EUROPEAN CONCERTED ACTION

INDOOR AIR QUALITY & ITS IMPACT ON MAN

COST Project 613

Environment and Quality of Life

Report No. 1

Radon in Indoor Air

Commission of the European Communities
Directorate-General for Science, Research and Development
Joint Research Centre - Ispra Establishment

EUR 11917 EN

November 1988

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Radon in Indoor Air

prepared by
James P. McLaughlin
on behalf of the Community - COST Concertation Committee

Commission of the European Communities
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Joint Research Centre - Ispra Establishment

EUR 11917 EN **November 1988**

PREFACE

Considering the likelihood of contributions of various indoor air pollutants to detrimental health effects, the Community-COST Concertation Committee of the Concerted Action "Indoor Air Quality and its Impact on Man" (COST Project 613) decided that indoor radon is a well studied indoor pollutant both in terms of occurring concentrations and expected adverse health effects.

In July 1985 the Article 31 Euratom Treaty Group of Experts set up a Working Party to study and report on this matter. Their investigations were published in May 1987 as the report "Exposure to Natural Radiation in Dwellings of the European Communities".

The following text is largely based on the above report but also includes other recent evaluations of this problem. The Community-COST Concertation Committee by publishing this text would like to provide further support to the work of the General Directorate XI (Environment, Consumer Protection and Nuclear Saftey) in this matter and offer it to the Commission of the European Communities for its consideration.

CONTENTS

INTRODUCTION

At present it is estimated that at approximately 2 mSv/year natural radiation exposures account for about 80% of the average annual effective dose equivalent received by members of the general population in the Member States of the European Communities. The single largest component of this dose, at about 40% of the total, arises from the irradiation of lung tissue following the inhalation of airborne radon daughter products in the indoor environment.

Radon-222 is a naturally occurring radioactive gas with a half life of 3.82 days. It is part of the uranium-238 series and its principal source in the environment is the trace amounts of its immediate parent radium-226 in rocks and soils. The major contributor to indoor air radon concentrations in dwellings is soil gas radon which may enter the indoor air spaces by diffusion or pressure driven transport through foundations and walls. In most countries, except in special cases, the contribution to indoor radon due to radioactivity in building materials is usually minor in comparison to that from soil gas.

Recent surveys in countries of the European Communities have shown that the average values of indoor radon concentrations range from about 20 to 50 Bq/m^3 with typical outdoor values being about an order of magnitude lower (CEC.87). Compared to other forms of natural radiation the chief characteristic of indoor radon levels is their variability. In many countries some dwellings exist with radon levels in excess of one order of magnitude times the average value. Tables 1 and 2 give a summary of the principal results available at the end of 1986 of indoor radon surveys in EC member states and in some non- member states. (See reference list for a selection of more recent data on indoor radon surveys in some EC member states.)

Appendices giving the radon decay scheme and definitions of relevant quantities are attached.

DOSES AND RISK FACTORS

The dose from inhaled radon gas is relatively low in comparison to inhaled radon daughters. Those when inhaled deposit on surfaces in the human respiratory tract and the most significant doses arise from the decay of alpha emitting daughters (Jam.87). The ICRP (International Commission on Radiological Protection) Task Group set up to study the lung cancer risk from indoor exposures to radon daughters has reported on these doses in ICRP Publication No 50 (I.87a). On the basis of current dosimetric models the ICRP Task Group considers a conversion coefficient of 20 Bq/m^3 per mSv y^{-1} between the time averaged activity concentration of radon gas and the annual effective dose equivalent to be appropriate to the indoor exposure of members of the public. (If an equilibrium factor of 0.5 is taken between the radon

daughters and radon this conversion coefficient may also be expressed in terms of the Equilibrium Equivalent Radon, (EER), concentration as 10 Bq/m^3 per mSv y^{-1}.) On the basis of this conversion coefficient typical annual doses in EC dwellings range from about 1.0 to 2.5 mSv with a small percentage of the population in some EC countries receiving more than 20 mSv per year.

For purposes of comparison it is worth noting that for average individuals in the European Communities the calculated effective dose equivalent from the effects of the Chernobyl disaster in the first year range from about 0.3 x 10^{-3} mSv in Portugal to about 0.3 mSv in parts of the Federal Republic of Germany, Italy and Greece.

It should be noted that exposure to radon is not a new phenomenon and documentary evidence from the sixteenth century indicates that elevated radon exposure was probably responsible for excess mortality in some underground miners during that period. In recent decades excess lung cancers have been observed in epidemiological studies of various groups of miners exposed to elevated radon and radon daughter concentrations. In the absence of any substantial and completed epidemiological study there is at present no clear evidence available of excess lung cancer among members of the general public exposed to elevated levels in the home. Such studies are now being mounted but may take some years to be completed. In the interim it appears prudent to make recommendations for limiting the exposure of members of the public to enhanced radon concentrations and indeed ICRP has done so in Publication No.39 (I.84). In this context it should be noted that even at typical indoor radon levels the lifetime exposure of a member of the public is only about one order of magnitude lower than the exposure level at which excess lung cancers have been detected in miners: in the case of elevated indoor radon levels the exposures of the general public are well above this level.

At present comprehensive reviews of risks from radiation exposure are being carried out by UNSCEAR*, by the U.S BEIR*-V Committee and also by Committee 1 on Biological Effects of the ICRP. The results of these several studies are expected to be available in less than two years. The BEIR-IV Committee has already reported on health risks of radon (BE.88). In addition the 1987 "Como Statement" of the ICRP indicates that previous risk estimates of radiation exposures may need to be raised by a factor of the order of two (I.87b). Based on these developments a risk factor of about 3 x 10^{-2} Sv^{-1} may be anticipated with some degree of confidence. This approach has already been adopted in a recent report in which it is estimated that about 1500 persons may die of lung cancer each year in the U.K. from indoor exposure to radon and daughters(O'R.88). In the U.K. some 40,000 persons die each year from lung cancer and thus the estimated risk from radon corresponds to about 4% of the total lung cancer risk. Estimates made for reference populations,

*UNSCEAR: United Nations Scientific Committee on the Effects of Atomic Radiation.

* BEIR: Biological Effects of Ionizing Radiation.

including smokers and non-smokers, indicate that 5% of the observed lung cancer frequency might be associated with radon daughter inhalation even at average concentrations of indoor radon (Ja.84a). At significantly high radon levels the estimated risk may be a substantial fraction of the total lung cancer risk. The combined effects of smoking and radon exposure are not clear but studies so far suggest a synergistic effect somewhat less than multiplicative (I.87a). It cannot be overstressed that here we are dealing with probabilistic and statistical estimated risks based on limited epidemiological and dosimetric studies. Notwithstanding the large uncertainties inherent in such studies the risks from radon and its daughters can no longer be regarded as "background" phenomena. The World Health Organisation is another international body which has reviewed the role of radon in indoor air quality (WHO.86).

The ICRP Task Group reporting in ICRP Publication No 50 (1987) presented a comparison of estimates from different risk projection models for the risk of lung cancer exposure to radon daughters. The Task Group has recommended a rounded reference value of 2×10^{-8} for the absolute lifetime risk of lung cancer attributable to chronic exposure to radon daughters in the indoor environment at a rate of 1 Bq h m^{-3} equilibrium equivalent exposure in each year. Both relative and absolute risk models were considered together with the inclusion of the influence from smoking to translate the lifetime risk from mining to the indoor domestic environment. It should be noted that the ICRP risk estimate is about half of the estimated value given in the U.S.-BEIR IV (1988) report but the BEIR committee view is that this difference is within the uncertainties of the models used (O'R 88). Irrespective of the bases on which these estimates have been obtained for radiological protection purposes a no threshold linear relationship is assumed to exist between dose and associated risk.

RECOMMENDATIONS ON THE CONTROL OF RADON EXPOSURE.

In the European Communities the radon problem has recently been studied and reported upon by a Working Party set up by the Euratom Treaty Article 31 Group of Experts (CEC.87). A number of recommendations have now been considered and approved by the Article 31 Group. The most important of these are as follows:-

There should be established an appropriate system for limiting the concentration of indoor radon daughters consisting of:-

(i) **A Reference Level** for the consideration of remedial action for existing houses. This Reference Level if exceeded should be cause for consideration to be given to simple but effective measures aimed at reducing the radon level. It should not be used for the purposes of legal regulation. The Reference Level should be an effective dose equivalent of 20 mSv/year. For practical purposes a derived Reference Level for the radon gas concentration of 400 Bq/m^3 may be used.

(ii) A **Design Level** for future housing. This should be an aid to the relevant authorities in establishing regulations, standards, codes of construction practices, etc. for those circumstances under which the Design Level might be exceeded. The Design Level should be an annual effective dose equivalent of 10 mSv/year. For practical purposes a derived Design Level for the radon gas concentration of 200 Bq/m^3 may be used.

(iii) In the application either remedial or preventative measures the principles of optimisation should be used in dealing with the above levels.

These recommendations are presently under the consideration of the appropriate legal section of the Commission of the European Communities.

It should be emphasised that the two levels given in these recommendations are not to be considered as either "safe" or "unsafe". They should rather be considered as levels which in the light of present knowledge afford an acceptable compromise between what is technically acheivable and what is ideally desirable in terms of reducing population doses from radon daughters. This perspective is in keeping with one of the central requirements of radiological protection of the ICRP namely: All exposures shall be kept as low as reasonably acheivable (the ALARA principle), economic and social factors being taken into account.

Using the estimated absolute lifetime risk of lung cancer recommended in ICRP Publication No 50 (1987) chronic exposure at the Reference Level corresponds to a lifetime risk of about 2.6%. The uncertainty of such an estimate is considered to cover a range given by a factor of from 0.3 up to about 2.

In a number of EC Member States and in other countries the competent authorities have set up working groups to draw up proposals for natural radiation control policies. In some countries this work is well advanced and recommendations on remedial action levels and limitations on construction levels may reasonably be expected shortly in some EC Member States. Outside the Community, the Nordic countries, in particular Sweden are well advanced in this direction (Rn.86).

As an example of recent developments in regard to the regulatory control of indoor radon the situation in the UK is worth noting. In 1987 the UK Government issued recommendations that exposure to radon daughters in dwellings should be limited (Han. 87). In essence these recommendations state, in terms of the effective dose equivalent arising from the inhalation of radon daughters, that there should be an Action Level of 20 mSv/year for existing dwellings and an Upper Bound of 5 mSv/year for future dwellings. In terms of radon gas activity concentrations the Action Level corresponds to 400 Bq/m^3 and the Upper Bound to 100 Bq/m^3. This is similar to the recommendations of the Article 31 Working Party except that the Upper Bound at 100 Bq/m^3 is half the 200 Bq/m^3 Design Level of the Article 31 Group.

In the U.S. the general problem of elevated exposures to radon daughters in dwellings has recently been adressed by two agencies. The National Council on Radiation Protection and Measurements (NCRP) has proposed a recommendation that remedial action should be applied to dwellings in which the annual effective dose equivalent to occupants is in excess of 20 mSv per annum (Nc 84a). The NCRP is an independent agency chartered by the U.S. Congress. A second U.S. agency the Environmental Protection Agency (EPA) has issued recommendations which represent the considered view of the U.S. Federal Government (EPA.86). The EPA levels are set according to various degrees of urgency: action should be taken within a few years above 8 mSv per annum (0.02 WL), within several months above 40 mSv per anum (0.1WL) within several weeks above 400 mSv per annum (1 WL). The EPA target after action is 8 mSv per year. Neither the NCRP or the EPA have suggested separate treatment to be applied to existing and future dwellings.

In a number of EC member states research efforts are being directed towards techniques aimed at reducing exposure to indoor radon and its daughter products. A variety of techniques are being investigated such as: radon barrier and diversion methods, air treatment to remove airborne radon and daughters etc. (C.87, J.88).

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MEMBER STATE	TYPES OF SURVEY	METHOD OF SELECTING DWELLINGS	NO. OF DWELLINGS ALREADY SURVEYED OR TOTAL PLANNED	COMPLETION DATE	METHODS USED AND TYPICAL INTEGRATION TIME	"AVERAGE" RADON CONC. Bq/m³	RANGE (Bq/m³) OR TYPE OF DISTRIBUTION
BELGIUM	Pilot survey	Representative geographical	78	1984	Alpha-track Karlsruhe type	41 (median) 50 (median)	10 - 263 log-normal
	National	Representative sampling of housing stock	300	1987	as above for 1 or 2 six month periods	not yet available	not yet available
DENMARK	Various small surveys	Random	450	1985	Mainly alpha track	50 (geom mean)	5 - 700
	National	Random from housing register	500	1986	Alpha track CR-39 (6 months)	Data not yet analysed	Data not yet analysed
FED. REP. OF GERMANY	National	Representative sampling of housing stock	6000 (approx)	1985	Alpha track Karlsruhe type (3 months)	40 (median) 49 (mean)	1%>200 Bq/³ approx. max 2000 Bq/m³
FRANCE	National	Representative sampling of housing stock	1056	1985	Alpha track CEA(LR-115) (1 month)	44 (median)	3 - 1258 5%>200 Bq/m³
GREECE	Regional	Random	37 (500 planned)	1987	Alpha track	20 (mean)	3 - 136
IRELAND	National	Random from electoral register	736 (2000 planned)	1988	Alpha track CR-39 (6 months)	37 (median)	3 - 1740
ITALY	Regional 1. Milano 2. Umbria	From selected groups of houses mainly on a geological basis	 261 70	 1984 1985	Alpha track CR-39 (3 months)	56 (mean)	132 (max) 85 - 292
	National	Random (more planned)	1000 approx.	1984	Alpha track CR-39	25 (median)	5 - 154
LUXEMBOURG	National	Random	12	not limited	Activated charcoal	40 (mean)	6.5 - 78
NETHERLANDS	National	Representative sampling of housing stock	1020	1984	Alpha track Karlsruhe type	24 (median)	8 - 118
UNITED KINGDOM	National	Systematic sample from postal register	2300	1985	Alpha track CR-39 6 months x 2	22 (arith mean) 14 (geom mean)	0 - 1100 log-normal
	Regional	Mainly on a geological basis					
	1. S.W. England	Margins of granite intrusions	366	1985	Active devices + Alpha track 6 months x 2	166 (geom mean) 311 (arith mean)	13 - 7700 log normal
	2.Scotland	Granite	150				

Table 1: Summary of Indoor Radon surveys in E.C. Member States up to 1986 (CEC.87). For more recent data consult reference list.

Table 2: Summary of Indoor Radon Surveys up to 1986 in some non-E.C. Countries

COUNTRY	TYPES OF SURVEYS	NUMBER OF DWELLINGS	COMPLETION DATE	METHODS USED	"AVERAGE" RADON CONC. Bq/m³	RANGE (Bq/m³) OR TYPE OF DISTRIBUTION
CANADA	National	14000	1980	Grab Sampling	33 (mean)	Log-normal
FINLAND	National	2154	1983	Bare LR-115 Alpha track	63 (median)	9.4% > 800
	S.W. region	754	1985	as above plus Karlsruhe type	370 (mean)	up to 13000 max.
SWEDEN	National	756	1984	Passive TL dosemeters	69 (geom. mean)	11 to 3300
	Various surveys	32548	1982	Various techniques	not applicable to this data	3348 houses > 400 (EER)
SWITZERLAND	National	123	1982	Alpha track (Karlsruhe)	60 (median)	15 to 4000
UNITED STATES	**Various regional surveys					
	Eastern USA	400	1985	Activated charcoal	not yet available	5% > 300
	Pennsylvania 1	1000 (approx)	1984	Various methods	not yet available	40% > 150
	Pennyslvania 2	1745	1986	: :	: :	40% > 150 11% > 740 1% > 3000

** In the case of the USA a national survey has not yet commenced. Most indoor radon surveys are being carried out in parts of the States of Pennsylvania, New Jersey and New York where very high indoor radon concentrations appear to be associated with a geological feature called the Reading Prong. Indoor radon concentrations ranging up to about 100000 BQ/m³ have been found. The Pennsylvania data quoted above in the main should be viewed as preliminary.

APPENDIX 1.

DECAY SCHEME OF RADON-222 AND ITS SHORT-LIVED DAUGHTERS*

Radionuclide	Half Life	Decay Constant (hr^{-1})	Principal Energies (in MeV)		
			Alpha	Beta	Gamma
^{222}Rn(Rn)	3.823 d	7.55 10^{-3}	5.49 (100%)	-	0.51 (0.07%)
↓ α					
^{218}Po(RaA)	3.11 min	13.6	6.00 (∿100%)		-
↓ α					
^{214}Pb(RaB)	26.8 min	1.55	-	0.65 (50%) 0.71 (40%) 0.98 (6%)	0.295 (19%) 0.352 (36%)
↓ β,γ					
^{214}Bi(RaC)	19.7 min	2.11	5.45 (0.012%) 5.51 (0.008%)	1.0 (23%) 1.51 (40%) 3.26 (19%)	0.609 (47%) 1.12 (17%) 1.76 (17%)
↓ β,γ					
^{214}Po(RaC')	164 μs	1.52 10^{7}	7.69 (100%)	-	
↓ α					

* Insignificant branch decays from Po-218 and Po-214 are neglected

APPENDIX 2.

SPECIAL QUANTITIES AND UNITS.

ACTIVITY:

The activity of a radioactive source is the number of its nuclei that decay in unit time.

The unit of activity is the Becquerel (Bq) equal to one nuclear transformation per second.
1 Curie (Ci) equals 3.7×10^{10} Bq.

ABSORBED DOSE:

The quantity of energy imparted to unit mass of material by ionising radiation.

The unit of absorbed dose is the Gray (Gy) equal to one Joule per kilogram. 1 Gy equal 100 rads.

DOSE EQUIVALENT:

The dose equivalent is the product of the absorbed dose and the quality factor for a specific type of radiation. The quality factor accounts for the ability of the radiation to cause biological damage. For beta particles, gamma rays and X rays the quality factor is usually taken as unity but for alpha particles it is 20.

The unit of dose equivalent is the Sievert equal to one Joule per kilogram. 1 Sv equals 100 rems. [NOTE: Effective dose equivalent is also expressed in Sieverts].

EFFECTIVE DOSE EQUIVALENT:

This is the sum of the products obtained by multiplying the dose equivalents to various organs and tissues by the appropriate risk weighting factor for each. This quantity is expressed in Sieverts.

POTENTIAL ALPHA ENERGY:

In the context of this report the potential alpha energy of an atom in the radon or thoron decay schemes is the total alpha-energy emitted during the decay of this atom along the decay chain down to Pb-210 or Pb-208 respectively. For example, in the case of Po-218 it is 13.7 MeV (i.e. 6.00 + 7.68). It is usually expressed in J or MeV.

POTENTIAL ALPHA ENERGY CONCENTRATION (PAEC)

The potential alpha energy concentration (PAEC) in air of any mixture of Radon-222 or Radon-220 (thoron) daughters is the sum of the potential alpha energy of all the daughter atoms present per unit volume of air. It is usually expressed in $J.m^{-3}$.

WORKING LEVEL (WL):

1 WL (radon) corresponds to a PAEC of short-lived radon daughters in equilibrium with a radon air activity concentration of 3700 Bq/m^3 [100pCi/l]. It represents a concentration of Radon-222 daughters which will deliver 2.08×10^{-5} $J.m^{-3}$ (or 1.3×10^5 $MeV.l^{-1}$) of air in decaying through Po-214 (RaC').

1 WL (thoron) corresponds to a PAEC of short-lived thoron daughters in equilibrium with a thoron air activity concentration of 275 Bq/m^3 (7.43 pCi/l). It represents concentrations of ThB (Po-212) and ThC (Bi-212) which yields 1.3×10^5 $MeV.l^{-1}$ of air in decaying to ThD (Pb-208).

POTENTIAL ALPHA ENERGY EXPOSURE:

This for an individual exposed to short-lived radon or thoron daughters is the time-integral over the PAEC of the daughter mixture to which the individual is exposed during a definite period of time. Its basic unit is $J.h.m^{-3}$ but is often expressed in units of WLM (see definition below).

WORKING LEVEL MONTH (WLM):

The WLM corresponds to an exposure of 1 WL (2.08×10^{-5} $J.m^{-3}$ during the working period of one month (170 hours). 1 WLM = 170 WLh = 3.5×10^{-3} $J.h.m^{-3}$ = 22.1×10^{6} $MeV.h.l^{-1}$.

EQUILIBRIUM EQUIVALENT RADON CONCENTRATION:

The equilibrium equivalent radon concentration (EER) is the concentration of radon (Bq/m^3) for which the daughters if they were in equilibrium with it would have the same potential alpha energy as the actual mixture of daughters have in the atmosphere of interest. In the literature a number of acronyms for equilibrium equivalent radon concentration are to be found. These are EER, EEC, and EC_{Rn}.

EQUILIBRIUM FACTOR F:

The equilibrium factor (F) with respect to potential alpha energy is defined as the ratio of the EER to the actual activity concentration of radon in air.

UNATTACHED FRACTION OF POTENTIAL ALPHA ENERGY f_p:

This is the fraction of airborne radon daughters that is not attached to aerosol particles, expressed in terms of potential alpha energy of the mixture and not in terms of the activity of any individual daughter nuclide.

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