic valuation of benefit:

in order to convince the public of the need to address the radon issue it is important to assess the economic value of the reduction of the lung cancer risk due to mitigating measures. A survey in Swedish radon-problem dwellings showed that the average willingness-to-pay for a reduction of 1 Bq/m³ was only about US$ 0.30 per person living in the same household (AK 88). For comparison, if costs of a radon reduction were based on costs usually considered in Sweden concerning general radiation protection the amount would be much higher: US$ 1.3 for 1 Bq/m³. This means that unless there is significant understanding of the benefit resulting from the radon mitigration, the public is likely to remain rather apathetic about the radon issue.

The WHO-Working Group on Indoor Air Quality has concluded after reviewing different strategies that effective radon risk communication involves (WH 93):

a) testing of alternative messages with appropriate audiences (scientists, home owners), prior to public distribution.
b) identifying target audiences, enlisting sources respected by the target audiences, and using the existing communications channels available to these sources.

The WHO-Group stressed the importance that the ultimate goal of such a communication programme should be to provide accurate scientific information to reduce radon health risks.
Encouraging results in this area are reported in the US due to the continuing efforts by the US-EPA (EP 92). An increasing number of dwellings are being surveyed and mitigated, largely during real-estate transfer, respectively as part of Government-initiated surveys.

4. CONCLUSIONS

Internationally the components of the radon risk management are at different stages of development:

a) surveys: the collection of indoor radon data in homes is fully ongoing in many countries. In addition to the present emphasis on homes these activities should also include work places, schools and public buildings in the future. Radon maps will provide valuable information for scientists and regulators

b) risk assessment: significant improvement has been achieved due to the availability of new data derived from case-control and cohort epidemiological studies. The remaining uncertainties may be further reduced by 1996 with data from the pooled analysis of forthcoming studies

c) risk communication: it remains a challenge to motivate the still largely passive society. Recently developed communication strategies are expected to improve this situation in the future, similar to relatively slow "learning-adoption processes" in the past, such as the now mostly mandatory use of seat-belts or the noticeable changes of smoking habits.

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Tab. 1: Analytical (case-control type) epidemiological studies on the standardized excess relative risk (RR) coefficients for radon-exposed uranium- and non-uranium miners.

LOCATION (principle investigator)	no. of cases	RR [% per WLM]
1. **SWEDEN**		
Malmberget (RADFORD, 1984; NAS, 1988)*)	51	1.4 - 3.6
2. **USA**		
Colorado (THOMAS, 1985; HORNUNG, 1987; NAS, 1988)*)	834	0.45 - 0.9
New Mexico (SAMET, 1991)	68	1.8
3. **CANADA**		
Port Radium (HOWE, 1987)	57	0.3
New Foundland (MORRISON, 1988)	113	0.9
Ontario (MULLER, 1984; NAS, 1988)*)	119	0.5 - 1.4
Beaverlodge (HOWE, 1986; NAS, 1988)*)	65	2.6 - 3.3
4. **FRANCE**		
Southern France (TIRMARCHE, 1993)	45	0.6
5. **CZECH REPUBLIC**		
Joachimsthal (SEVC, 1988, 1990, 1993)*)	1758	1.4 - 1.9
6. **CHINA** (XUAN, 1993)*)	981	0.2 - 0.6
7. **AUSTRALIA**		
Radium Hill (WOODWARD, 1991)	54	5
*) multiple analysis		

Tab. 2: Analytical (case-control type) epidemiological studies on the lung cancer incidence among radon-exposed residents in "normal" dwellings

LOCATION (principle investigator)	no. of cases	no. of controls	RESULTS
1. **SWEDEN**			
Oeland (EDLING, 1984, 1986)	23	202	stat. significant trend of increasing lung cancer risk with radon exposure
Southern Sweden (AXELSON, 1988)	177	677	increased lung cancer risk for rural inhabitants
Stockholm (PERSHAGEN, 1992)	210	400	stat. significant trend, stronger for younger persons
Sweden (PERSHAGEN, 1993)	1360	2847	stat. significant trend,stonger for low ventilations rates
2. **USA**			
New Jersey (SHOENBERG, 1990)	1360	402	stat. significant trend
3. **CANADA**			
Ontario (LEES, 1987)	27	49	significantly increased relative risk
Winnipeg (LETOURNEAU, 1993)	750	750	no association
4. **FINLAND**			
(ROUSTEENOJA, 1991)	291	495	no association
5. **CHINA**			
Shenyang (BLOT, 1990)	308	356	no association

Tab. 3: Increase in the number of health effects (other than lung cancer) associated with elevated radon exposure in miners and the general population

LOCATION (principle investigator)	STUDY POPULATION	HEALTH EFFECT
Canada (MORRISON, 1988)	fluorspar miners	salivary gland cancer
Sweden (RADFORD, 1984)	iron ore miners	multiple myeloma stomach cancer liver cancer gallbladder cancer
France (TIRMARCHE, 1993)	uranium miners	laryngeal cancer
Czech Republic (SEVCOVA, 1978, 1984)	uranium miners	basalioma of the skin
United Kingdom (HENSHAW, 1990); (BRIDGES, 1991)	residents residents	myeloid leukemia mutation frequency in peripheral lymphocytes

Tab. 4: Examples for different regulatory approaches to radon exposure control indoors and at the work place above/below ground

ORGANIZATION	PARAMETER	VALUE
1. ***ICRP***		
dwellings	radon indoors	400 Bq/m^3
work places (above ground)	radon indoors	1000 Bq/m^3
mines:	decay products	
- average over 5 years		3 WLM/year
- maximum in 1 year		7.5 WLM/year
2. ***COMMISSION OF THE EUROPEAN COMMUNITY***		
existing dwellings	effective dose	20 mSv/year
future construction	from decay products	10 mSv/year
3. ***SWEDISH RADON COMMISSION***		
building codes applicable:		
traditional building construction	radon in soil gas	< 10 kBq/m^3
radon-protective construction		1-50 kBq/m^3
radon-safe construction		> 50 kBq/m^3

Tab. 5: Mean lifetime risk from 52 atmospheric pollutants in dwellings

LOCATION	MEAN RISK
U.S. dwellings (average)	
New Jersey	$2\,500 \times 10^{-5}$
California	180×10^{-5}
Dutch dwellings (range)	$130 - 220 \times 10^{-5}$