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RADON POLICY : THEORY AND PRACTICE

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RADIOPROTECTION

SOMMAIRE

Ce numéro contient les textes des exposés présentés le 13 octobre 1995 lors d'un séminaire organisé à Bruxelles par l'Association belge de Radioprotection consacrée à:

INHOUD

Dit nummer bevat de teksten van de uiteenzettingen gedaan in Brussel op 13 oktober 1995 ter gelegenheid van van een studiedag van de Belgische Vereniging voor Stralingsbescherming gewijd aan:

Radon Policy: Theory and Practice

EDITORIAL

The increasing awareness about the potential health effect of radon exposure is an issue of concern for many authorities. In Belgium, steps have been taken by the federal and regional governments to implement the recommendations of the E.U. in a legislative framework.

The purpose of this conference was to present the regulatory and the practical approach in different countries for radon at work and in the indoor environment, with special attention to related communication problems.

All papers were presented by invited speakers.

The introductory paper summarises the CEC approach and does give some insight in the huge radon problems encountered in the Wismuth area of the former DDR.

The papers in section A describe the situation in those countries of Europe, the Czech republic, Ireland, Sweden and the UK, where the authorities have tackled the radon problem with success.

Papers in section B deal with the initiatives taken and the approaches followed in most other countries of Europe.

The invited speaker from the US was unable to attend the seminar. As lessons can be learnt from overseas experience his paper is presented in the appendix.

The large attendance from abroad, is an indication of the general interest in this legislation problem. From the discussions it became clear that, although building materials are by far not the most important source of radon, this item is of particular concern for the general public in many countries. Therefore study of the publics' attitude to radon in general and the dissemination of appropriate information is one of the principal challenges for the future.

The seminar was organised by the Belgian Association for Radiation Protection on behalf of The Radiation Protection Department of the Belgian Ministry of Public Health. The substantial support obtained from the, CANBERRA PACKARD NV, EU-DGXI, GEMEENTEKREDIET/CREDIT COMMUNAL, LANDRE & GLINDERMAN NV, NIRAS/ONDRAF, NUCLEAIRE VERZEKERING and SABENA made it possible to invite an exquisite set of international experts and contributed very much to the success of the seminar.

To all of them we want to express our gratitude.

On behalf of the organisers

A. POFFIJN R. JACOBS

SECTION A

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UK RADON POLICY

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Abstract
All four countries comprising the United Kingdom have radon programmes. These share the essential components of surveys to identify radon Affected Areas followed by measurements to pick out individual houses with high radon levels in which remedial measures should be introduced. A number of radon Affected Areas have been declared, though this process is not yet complete. Measurements have been completed in approaching 200 000 homes and about 18 000 have been found to have radon concentrations above the UK Action Level of 200 Bq m^{-3}.

INTRODUCTION

1. Radon has been recognised as a potential hazard in mines for many years. However, the recognition that houses might also be affected is more recent. In the early 1980s NRPB set up a programme to investigate radon concentrations in UK dwellings. It was found that the mean radon concentration was around 20 Bq m^{-3} but that there was very large variation with a significant number of homes having radon concentrations of 1000 Bq m^{-3} or more. In the light of these findings (NRPB, 1987) NRPB proposed that action should be taken to reduce levels of radon in dwellings where levels were high and that building practices in selected high radon areas should be modified to help prevent high levels in new houses. The advice was accepted by government, (Parliament, 1987) which also funded surveys by NRPB to identify dwellings with high radon levels. The NRPB advice was updated and refined (NRPB, 1990) with the introduction of the concept of radon Affected Areas B parts of the country where an appreciable fraction of the dwellings were likely to have concentrations of radon above the prescribed Action Level, which was set at 200 Bq m^{-3}.

2. In 1991 the House of Commons Environment Committee reviewed radon in a report on indoor pollution (HMSO, 1991). It recommended that the government should commit itself to ensuring the identification of the majority of homes above the Action Level by the year 2000. The government supported this objective and anticipated that the surveys being undertaken would achieve this goal Parliament, 1991).

INTERNATIONAL STANDARDS

3. The UK is not alone in the identification of indoor radon as a potentially serious public health problem. There are broadly similar radon programmes in other European countries, with those in Sweden and the UK perhaps the most well developed. In 1990, the Commission of the European Communities made a recommendation (CEC, 1990) on the control of radon in dwellings. A reference level of 400 Bq m^{-3} was put forward for existing buildings above which remedial measures should be considered; preventative measures in new buildings should be aimed at ensuring that 200 Bq m^{-3} was not exceeded.

4. Recently ICRP, in Publication 65 (1993), has surveyed the accumulated evidence on the risks of exposure to radon and on the practicabilities of controlling exposures. In authoritative recommendations it has refined its previous approaches to controlling doses from radon in both the domestic and occupational setting. ICRP recommendations allow national authorities a significant degree of autonomy in setting Action Levels. However, its suggested ranges of 200-600 Bq m^{-3} in dwellings and 500-1500 Bq m^{-3} in workplaces are consistent with the UK and European Action Levels for dwellings and very similar to those for workplaces.

5. The UK radon programme is thus firmly based on European and international standards. The aim is to develop cost-effective techniques to find houses with high radon levels and then to encourage the householder to undertake remedial work. The present article concentrates on the first of these objectives.

MEASUREMENT OF RADON CONCENTRATIONS

6. Radon gas concentrations can be determined by taking samples of air and measuring the activity with appropriate electronic apparatus. However, such short-term measurements can be quite misleading in assessing the exposure of people to radon because of the considerable diurnal (Figure 1) and seasonal (Figure 2) variation in levels.

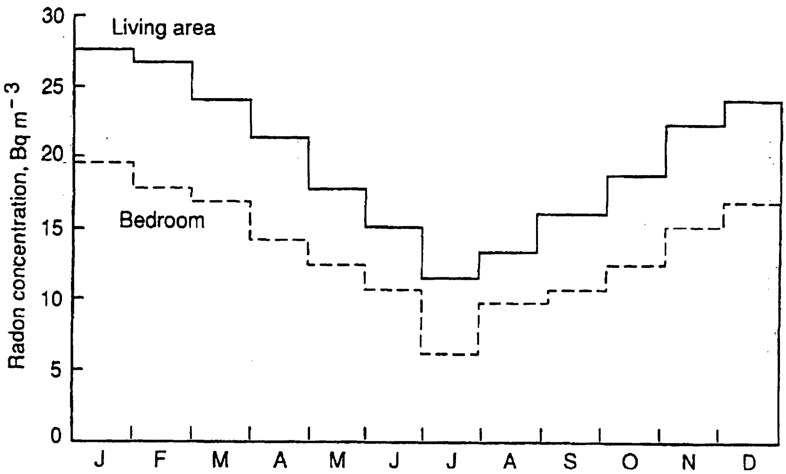

Figure 1. Variation of radon levels in a house over a 24-hour period

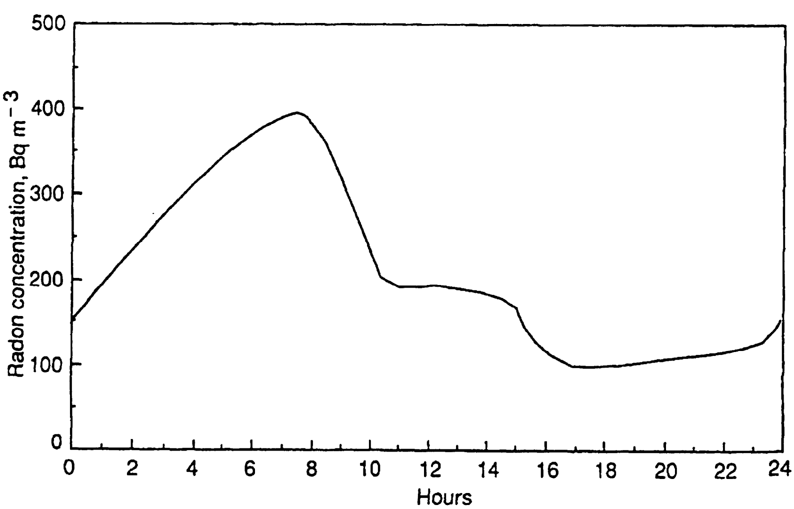

Figure 2. Annual variation in radon concentrations in ground-floor living rooms and first-floor bedrooms

7. To determine annual average values it is far better to make measurements lasting a few months so that short term variations are averaged out. This can be done by using passive radon detectors which are left in place in dwellings during the measurement period. The detector consists of a small chamber containing a sensitive plastic material, CR-39. Radon diffuses into the chamber and decays through its chain of decay products. Some of the alpha particles emitted damage the plastic detector, and this damage is revealed later by etching the plastic in a solution of sodium hydroxide. The damage tracks are counted with an automatic image analyser, and their number is proportional to the exposure of the detector to radon. The detectors are small enough to go through the post and are relatively inexpensive and so are suitable for large surveys of radon in dwellings.

8. The results presented in this paper are based on measurements using this type of detector. Two detectors are sent to each home, one for the living room and one for an occupied bedroom, and left in place for at least three months. The seasonal variation in average radon concentrations has been previously assessed and used to derive correction factors for measurements over different periods (NRPB, 1992). These factors have been applied in estimating the annual average radon concentrations in homes presented in this paper.

DEVELOPMENT OF RADON PROGRAMME IN ENGLAND

9. The early surveys of domestic radon exposures in England had indicated that levels were highest in the southwest, and the Department of the Environment commissioned further studies, at first in Cornwall and Devon. A measurement service was also made available to householders throughout England and was financed by D E except in areas where radon levels were known to be low. Following the formal advice to government that the whole of the counties of Cornwall and Devon should be regarded as an Affected Area (NRPB, 1990a), D E arranged for an explanatory leaflet, offering free measurements, to be delivered to all homes in the two counties. This initiative has so far enabled measurements to be completed in 15% of the total housing stock in Cornwall and in 11% of homes in Devon. Similar exercises have since been undertaken in the counties of Derbyshire and Northamptonshire and one is in progress in Somerset: Affected Areas have been designated in all these counties (NRPB, 1990a). Some district councils and other landlords both in the Affected Areas and elsewhere have also commissioned surveys of dwellings under their control.

10. A comprehensive survey covering all of England is virtually complete (Kendall et al, 1994). The aim is to draw a definitive radon map of the whole country and identify any other areas with raised radon

levels that might qualify for Affected Area status. The plan, wherever possible, is to measure at least 12 homes evenly spread throughout each 10 km square of the Ordnance Survey grid. Where mean radon concentrations are elevated, approaches are made to other householders to obtain five measurements in each 5 km grid square. This survey involves a total of about 18 000 measurements.

DEVELOPMENT OF RADON PROGRAMME IN NORTHERN IRELAND

11. An analysis of the initial UK survey suggested that there were likely to be some areas in Northern Ireland where a few per cent of dwellings might be above the Action Level. The Environment Service of the Department of the Environment for Northern Ireland commissioned more detailed surveys, (DOE(NI), 1989). The indications were that several hundred dwellings, many in the southeast, would have radon levels in excess of 200 Bq m^{-3}.

12. The Environment Service commissioned further surveys to complete the radon map for the whole of Northern Ireland and to provide data to delineate the boundaries of an Affected Area. The policy of offering surveys on demand to householders without charge was also continued. The results of these studies and formal advice of the Affected Area in Down and Armagh were published (NRPB, 1993a, Green et al, 1993). Following publication, the Environment Service made arrangements for radon measurements to be offered, free of charge, to all individual householders within the Affected Area. In addition, further studies are planned in other, much smaller areas of Northern Ireland where the indications are that some homes may have radon levels slightly above the Action Level.

DEVELOPMENT OF RADON PROGRAMME IN SCOTLAND

13. In the light of the findings of the initial UK survey, the Scottish Office Environment Department commissioned further surveys in parts of Grampian and Highland Regions. Following the publication of the results and the declaration of Affected Areas in parts of Kincardine and Deeside and Gordon Districts in Grampian Region and in parts of Caithness and Sutherland Districts in Highland Region (NRPB, 1993b), the Scottish Office Environment Department has published an information leaflet for householders and commissioned further surveys.

14. The leaflet, which recommends concerned owner-occupiers to write to NRPB for a measurement, has been made available to the public in Affected Areas. Furthermore, householders in the 2500 homes with the highest probability of elevated concentrations, have been individually invited to apply for a measurement. All measurements, for owner-occupiers in the Affected Areas, are sponsored by the Scottish

Office and are therefore free of charge to the householder. Some public and private landlords have also commissioned surveys of dwellings under their control. In the longer term, the Scottish Office Environment Department has commissioned measurements throughout Scotland to develop a radon map of the whole country.

DEVELOPMENT OF RADON PROGRAMME IN WALES

15. The Welsh Office commissioned an outline survey of the country and more detailed measurements in those areas where the initial UK survey had shown elevated radon levels. Following the publication of the results of these studies (Lomas et al, 1992), further surveys were commissioned. The first survey is concentrating on those parts of the country where high levels have already been found, and will provide data to delineate the boundaries of any Affected Areas in these regions. The second survey, covering all of Wales, is facilitating the completion of a radon map of the country and will show any other areas with raised radon levels.

16. In addition, the policy of offering measurements on demand to concerned householders is being continued. Such measurements are free of charge to the householder except in areas where the levels are known to be low.

RESULTS OF MEASUREMENTS IN THE UK

17. It is found that the results of radon in house measurements follow a log-normal distribution. This is very useful, both for smoothing survey data in order to produce radon contour maps from which Affected Areas are defined and also to make deductions about the upper tail of the distribution so that the percentage of homes above the Action Level can be deduced. Table 1 provides a summary of the available data by country and shows that almost 20% of the estimated 100 000 homes with radon concentrations above the Action Level have been identified to date. This percentage is mainly determined by England where most measurements have been completed. It is expected, however, that increasing percentages will be found in Scotland, Wales and Northern Ireland. These data are presented in the form of a surface map in Figure 3.

TABLE 1 Radon measurements in the countries of the UK

	England	Scotland	Wales	Northern Ireland	United Kingdom
Total housing stock	19 000 000	2 000 000	1 100 000	600 000	22 000 000
Population weighted average radon concentration (Bq m^{-3})	21	16	20	19	20
Number of results available	185 000	2 600	1 700	1 600	191 000
Number in progress	24 000	300	130	700	25 000
Number at or above the Action Level	17 500	83	85	35	17 700
Number estimated above the Action Level	100 000	2 000	3 000	500	100 000
Percentage identified above the Action Level	18%	4%	3%	7%	18%

18. Table 2 has similar data for each county or region which has been wholly or partially declared a radon Affected Area. It is noteworthy that around one-quarter of the estimated total number of homes with elevated radon levels have been identified in the English counties of Cornwall, Devon and Northamptonshire. Nevertheless considerably more work needs to be done to achieve the target of identifying the majority of homes above the Action Level by the year 2000, the target set by the Select Committee (1991) and endorsed in principle by government (Parliament, 1991).

TABLE 2 Radon measurements in Affected Areas

	Cornwall	Devon	Derbyshire*	Northamp-tonshire*	Somerset*	Grampian And Highland*	Down and Armagh*
Number of results available	34 000	57 300	25400	42 000	5 000	2000	1500
Number in progress	200	400	400	16 700	100	300	1000
Number at or above the Action Level	8 500	4 100	1 600	2 400	210	80	35
Number estimated above the Action Level	36 000	17 000	13 000	10 000	4 000	1 100	200
Percentage identified above the Action Level	24%	24%	12%	24%	5%	7%	18%

* Only parts of these counties and regions have been declared Affected Areas; the figures apply to these areas.

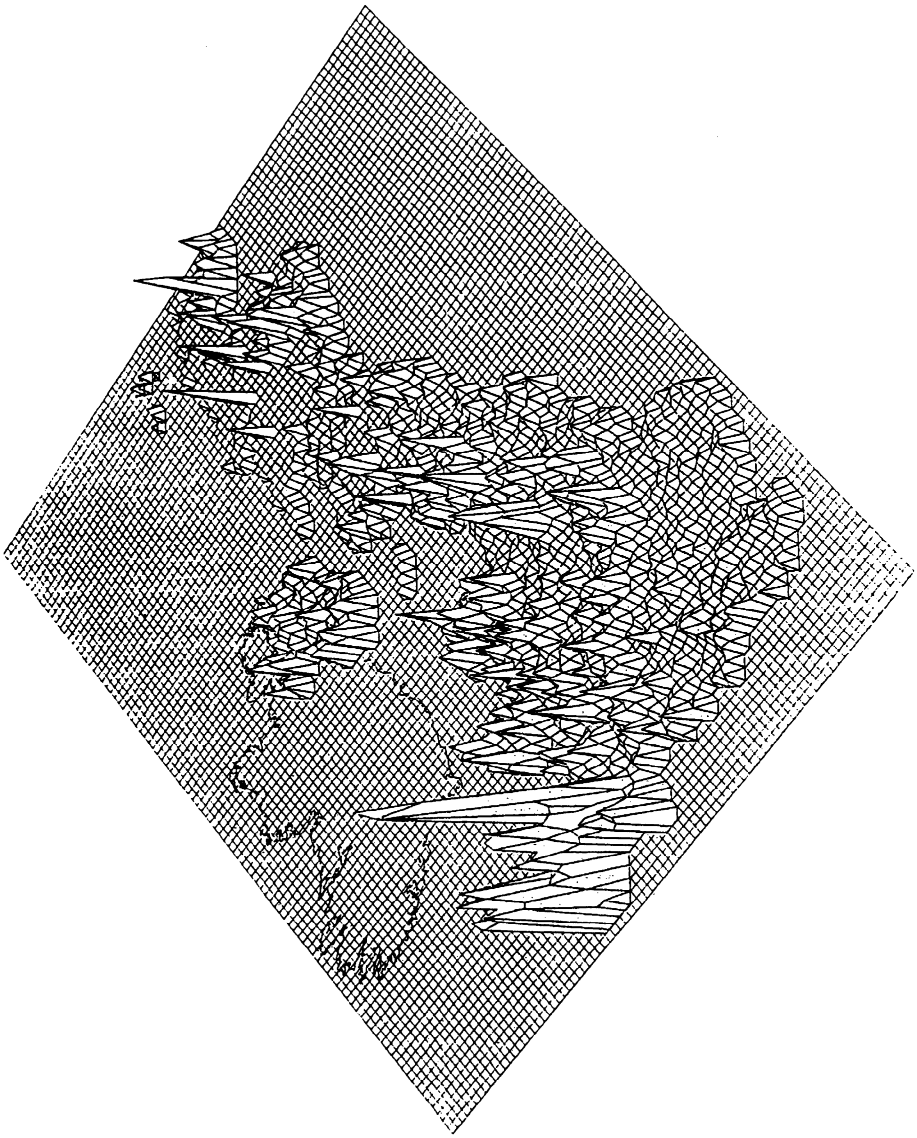

Figure 3. Surface map of radon levels in UK dwellings

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Annalen van de Belgische Vereniging voor Stralingsbescherming, Vol.21, n°1, 1996
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PRACTICAL IMPLICATIONS OF RADON REGULATION IN SWEDEN

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Abstract
The radon programme in Sweden started in 1979. The first action levels were issued in 1980 and revised in 1990 and in 1994. The aim is to decrease the average radon concentration in the Swedish housing stock to 50 Bq m^{-3}. This is half the current national arithmetic average of 100 Bq m^{-3} found in a random sample of dwellings. The National Board of Health and Welfare and the Board of Housing and Planning are the national authorities responsible for the health in existing and new buildings respectively.

Limits. The limit for existing buildings, both dwellings and workplaces with the exception of rock work, is 400 Bq m^{-3} of radon gas (earlier 200 Bq m^{-3} EER). When the radon concentration exceeds the limit the owners of single-family houses can receive a grant for part of the cost to decrease the levels. It is recommended to decrease the levels when they are higher than 200 Bq m^{-3}, which also is the limit for new buildings (earlier 70 Bq m^{-3} EER).

Measurement protocols. We have two separate measurement protocols: one for legal purposes and one for short-term advisory measurements, as when buying and selling houses. For legal purposes at least two months integrated measurements during the heating season are required. The measuring companies have the possibility to be voluntarily accredited. We are discussing certification of radon measurement consultants.

Buildings investigated. The local health and building authorities are responsible for the health indoors. Most radon measurements in Sweden are conducted by these authorities. Up to 1992 they had conducted 151,600 measurements in dwellings and workplaces. Together with measurements by others about 240,000 objects had been measured. A further 50,000-100,000 dwellings and workplaces have been measured between 1992 and June 1995.

Buildings mitigated. About 15,000, half of the number of dwellings with levels higher than 400 Bq m^{-3} found up to 1992 had been mitigated at that time. A further 10,000 dwellings are estimated to have been mitigated since then. New mitigation methods have been developed.

New buildings. A decrease of the average radon concentration in dwellings built since 1981 to half the average before that time can be seen from the random sample of Swedish dwellings. This is partly because the radium rich alum shale based concrete has not been produced since 1975, but also because construction to decrease the inflow of soil radon has been improved as a result of limit for new dwellings in the 1980 Swedish Building Code together with information and training.

Workplaces. Systematic investigations of workplaces have been started. Earlier, many schools, nurseries, and mines have been investigated and, when needed, usually mitigated. The limit for workplaces is the same as for dwellings, 400 Bq m^{-3}. For miners and other rock workers the limit for radon progeny concentrations is 2 $MBqhy^{-1}$. The latter limit is being revised.

Water. During the last year a great interest in radon in drinking water has been aroused. About 10,000 private wells are estimated to have radon concentrations exceeding 1000 Bq/l. Also some public water plants have high concentrations. It is recommended since 1984 that reduction of radon levels should be considered when the concentrations are between 100 and 1000 Bq/l. Levels exceeding 1000 Bq/l should be decreased. The National food administration has proposed limits for radon in drinking water

Training and information. The demand for training courses has increased. For the autumn of 1995 a radon campaign is planned. New booklets will be presented, articles for the daily press will be written and the local health and building authorities will receive updated information. An interim report with suggestions for future work to the government has given rise to great interest in mass media. This interest has increased the number of measurements and also the number of mitigated buildings.

Introduction

The radon programme in Sweden started in 1979 when the Swedish Radon Commission was formed and recommended a strategy for the work. The action levels were decreased to half in 1990 and changed from radon progeny to radon gas activity in 1994. These decisions were based on a risk estimate of 300-1500 lung cancer cases per year in the Swedish population of 8.5 million due to radon exposure. The aim is, as soon as possible, to decrease the average radon concentration in the Swedish housing stock to 50 Bq m^{-3} as a long-term arithmetic average of the existing dwellings. This is half the current arithmetic average of 100 Bq m^{-3}, found in a random sampling of dwellings in apartment blocks and detached houses (Swedjemark et al 1993). The National Board of Health and Welfare and the Board of Housing and Planning are the authorities responsible for the health in existing and newly-built buildings respectively. The National Board of Occupational Safety and Health is responsible for workplaces. The role of the Swedish Radiation Protection Institute is to give advice based on its own and solicited research to the concerned national authorities, and to give the possibilities for the measuring companies and others to make correct measurements.

The limit for existing buildings, both dwellings and workplaces with the exception of mines and other under ground workplaces, have been changed to 400 Bq m^{-3} of radon gas (from 200 Bq m^{-3} EER[a)]). When the radon concentration is higher the owners of single-family houses can receive a grant for 50% of the cost up to SEK 15 000 (about L 1500) for measures to decrease the levels. It is recommended to decrease the levels when they are higher than 200 Bq m^{-3} of radon gas. That level is also the limit for newly-built buildings (which earlier was 70 Bq m^{-3} EER). The random sample study found that about 4% of the dwellings had radon concentrations above the limit, 400 Bq m^{-3}, for existing buildings and about 14% above 200 Bq m^{-3}, the limit for newly-built buildings, Fig. 1.

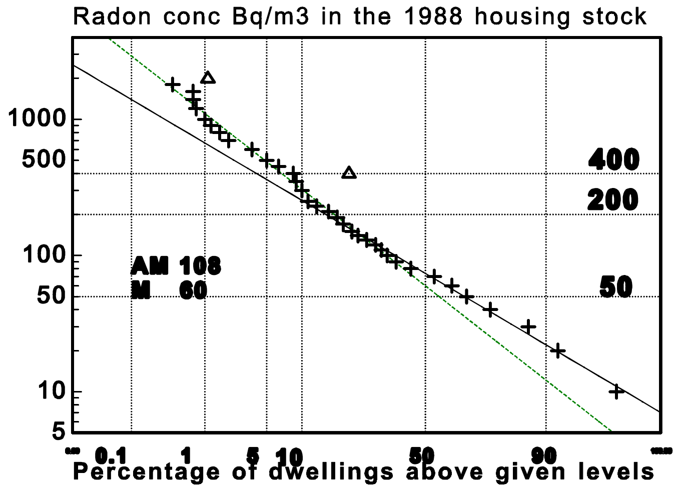


Fig. 1. Percentage of dwellings above given level in the 1988 housing stock (+). Ditto for the dwellings measured by the municipalities ( ). Dwellings in both single- and multi-family houses were included.

Measurement protocols

The measurement protocols for radon in air from 1988 were revised in 1994. We now have two separate protocols: one for legal purposes and one for short-term advisory measurements as at real estate transactions. For legal purposes at least two months integrated measurements during the heating season are required. The measuring companies have the possibility to be voluntarily accredited. We are discussing certification of radon measurement for consultants and how to put more pressure on the nuclear track film laboratories to become accredited.

The measuring protocols are based on the results of time variation measurements in 158 single-family houses and of detailed measurements in a few single-family houses (Hubbard et al 1995). The results demonstrate that the average monthly radon level varies over the year with a minimum in late spring/early summer and a maximum in late autumn. This collective data is inversely dependent on outdoor temperature except during winter, some with and some against the temperature. An annual average based on a 2- or 3 month integration is only marginally better than one based on a one month integration. Summer measurements for annual average are the least accurate. The same annual pattern as an average of all the houses sampled is seen regardless of the ventilation system.

Buildings investigated

The local health and building authorities are responsible for the health indoors. Measurements are ordered by them and by private persons from measuring companies. Therefore, we have no statistics of the number of dwellings and workplaces measured without questioning the local health and building authorities. The last time the municipalities were asked was for the period up to 1992, when 151,600 dwellings and workplaces had been measured. Together with measurements by others about 240,000 cases had been measured. A further 50,000-100,000 dwellings and workplaces have been measured between 1992 and June 1995 (Åkerblom, personal communication).

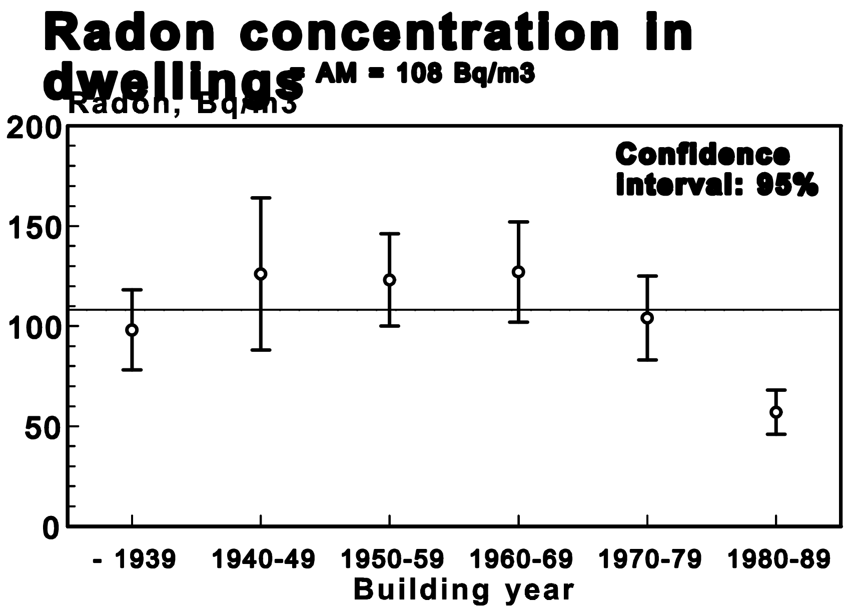
Dwellings mitigated

About half of the dwellings, about 15,000, with levels higher than 400 Bq m^{-3} found up to 1992 had been mitigated at that time. A further 10,000 dwellings are estimated to have been mitigated since then (Åkerblom, personal communication). An English version of the handbook for mitigation is published (Clavensjö and Åkerblom 1995). Mostly the mitigation methods work very good, sometimes several attempts have to be done to decrease the concentration. New mitigation methods have been developed to decrease the concentration in houses when the building material is the major radon source. One is a wallpaper containing charcoal (Blücher GmbH 1994). In a research study it gave very good results, but used in full scale to mitigate whole homes the results have been less encouraging. It has been found that the low radon concentrations after different types of mitigation are not always retained (Clavensjö and Erikson 1993). In about 25% of the cases the radon concentration had risen by more than 30% only a few years after reduction actions had been taken. 15 dwellings showed at least double as high radon concentration as immediately after the mitigation. This change was not specific to any given method.

The limit for existing buildings is in principle compulsory. In a building with more than 400 Bq m^{-3} the radon exposure is insanitary. For buildings which are rented the practice is that the local health boards can require penalty when nothing is done in buildings with levels exceeding the limit. For detached houses where the owner lives with his/her family the practice has been only to inform about the risks when the level is above the limit. However, one municipality required measures when children lived in such houses and one house owner appealed against the decision. The case has gone through several rounds and has not yet been finally decided.

New buildings

A decrease of the average radon concentration in dwellings built since 1981 to half the average before that time can be seen from the random sample of Swedish dwellings, see Fig. 2. This is partly because the radium rich alum shale based concrete has not been produced since 1975, but half of the decrease depends on the improvement of ground constructions to decrease the inflow of soil radon as a result of the 1980 Swedish Building Code together with information and training. The limits given in the Building Code are compulsory but is applied in different ways. One way to see it is that when buildings are finished they are existing houses. Another is that all buildings built after the limitation system came into force should have concentrations below the limit.



Workplaces

Systematic investigations of workplaces (other than mines, etc.) have been started by the National Board of Occupational Safety and Health. Earlier, schools and nurseries were investigated and, when needed, usually mitigated. Few other workplaces above ground have been mitigated. The limit for workplaces are the same as for dwellings, 400 Bq m^{-3} radon gas. For miners and other rock workers the limit for radon progeny concentrations is 2 M Bq h y^{-1}. (equivalent to 2 200 Bq m^{-3} of radon gas for 2000 working hours per year and F=0.5[b)]). Revision of the limit is being pursued.

Water

During the last year a great interest in radon in drinking water has occurred. About 10 000 private wells are estimated to have radon concentrations exceeding 1000 Bq/l. Also some public water plants have high concentrations. It has been recommended since 1984 that reduction of radon levels should be considered when the concentrations are between 100 and 1000 Bq/l. Radon levels exceeding 1000 Bq/l are recommended to be decreased. The National Food Administration has proposed limits for radon in drinking water; for public water plants more than 100 Bq l^{-1} would be suitable with remark for use, and 500 Bq l^{-1}, for private wells. Water with more than 1000 Bq l^{-1} would not be suitable for drinking. We have noted that the interest to decrease the radon concentration in drinking water is much higher than to decrease the radon concentration in the air in the dwellings.

During the last years several companies have developed different types of radon removal equipment, some of them with a guaranty that the radon concentration after installation should not be higher than 100 Bq l^{-1}. Investigations of conventional water cleaners have shown that the influence on the radon concentration is small (Boox 1995, Lidén et al 1995). If the limits will be established measurement protocols will be given and accreditation of the measuring companies will be required.

General experiences

The scope of the information problem is illustrated by the fact that around 1000 official persons in 284 municipalities, around 100 000 building professionals, and a large proportion of the more than 8 million population, must be reached. The dissemination of information with new knowledge to all these people had to be done.

One Swedish report deals with the growth, dissemination and implementation of knowledge regarding radon in buildings (Tell and Swedjemark 1991). The experiences of the Swedish radon work was generalised to general health problems obtained from buildings:

- *Identification* (satisfactory evidence of serious health hazards).

- *Acceptance* (that the public at large, the authorities, parliament, the building industry, researchers etc. must be given information so that they can judge whether the hazards can be regarded so serious that action to limit these are necessary).

- *Political, technical and economic limitations* (to what extent it is feasible to limit health hazards by means of specific action).

- *Supplementary knowledge* (the basic knowledge must be supplemented by goal oriented research and experience on the part of authorities and practitioners).

- *Conversion and dissemination of information* (that knowledge must be converted into information of practical application which is disseminated to all concerned).

- *Barriers in implementation* (that there is a need for both compulsion and incentives in order that action shall be taken so that health hazards are reduced at the desired pace and to desired degree).

- *Steering and control* (that the principal areas of responsibility must be defined for:
  - a joint group for investigations of health hazards, and co-ordinated efforts to limit these.
  - the preparation of requirements etc. for the steering and control of action.
  - application and checking of results.
  - evaluation and follow-up of results)

- *Division of responsibility and collaboration* (a need for properly functioning horizontal collaboration).

Risk perception and risk communication

Studies on risk perception and risk communication has been done by Lennart Sjöberg at Risk Centre, Stockholm (Sjöberg 1994). For radon he found:

- The radon risk, both general (for others) and personal, was judged as lower than the average risk,
- The denial of the risk (general - personal risk) was also judged lower than the average risk denial, but still the personal risk was judged to be higher than the general,
- The probability for harm was judged to be lower than the average,
- The possibility to protect against the risk was judged lower than the average,
- The risk was judged as forced on the inhabitants,
- The consequences were judged as over the average in severity degree,

- The desired decrease of the risk was judged as high.

Why do people not care more about the radon risks? A house buyer seems to be more inclined to require testing of radon than what the existing house owners were. Maybe, the different attitude to one's own and to another's house depends on the feeling of a house as an extension of me. If it is so, the conclusion might be pessimistic regarding how to influence people to test houses where they already live. When more knowledge about the radon risk is spread, maybe also the prices of the houses will be influenced, which should influence the buyers still more to require testing. Swedish data indicate, however, that the house prices have not yet been influenced by radon occurrence. This result is contradicted by the Swedish National Tax Board which sets a lower market value for radon houses.

Consequently, the risk seems to be underestimated and the possibility to decrease the risk by one=s own handling is underestimated. The recommendation is therefore to increase the consciousness of the health hazard and at the same time improve the knowledge of risk mitigating measures. To inform about a risk is mostly without problems because of the risk denial: it does not happen to me.

A common explanation of the weak reactions on the radon risk is that a "bad guy" is lacking. Often we have had the comment that we have always lived in houses on the ground, so what? Radon occurs in the nature but can also be generated by the building materials and be sampled in the indoor air due to insufficient ventilation. What is then natural about the radon risk?

Training and information

What are we then doing in Sweden on basis of all these experiences? Radon issues are now dealt with in basic education in most higher secondary schools and universities. Further training of employed professionals has taken place via external courses of 1-3 days. A radon campaign is going on during autumn 1995. Our booklets are rewritten, articles for the daily press are written, and the local health and building authorities have received updated information. The demand for training courses has increased and our institute gives courses on measurements, one basic course and one for accreditation, a course for radon risk mapping, one for mitigation, and one for testing and mitigation of drinking water. Seminars in different parts of the country are planned. A training course on radon given by the European Radiation Protection Education and Training (ERPET) and the Swedish Radiation Protection Institute was held in Stockholm 11 - 15 September 1995.

During the last years our institute has given the high schools the possibility to order nuclear track films, which the pupils themselves place in yoghurt mugs with a sheet of plastic. We etch the films chemically after exposure and give a calibration factor, so that the pupils can count the marks on the film and calculate the radon concentration.

Conclusions

The interim report to the government in 1994 and the suggestions for future work raised a great interest in mass media which is still lasting. This interest has increased the number of measurements and also the number of mitigated buildings. Most Swedes know something about radon indoors today. Our experience is that it takes a ten year period for implementation of the knowledge to health inspectors, builders, inhabitants etc. However, after 15 years work with the radon problem only about 10-20% are mititgated of the expected number of existing dwellings with levels higher than the limit.

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[a] EER stands for the Equilibrium Equivalent concentration of Radon. EER is derived by multiplying the radon gas concentration by the equilibrium factor F, which in most countries is around 0.3-0.5.

[b] F stands for the equilibrium factor.

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PRACTICAL IMPLICATIONS OF RADON REGULATION IN IRELAND

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Abstract
In Ireland, the first study to determine the extent of the radon problem was carried out by the Experimental Physics Department of University College Dublin (UCD) between 1985 and 1989. In this population-weighted study, the radon concentration was measured in 1,300 houses across the country. The results indicated that the average radon concentration in houses was 60 Bq/m^3 and that an estimated 4% of the national housing stock would have annual average radon concentrations in excess of 200 Bq/m$^{3.}$

In 1988, The Radiological Institute (RPII), which is the national organisation with regulatory, monitoring and advisory responsibilities in matters pertaining to ionising radiation, initiated a comprehensive radon monitoring programme. The aims of this programme are twofold. The first is to indentify those existing houses with radon concentrations in excess of the Reference Level. The second is to identify areas at particular risk from radon so that planning authorities can be advised of the need to incorporate radon preventive measures in future buildings.

A ReferenceLevel of 200 Bq/m^3 annual average radon concentration was adopted in 1990 by the Irish Government. This level applies to both existing and future houses. In the case of existing houses where the radon concentration exceeds the Reference Level, the householder is advised to consider having remedial work carried out. This advice is in the form of a recommendation and is not legally enforced. Any cost involved must be borne by the householder.

For new buildings, the question of radon is addressed in the Building Regulations (1991) issued by the Department of the Environment. In Technical Guidance Document C of these Regulations, builders are advised to consult with the RPII with a view to determining whether radon preventive measures are required in a proposed new building. These regulations are currently under review and the new regulations are likely to be more explicit.

While the Reference Level in houses has been set at 200 Bq/m^3, special consideration has been given to the exposure of children in schools. In 1990, a Reference Level of 150 Bq/m^3, was determined for all schools. Exposure to this radon gas level over the school year was estimated to give rise to a dose of 1 mSv using the conversion factors which were applied at that time.

The setting off a Reference Level for workplaces is currently under review. At present, workplace measurement results are assessed in the light of the ICRP recommended Reference Level band for workplaces of between 500 and 1500 Bq/m^3.

The practical implications of implementing this radon policy will be elaborated in the presentation and paper.

1. Introduction

In Ireland, the first study to determine the extent of the radon problem was carried out by the Experimental Physics Department of University College Dublin (UCD) between 1985 and 1989 (McLaughlin and Wasiolek, 1988). In this population-weighted study, the radon concentration was measured in 1,300 houses across the country. The results indicated that the average radon concentration in houses was 60 Bq/m^3 and that an estimated 4% of the national housing stock would have annual average radon concentrations in excess of 200 Bq/m^3 . In particular, the UCD survey indicated that the probability of finding a house with elevated indoor radon levels was greatest in the western counties of Ireland, with 11% of the housing stock in counties Mayo-Galway-Clare being predicted to have elevated indoor radon concentrations.

Following the UCD survey, the Radiological Protection Institute of Ireland (RPII) undertook follow-up surveys in some of the identified potential high radon areas. These surveys were carried out between March 1989 and December 1992 and comprise low-density monitoring surveys in counties Mayo, Galway, Clare and part of north Kerry. More intensive surveys were carried out in selected areas in Co. Galway and south Cork city (Madden *et al*., 1994). In 1994, a further survey encompassing the whole of Galway city was undertaken. The measurements resulting from each of these surveys were used to classify the 10 km grid squares of the Irish National Grid System on the basis of the predicted proportion of houses in the grid square with radon concentrations above 200 Bq/m^3.

The results show that the annual average radon concentration ranges from 31 Bq/m^3 in north Kerry to 223 Bq/m^3 in Galway city. In some grid squares as many as 30% of the houses monitored had radon concentrations in excess of 200 Bq/m^3.

While the UCD survey did highlight some of the potential high radon areas, it was clear that a more detailed survey was required to assist in identifying areas of greatest risk from elevated indoor radon levels.

In 1992, the Institute initiated a national geographically-based radon survey which is due to be completed in 1998. The aims of this survey, which is being carried out on a phased basis, are twofold. The first is to identify those existing houses with radon concentrations in excess of the Reference Level. The second is to identify areas at particular risk from radon so that planning authorities and builders can be advised of the need to incorporate radon preventive measures in new buildings. The survey involves, radon measurements in at least 10 houses in each 10 km grid square across the country giving a total of approximately 6,000 measurements. Householders are selected at random and invited to participate and all of the measurements are carried out free-of-charge and are confidential. Measurements are made using passive track-etch detectors, one placed in a living area and the other in a bedroom for a period of one year.

To date, the survey has been completed in 13 of the 26 counties of Ireland and is ongoing in a further 6 counties. The results indicate that in some areas as many as 40% of houses may have radon levels in excess of the Reference Level.

2. Radon in Domestic Dwellings

2.1 Reference Level

In 1990, the Irish Government, on the advice of the then Nuclear Energy Board, adopted an annual average radon concentration of 200 Bq/m^3 as the national Reference Level above which remedial action to reduce the indoor radon level in a house should be considered. While this level is lower than the 400 Bq/m^3 action level for existing dwellings suggested by the International Commission on Radiological Protection (ICRP) in its publication No. 39 (ICRP, 1984) and subsequently recommended by the Commission of the European Communities (CEC, 1990), it was seen to be achievable and in keeping with a high standard of radiological protection. On the basis of the UCD survey which estimated that 4% of houses may have radon concentrations in excess of the Reference Level, a possible 40,000 houses of a total housing stock of 1,000,000 houses might be affected.

2.2 Existing Houses

With regard to existing houses, the Reference level is a recommendation only and is not legally enforced. The responsibility for having remedial work carried out rests with the householder. In advising householders who have been shown to have radon high concentrations, the Institute considers a number of criteria in defining a timescale for action. These include

- (a) Radon level
- (b) Occupancy level
- (c) Cost
- (d) Age profile of household
- (e) Smoking habits in the household.

Advice on the remedial actions which may be undertaken is available from the Environmental Information Service of the Department of the Environment. Professional bodies such as the Royal Institute of Architects of Ireland and the Institute of Engineers of Ireland also provide information.

To date, the Institute has carried out radon measurements in a total of 6,200 houses. Of these, 1078 (approximately 17%) have been found to have radon concentrations above the Reference Level. The contrast between the value of 17% above the Reference Level as determined by the Institute and the value of 4% estimated by the UCD survey may be accounted for by the fact that Institute surveys have tended to concentrate efforts on those areas where there is known to be a higher than average occurrence of high radon levels. Although, the Institute radon monitoring programme has been in operation for the past seven years, the success rate in terms of houses remediated is low - approximately 2.5%. The main contributors to the lack of response on the part of householders are

(a) Cost - currently the cost of remediation is borne exclusively by the householder. The possibly of some form of assistance to householders is under consideration at national Government level.

(b) Co-ordination of message that radon is a health hazard - the division of responsibility regarding the radon problem has given rise to a somewhat fragmented message being given to the public. A new group of interested bodies has recently been formed and it is hoped that this will give rise to a more co-ordinated approach.

(c) The difficulty of the epidemiology message - the public generally have a difficulty in interpreting the hazard due to a naturally occurring substance which has always been present.

2.3 New Houses

For new buildings, the question of radon is addressed in the Building Regulations (1991) issued by the Department of the Environment. In Technical Guidance Document C of these Regulations, builders are advised to consult with the Institute with a view to determining whether radon preventive measures are required in a proposed new building. The current version of the Building Regulations is somewhat ambiguous and could be interpreted as requiring all new buildings to include radon preventive measures or, as a minimum, to have all building sites investigated for the presence of radon.

In 1995, the Institute reviewed its policy in relation to the carrying out of site investigations and concluded that they were labour intensive and difficult to interpret accurately. It now advises that preventive measures be incorporated into all new houses in areas where more than 10% of houses are predicted to have radon levels in excess of the Reference Level on the basis of surveys of radon in houses. The Building Regulations are currently under review and the new regulations, which are due to be published in 1996, will be more explicit in content.

Although there are no official figures available for the number of houses in which preventive measures have been incorporated, a number of official bodies such as Local Authorities or County Councils, have ruled that preventive measures be incorporated into all new buildings within their areas of control.

3. Radon In Schools

During an early survey carried out in the west of Ireland, measurements in one school indicated that a number of classrooms had elevated radon concentrations. The children attending the school ranged in age from 4 to 12 years and there was considerable concern regarding the effects of high radon levels on the health of the children. While the Reference Level for houses had been set at 200 Bq/m^3 , special consideration was given to the exposure of children in schools. In 1990, a Reference Level of 150 Bq/m^3 became the accepted value on the basis that exposure to this radon concentration over the school year would give rise to an estimated dose of 1 mSv, using the ICRP conversion factors which were applied at that time (ICRP, 1987).

Since 1990, radon surveys have been carried out in schools in four counties in the west of Ireland, i.e. counties Clare, Galway, Mayo and Sligo. In addition, measurements have been carried out in a number of other schools at the request of the School Principal or Board of Management. The measurement protocol for radon in schools is that radon be measured using passive detectors in all ground floor classrooms and offices for the period of the school year i.e. September to July.

To date, measurements have been conducted in 541 schools, and in 85 of these, one or more classrooms have been found to have radon concentrations in excess of the Reference Level. Of the 85 schools, approximately 40% have had remedial work carried out. The degree of success of this programme is due to the fact that all remedial work is co-ordinated and funded by the Department of Education.

4. Radon in Workplaces

As yet, no Reference Level for radon in workplaces has been adopted and no large-scale surveys of radon in the workplace have been carried out. Surveys in 145 workplaces have, however, been carried out at the request of the management or owner of the business. The measurement protocol for a workplace survey is one passive detector per ground floor office or, in an open plan office, one detector per desk or per 10 m^2 of floor area, depending on usage. The measurement period is a minimum of three months. At present, workplace measurement results are assessed in the light of the ICRP recommended Reference Level band for workplaces of between 500 and 1,500 Bq/m^3 (ICRP, 1994). In those workplaces where elevated radon concentrations have been measured, further surveys are currently underway.

4.1 Radon in Show Caves

The particular problem of radon in underground workplaces, such as show caves, has been addressed separately. In Ireland, there are four show caves which are open to the public, mainly during the summer season (April to October). In 1993, a survey of radon gas and decay product concentration was carried out in these caves. Assuming a 300 hour working year, radiation doses to tour guides working in the caves were estimated to be in the range 2 - 7 mSv on the basis of active and passive measurements carried out in the caves (Duffy *et al*., 1995). In order to verify these results, a personal monitoring programme was carried out in two of the caves. Tour guides were asked to wear a personal dosimeter (consisting of a passive radon monitor) while working in the cave and to record the total number of hours spent in the cave. The results of this programme gave doses of between 1 - 5 mSv per year.

As the Act which defines the responsibilities of the Institute was drawn up with exposure to artificial sources of ionising radiation in mind, it does not make any specific reference to the regulation of exposure to natural sources of ionising radiation. In order, therefore, to regulate exposure to tour guides in show caves, the assistance of the Health and Safety Authority, the statutory body with responsibility for health and safety in the workplace, has been sought. The approach adopted has been on the basis that workers not occupationally exposed are treated as members of the public. In order, therefore, that a tour guide does not receive a dose due to radon in excess of that which he would be allowed in his own home (3 - 5 mSv), an operational dose limit of 5 mSv per year has been adopted for tour guides. Compliance with this limit is monitored by requiring all tour guides to wear a personal dosimeter. If a tour guide is found to be exposed to doses in excess of this limit, he may be requested to reduce the number of hours spent in the cave, or to be designated a "radiation worker" and subjected to the same dose limits/controls as an occupationally exposed worker, for example, in a hospital.

5. Summary and Conclusions

In Ireland, a Reference Level of 200 Bq/m^3 annual average radon concentration is applied to both new and existing houses. For existing houses where the Reference Level is exceeded, the householder is advised to consider having remedial work carried out but is not legally required to do so. For new buildings, planning authorities and builders are required to ensure that the Reference Level is not exceeded and the steps which might reasonably be expected to achieve this end are currently being elaborated.

A Reference Level of 150 Bq/m^3 is applied in schools and, in the absence of a specific Reference Level for workplaces, radon measurement results are assessed against the ICRP recommended Reference Level band of 500 - 1500 Bq/m^3. Special consideration has been given to the exposure of tour guides in underground show caves and an operational dose limit of 5 mSv is applied.

The success of the radon programme in terms of the percentage of houses with elevated radon levels remediated is low. This problem is being addressed in two ways: (1) adoption of a more co-ordinated approach by Government agencies with responsibility in the area of radon, and (2) consideration of some form of assistance to householders at national Government level. Regarding new houses, no official figures on the incorporation of preventive measures are available. It is clear, however, that completion of the national radon survey and clarification of the Building Regulations will improve the situation.

In schools, the success of the programme of remediation has been enhanced by the involvement of the Department of Education, while in workplaces, in general, no specific Reference Level or regulations have, as yet, been adopted.

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THE RADON APPROACH IN THE CZECH REPUBLIC

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Abstract

20 years ago we were the only institute which measured radon daughters (underground, uranium mines). After the beginning of the radon boom in former Czechoslovakia we were asked to measure différent environments. Since 1989 we are specialized in

metrology
solid state nuclear track detectors

The Czech republic is an exception from two points of view:

1. The limit of intake is defined for WL (PAEC) not for radon gas!
2. The investigation level is stated in Decree ofMinistry of National Health and is thought of as a limit (200 $Bq.m^{-3}$ for existing dwellings, 100 $Bq.m^{-3}$ for future houses).

When the EEC in the dwelling is greater than 200 $Bq.m^{-3}$, the owner can ask the regional office for fmancial support.
In detail the row of steps appears as described below:

- measurement (mostly passive SSNTD)
- official decision as to whether the measured values correspond with the Decree or not
- asking for support
- radon diagnosis (the bill is paid by Regional Office)
- official classification into three categories (categories influence the maximal support)
- owner orders design of mitigation, which must be approved by the Committee
- realisation of mitigation
- final measurement (at least seven days long) Building Office allows the house to be used

Preventive actions are organized mostly in the fields of barrier against radon flux from soil. The process starts by measurements of radon in soil (and estimation of the permeability) called classification. When the medium of high risk is defined foils must be applied etc.

A control of effectiveness is building - at least seven days measurement is asked after finishing the house (but only in part of the country).

Remarks:
The most probable method of SSNTD distribution is through regional hygiene stations (to Ju1y1995), which follow radon risk map and prefer placing SSNTD in radon risk areas. The

people distributing detectors are mayors of little villages, employees of subregional hygiene stations, employees of building offices etc.

Inhabitants in 99% cases get detectors free of charge (the rest are non-urgent cases in radon-prone areas). Inhabitants are informed (receiving detectors) that the state could support possible remedies.

In spite of prohibition, many houses were built from the material with elevated radium content. The state is partially responsible for this and so in these cases a special approach is applied - e.g. the state offered to buy these houses from the owners.

Every year a Radon conférence for regional clerks was organised. This conférence must be held every year because of a high turnover of personnel.

Introduction

At this time the state is divided into 8 regions (approximately 1 million inhabitants each) and each region into 10 subregions approximate population 100 000 each. Till the summer of 1995 every region had a so called Regional Hygiene Station of which part was a Department of Radiation Hygiene with approximately 10 employees. This staff took care of natural radioactivity and other aspects of radiation protection in its region. In the summer 1995 radiation protection was reorganized and the responsible body is the State Office for Nuclear Safety.

History

Twenty years ago the Institute for Occupational Hygiene in the Uranium Industry was the only institute that measured radon and its daughters in mines. After the beginning of the radon boom in the former Czechoslovakia we were asked to measure in différent environments. In the late eighties the import of devices, the development of own Czech equipment began. After 1989 many private companies were created to measure radon in the soil. Since then we have specialised in metrology and solid state nuclear track detectors, still providing common measurements in a limited number.

Legal circumstances

The approach in the Czech Republic (and the Slovak Republic) is différent from that in many other countries from two points of view

1. The limit of intake (concentration) is defined in WL (EER)
2. The investigation level is stated in a Decree of the Ministry of National Health and is interpreted as a limit. It is probably a relic of the former regime, when any official paper was thought as a law

In the Decree of the Ministry of National Health 76 (1991) the following levels are stated:

a. 200 $Bq.m^{-3}$ of EER for existing dwellings (for rooms occupied for more than 1000 hours a year)
b. 100 $Bq.m^{-3}$ of EER for future houses
c. Building materials with a radium content greater than 120 $Bq.kg^{-1}$ may not be used without permission
d. Drinking water may not be used for public consumption without permission when it is characterized by a concentration greater than 50 Bq/l.

When the concentration is above the stated level, the Decree does not give detailed actions to be taken.

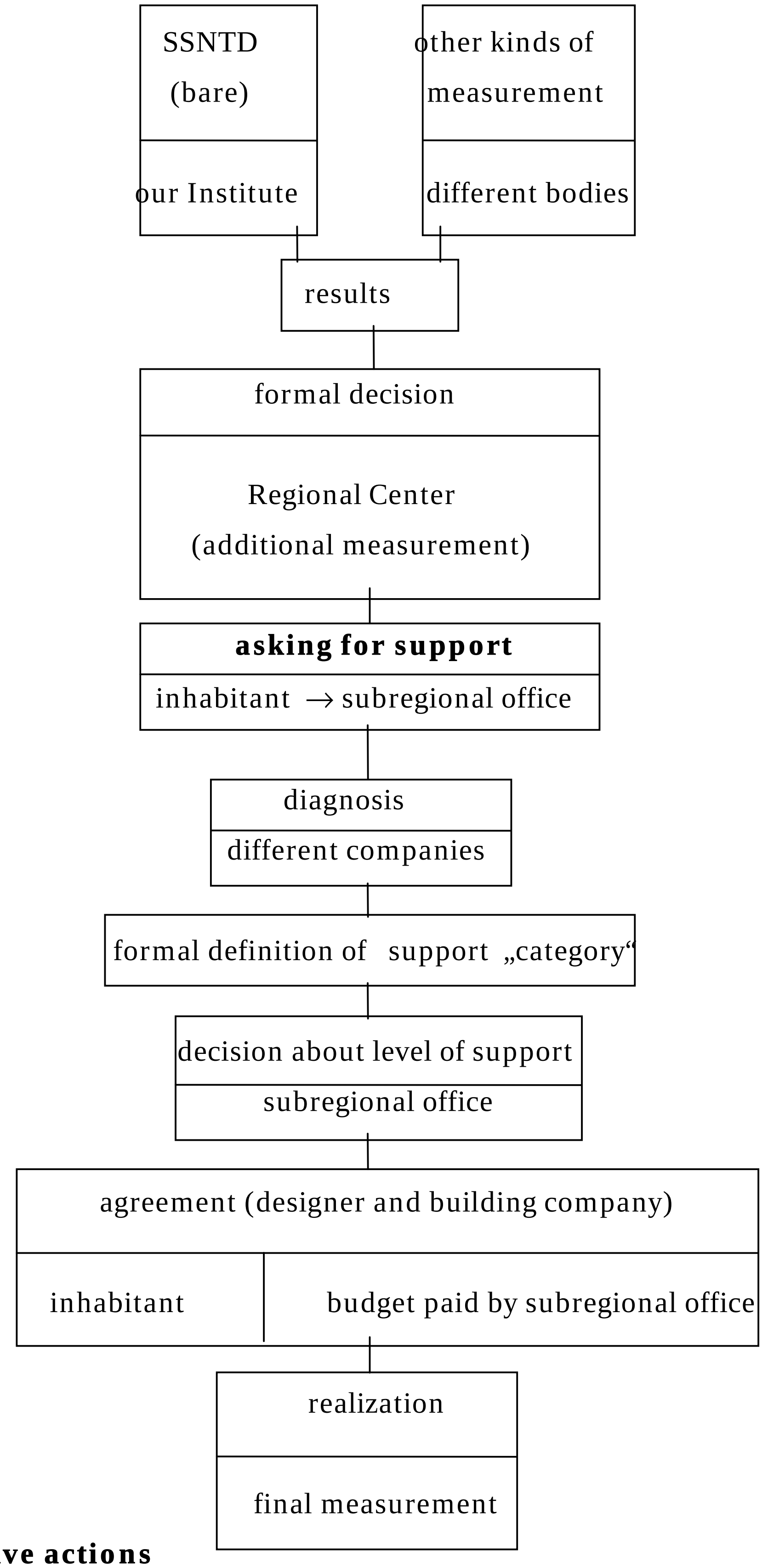
In the case of new buildings (b) the owner does the improvement. In our experiences these cases are scarce and they are caused by unadequate construction and very limited ventilation.
In the case of building material (c) the producer (after been refused the usage of material) must add the required input of inactive material.
In the case a. and d. the state supports improvement financially.

Water
In the water stations for common supply anti-radon towers are implanted. One could estimate the number of these mitigations as 250. In detail the process of mitigation is as follows:

- three results of radon in water measurement (realized by organisation with devices with certificate of metrologic body and having accreditation)
- asking the Interministery Radon Committee for financial support
- the Interministery Radon Committee decides whether the budget is adequate

The usual support is about 200 000 BF. Actually it is not support, but the aeration tower is almost completely paid by state.

Dwellings
When the EER in the dwelling is greater than 200 $Bq.m^{-3}$, the owner can ask the Subregional Office for financial support of mitigation. The Subregional Radon Committee decides whether this request is appropriate.
The Subregional Office proposes the Ministry of Finance a general budget at the start of year. In most cases subregional offices get it (sometimes partially), so the Committee can promise support. The fundamental documents to get this support are proofs of ownership and full time occupation of the house.
The maximum value for support for one house is principally equivalent to 250000BF.
In the case of schools etc. the limit (maximum support) is not defined and the demand has to be directed to the Interministry Radon Committee. It can be estimated that about 210 schools have been mitigated .
The différent steps are shown in detail in the flowchart below :



Preventive actions

Preventive actions are organized in the field of:

- water consumption (improvement of a new water supply is not supported by the state)
- use of the building material (described above)
- decrease of the radon flux from soil into houses

In most subregions local authorities declare the compulsory measurement of radon in soil. The method is very simple - it is necesary to take 15 samples at the depth of 0.7 m below the ground surface (if possible) and to classify the permeability of the soil from at least one point (for one-family detached house). The radon concentration and permeability serve for site classification in three categories: low, medium, high risk.

In the case of low risk no action need be taken. In the two other categories, foils must be applied. There is a system of education and training for designers who use special foils etc. A control of effectiveness of this part of the anti-radon fight is building inspection. For permitting the house to be used, the owner must ask the Building Office for an offical stamp. (In many cases the houses are built by owners themselves without help of professionals). Part of this process is measuring radon in the new house. Actually this is asked for only in part of the subregions. These measurements (at least seven days) are performed by means of electrets or Czech devices similar to the Honeywell system (RADIM).

In some cases the mitigation is unsuccessful. The reasons were the lack of qualification of designers and a failure of workers to carry out instructions. In a limited number of cases designers do not follow recommendations - part of radon diagnosis, e.g. tightening the cellar door etc. In some cases the lack of success was caused by a lack of experience ; the subslab layer was applied only in part of the house.

Measurements

In near all cases the process starts by the use of passive SSNTD (distributed by our Institute). The most probable method of distribution is through regional hygiene stations (to July 1995), which follow radon risk map and prefer placing SSNTD in radon risk areas. The people distributing detectors are mayors of little villages, employees of subregional hygiene stations, employees of building offices etc.

In the past 2-3 detectors per house were sufficient: now it is necessary to monitor all „big“ rooms close to the ground, every third in upper floor etc.

In rare cases the process starts by radon diagnosis or one-week measurement or measurement of radon influx.

Elevated concentrations are in most cases caused by high concentration of radon in the soil and imperfect floors (cracks, wood). In limited cases (Jachymov) it is the result of special circumstances (uranium mining history).

Solid state nuclear track detectors

In table I results of the usage of SSNTD (Kodak LR115) are summarized:

Table I

	Total	EER >200Bq.m^{-3}
Town Jachymov	1188	700 (59 %)
Middlebohemian Pluton area	2846	1742 (61%)
Houses „Start“	3626	508 (14%)
Rest of country	121440	10922 (9%)

Representative studies show, that the percentage of flats with EER greater than 200 Bq.m^{-3} is 3.1% (measured), 1.6% (estimated). The geometric mean of EEC could be estimated as 44 Bq.m^{-3} with a GSD 2.1.

Houses „Start“

In spite of prohibition, many houses in the Czech Republic were built from materials with elevated radium content. The state is partially responsible for this and so in these cases a special approach is applied :

- the state offered to buy these houses from the owners
- limited diagnosis was provided

They looked for other solutions, for example the application of air condition.

The radon concentrations were in general not to high (of the order of 200 Bq.m^{-3}).

History

The discovery of elevated concentrations in dwellings (Jachymov) was by chance - the testing of devices for underground measurement in home. After the set of grab sampling measurements, the building in the town was stopped. About five years later SSNTD were applied in most houses and the former estimation was confirmed (of course in individual cases there were differences as result of the limited validity of short time measurements). These are untypical cases with dose rates up to 20 uGy/h, historically worthy mediaeval constructions etc.

Starting the system

Due to the personal interest and the courage of one of the heads of the Hygiene Department Radiation Protection in the eighties, the system was developped. Also, an elevated radium content in some blocks of aerated concrete was discovered. First the attempt was made to measure (grab sampling, SSNTD) in kindergartens, nurseries as the easiest environment to try these methods etc. (Schools were subject to many controls - food, lavatories etc.)

Information system

Building officers are periodically called to be informed about new regulation etc. On this occasion they also get information about radon.
Every year a Radon conference for subregional clerks was organised. They deal with „radon money“. At this occasion information is also provided about the distribution of funds and about new instructions of Minister of Finance.
This conference must be held every year because of a high turnover of personnel.

The pattern of decision

The measurements are realised by means of SSNTD, continuous measuring devices and electrets (with decreasing order of validity). It is widely used the system for formal decision, whether the room (house) is convenient with Decree of Minister of Public Health. If the values measured by electrets are lower than the limit, the room is considered as being allowed to live in. In opposite case more reliable and detailed measurements have to be performed.

Financial pressure

In almost all situations, the inhabitants get the detectors free of charge (the rest are non-urgent cases in radon-prone areas). On receiving detectors, inhabitants are informed that the state could support possible remedies (in most cases this means the repair of floors, the installation of air-condition) and that this can only increase the value of the house.
In the period 1991 - 1995 nearly 1 milliard BF was spent for mitigation.

Future tasks

The major challenges for the future are :

1. Improving the efficiency of mitigation.
2. Stopping the (unprofessional applied) energy saving tendency, causing only air quality problems indoors.
3. Designing houses with construction details to decrease the stack effect.

Acknowledgement

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SECTION B

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RESULTS OF RADON SURVEYS PERFORMED IN SPAIN

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Abstract

A monitoring program, "Radon Project", was launched by the CSN in 1988 for studying the natural isotopes content, specifically radon, inside dwellings in Spain.
This program has been carried out by means of contracts with external institutions, such as the Centre for Environmental and Technoloqy Research (CIEMAT) , and four laboratories associated to the Universities of Cantabria, La Laguna (Canary lslands) , Autonoma de Barcelona and Valencia.
In the case of the University of Cantabria, the programme includes additionally the measurements of natural radionuclides (Ra-226, Th-232 and K-40) concentrations in soils and construction materials. Also included are measurements in spas and consumption waters.
The assessment of radon indoor concentrations has been done by the following type of surveys:

- One survey in the cities of Madrid and Barcelona (700 homes)
- Two regional surveys in the Canary lslands (300 homes and in the Comunidad de Valencia (600 homes and 64 schools)
- One nation-wide survey in rural areas dwellings (1800 homes)

From the national survey, an annual geometric mean value of 43 Bq/m^3 for the country has been obtained , with a range of less than
10 to 2068 Bq/m^3, for 98 % of the measurements.
Values in a small village in the uranium rich area of Salamanca reached punctually very high levels, where 41 % of houses resulted in values over 600 Bq/m^3.
As a general conclusion, Spain does not present special problems concerning the risk from radon in dwellings, except the above mentioned area in which some houses were built over uranium rich terrains, presenting high values of radon.
This area is being the subject of a more detailed measurement program by the University of Cantabria under a contract with the CSN.
In order to come out with any recommendation of corrective actions, the ICRP documents and the UE recommendations are taken into account.

INTRODUCTION

The principal goal of this paper is to show, in a general way, the current situation in relation with indoor radon in dwellings in Spain.
To know the indoor radon levels in Spanish dwellings is the main objective of the "Radon Project". This Project is a monitoring programme that was launched by the Nuclear Safety Council (CSN) in 1988 , for the study of the natural isotopes in the environment, in

collaboration with different institutions such as the Center of Technological and Environmental Studies (CIEMAT) and the following universities: Autonoma de Barcelona, Cantabria, La Laguna and Valencia.

Other Project goals are the following:

- ^{226}Ra , ^{232}Th and ^{40}K measurements in soils and construction materials, as well as analysis of ^{222}Rn and ^{226}Ra in consumption water, principally from villages located in a uranium mining region and from health spas.
- Development of protocols for the measurement, in different soil types and building materials, of the physical parameters that have influence in the indoor radon levels such as radon emanation factor exhalation rate, diffusion coefficient, porosity and permeability.
- Study of radon ingress models and mitigation techniques.

Following is presented a brief overview about the items listed above.

RADON INDOOR LEVELS

For the moment, measurements have been made in over 3700 homes and 64 schools, and the data has been obtained by means of different survey types. One, in the cities of Madrid and Barcelona, two regional surveys in the Canary Islands and Comunidad Valenciana and one nationwide survey in rural area dwellings.

The measurements in the cities of Madrid and Barcelona were fulfilled by the CIEMAT and the Autonoma de Barcelona University, in two campaigns The first one, was a preliminary survey, in which, a total number of 337 detectors were distributed and exposed during two periods of three months [(1)]. In the second survey, 2000 dosimeters 1000 in each city, were placed in the houses during two periods of six months[(2)].

The conclusions obtained from this survey, were the following: low concentration values in general, highest in winter, underneath soil influence in both cities and type soil influence in Madrid, highest values in relation with arkosic soils.

The results are summarized in the Table 1

Table 1. ^{222}Rn concentrations in Madrid and Barcelona $Bq.m^{-3}$

	MADRID		BARCELONA	
	1st survey	2nd survey	1st survey	2nd survey
Mean value				
Arithmetic	68	63	40	32
Geometric	51	45	32	28

The survey in the Canary Islands is being carried out by La Laguna University. To date, measurements have been done in about 300 dwellings, belonging to six islands of the seven that compose the group[3] [4]. The measurement devices generally used were etched track detectors, that were exposed during three months. At the beginning of the programme were used also charcoal detectors for screening purposes. Now it is in progress a survey in the last island Gran Canaria.

Following the principal conclusions extracted until now from this survey are indicated: low concentration values in general, ventilation influence in the values obtained highest values at uninhabited and unventilated homes in Tenerife with an underneath soil influence.
The mean values for each island are presented in Table 2.

Table 2. ^{222}Rn concentrations in Canary Islands $Bq.m^{-3}$

TENERIFE	FUERTEVENTUR	LE HIERRO	LA GOMERA	LA PALMA	LANZAROTE
109	60	45	45	28	48

The monitoring programme in the Comunidad Valenciana administrative region, has been carried out by the Valencia University. This programme can be divided in two parts, schools and dwellings. The first programme was a survey directed to know the radon levels in a group of 64 secondary and high schools in 32 towns of the region[5]. In this survey a concentration mean value of 27 Bq . m^{-3} was found.
The second survey was focused to dwellings, considering 876 houses located in 111 localities distributed in the three provinces that compose the administrative region[6] [7] [8].
In both surveys, activated charcoal cartridges were used as measurement device.
The second survey has finished this year and the concentration mean values measured in each province are presented in the Table 3.
The concentration values in this survey have been low without radiological signification.
Tabla 3. ^{222}R concentrations in the Comunidad Valenciana

PROVINCE		
CASTELLON	VALENCIA	ALICANTE
52	37	41

The nationwide survey was fulfilled by the Cantabria University in 1796 randomly chosen rural area homes, taking into account the different geologic areas of the country in order to discover possible locations with high values[9] [10]. Two measurement methods were used, scintillation cells, for screening purposes and passive etched tracks detectors with the main goal of obtaining integrated values and confirming the previous results obtained with the active detectors[11].

The results that were obtained in this survey, are shown for each Autonomic Community in Table 4 .

Table 4. ^{222}Rn concentrations in different administrative regions

Comunidad Autonoma	Number of Dwellings	Mean Value Bq.m^{-3}
Andalucia	278	31
Aragon	130	39
Asturias	54	43
Baleares *	27	27
Canarias **	60	64
Cantabria	103	40
Castilla-La Mancha	168	43
Castilla Leon	309	68
Cataluna	78	23
Extremadura	111	90
Galicia	112	118
Madrid (highlands)	29	95
Murcia	59	25
Navarra	49	20
La Rioja	26	19
Pais Vasco	79	28
Comunidad Valenciana	124	18
SPAIN	1796	43

* Island of Mallorca ** Island of Tenerife

In this survey, was obtained a mean value of 43 Bq.m^{-3} for the country[12], and was observed that the elevated indoor radon levels were more prevalent in the northwest and west than in the rest of the country, considering the underneath soil as the principal radon source.
In the west part, close to the border with Portugal a small village was found where 41% of the houses in which have been made measurements, are over 600 Bq.m^{-3} and 76 % over 400 Bq.m^{-3}

In this village and in others located in this area, it is foreseen to take more measurements in the next year and begin the study of the potential remedial actions for the houses where the highest values have been found.

OTHER PROJECT GOALS

In relation with the other Project goals enumerated previously, characterization of sources of radon, measurement of physical parameters, study of radon ingress models and mitigation techniques, the actual situation in our country is the following:

Measurements of radionuclide concentrations in soils, have been made principally by the Cantabria University, that carried out, a national survey in 952 locations during a period of four years, taking a total of 4, 760 samples In all these samples the content of ^{226}Ra, ^{232}Th and ^{40}K was analyzed(13).

Table 5 shows the average values as well as the ranges obtained.

Table 5. ^{222}Ra, ^{232}TH and ^{40}K concentrations in Spanish soils. Bq/kg.dry

^{226}Ra	^{232}Th	^{40}K
32	35	476
8 - 310	5 - 258	31 - 204

Additionally, La Laguna University, fulfilled a specific programme in the Tenerife island, considering 103 sampling points and the same isotopes indicated before. The average values and the ranges are presented in Table 6(3).

Table 6. ^{222}Ra, ^{232}Th and ^{40}K concentrations in Tenerife island soils. Bq/kg.dry

^{226}Ra	^{232}Th	^{40}K
43	54	665
7 - 104	12 - 110	142 - 1488

The Cantabria University is performing a programme for the measurement of radioactivity in building materials of common use in Spain, with special emphasis on cements and granites(14)
The granite is used in Spain as a primary building material in some parts of the country.
A total of 110 granite samples, representing 98% of those used in Spain were collected, and the content of ^{226}Ra was analyzed. A 28% of the samples were over 100 $Bq.kg^{-1}$.

The cement is a component of concrete, the main building material in Spain, in this case a total of 120 cement samples were collected from different producers covering about 95% of the Spanish cements, and a small proportion of imported cements (10 samples).
The results showed that 7% of the Spanish cements and all of the imported samples had values over 100 $Bq.kg^{-1}$.

A new programme is foreseen to be carried out by the Cantabria University for the identification, classification and measurement of radioactivity in Spanish shales.

The same working group, performed a measurement programme of ^{222}Rn and ^{226}Ra in water from 54 health spas in the country[15], and now a survey is being carried out about radioactivity in drinking water from villages located in a uranium mining area on the west of the country. This survey enlarges and completes a previous survey that was fulfilled in the same region in a less number of villages[16] [17].

The works in relation with the measurement of physical parameters that have influence in the indoor radon levels, are being performed by the group belonging to the Cantabria University.
For the emanation factor and the exhalation rate measurements, the group has developed a technique that was presented at the meeting in Rimini[18] and has been applied to studying the dependence on humidity for a set of soils as well as for granites and concrete.
For the diffusion coefficient measurement a new method has been developed to be applied to granite and concrete samples.[19]
Finally, for the measurement of porosity and permeability, a plan has been established with the Department of Materials at the Cantabria University, to refine a highly sensitive technique for the laboratory measurement of these parameters.
The Cantabria University Group, has started the study of some calking compounds in the reduction of radon levels in homes and has developed laboratory mitigation tests where epoxy, polyurethane and acrylic paints commonly used for decoration of walls and ceilings have been tested.
By means of these tests, they have found that using epoxy and polyurethane paints, the contribution of granite to indoor radon, can be reduced in a 50%.[19]

The Autonoma de Barcelona University working group, is carrying out a project with the aim of studying the ternporal variations of indoor radon in four Cataluna types of houses by the radon entry and behaviour modelling and experimental measurements.[20] [21] [22]

CONCLUSION

As a general conclusion and considering the results obtained up to date, it can be said, that there is not a general problem in Spain concerning indoor radon in dwellings. For this reason, general recommendations have not been issued.

The exception has been found in a small village, where it is foreseen to carry out measurements in the rest of dwellings and begin the study of the potential mitigation techniques according to U.E and ICRP recommendations.

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SWITZERLAND AND ITS RADON

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Abstract
On October 1994, the new Radiological Protection Act and the Radiological Protection Ordinance came into force in Switzerland. 50 there are now legal bases for the handling of radon problems (Art. 24 of the act; Art. 110 to 118 of the ordinance). Fixing those decisions was performed in order to find a compromise between the followings :

- health protection
- own responsability
- economic allowance

Dealing first with houses showing a very high concentration of radon was desired quite early The goal was never to lower the country mean concentration value. In order to help the remedial work for the concerned houses to be done, it was clear that a binding limit value had to be established. A limit value of 1000 Bq/m3 was adopted in residential and recreational premises. A reference value of 400 Bq/m3 was adopted for new and reconstructed buildings as well as for those where a remedial work has to be carried out.
The ordinance confers new tasks on the Cantons. They must ensure that a sufficient number of measurements are made throughout their territory. On the basis of these measurements, the Cantons establish a chart of areas with elevated concentrations of radon. In those areas, building regulations have to be enacted in order to conform to the limit and reference value. The Cantons have to ensure that remedial work is completed at the latest 20 years after that the ordinance came into force.
lt shall be possible that measurements are performed upon request from the house owner, any other person concerned or the Canton. The person concerned has a right to know these results. The house owner has to carry out the necessary remedial work, if the limit value is exceeded. The Canton can order the execution of the necessary measures. The costs of remedial work shall be borne by the house owner
The Federal Office of Public Health is operating a Radon Technical and lnformation Centre. The main aim during coming years will be to find houses with elevated radon gaz concentration and to carry out the necessary remedial work. The Cantons will be advised and assisted for performing of measuring campaigns. The public at large shall be provided with regular information regarding radon problems and the harmful effects on health. House owners must be motivated to carry out remedial work and this also when these measures do have financial repercussions for them. To allow proper remedial measures to be taken, the construction experts must know the different possibilities helping to lower the radon gas concentrations in the residential and recreational premises. Therefore, an efficient collaboration with

educational establishments and the different professional associations has to be achieved. Faults and/or ineffectivenesses should be detected or avoided in time by carrying on regular evaluations regarding the effects of implemented measures.

Introduction

On October 1994, the new Radiological Protection Act and the Radiological Protection Ordinance came into force in Switzerland. So there are now legal bases for the handling of radon problems (Art. 24 of the act; Art. 110 to 118 of the ordinance). Fixing those decisions was performed in order to find a compromise between health protection, own responsibility and economic allowance.

In Switzerland, some houses with very high radon concentrations (over 10'000 Bq/m^3) were found since the first radon measurements in 1980. More than 8'000 houses have been measured until now. The median value of the concentrations for inhabited rooms is about 60 Bq/m^3. Approximately 5 % show concentrations above 400 Bq/m^3 and 1 to 2 % are even above 1'000 Bq/m^3. Dealing first with these high concentrations was desired quite early. Accordingly, the goal was never to lower the country mean concentration value.

In order to help the remedial work to be done, a binding limit value had obviously to be established. It was set at 1'000 Bq/m^3. This means that thousands of houses have to be mitigated. However, it must be noticed that the distribution is biased, because single family houses are overrepresented, most measurements were performed in winter and some regions with high population density are still not sufficiently analysed.

Therefore, one of the first goals to achieve must be the delimitation of radon areas. A sufficient number of measurements have to be made on the whole territory. On the basis of these measurements, a chart of areas with elevated concentrations of radon can be established. In those areas, building regulations have to be enacted in order to conform to the limit and reference value. Remedial work has to be completed at the latest 20 years after that the ordinance came into force.

Limits and Tolerance Values

A limit value of 1000 Bq/m^3 was adopted in residential and recreational premises. A reference value of 400 Bq/m^3 was adopted for new and reconstructed buildings as well as for those where a remedial work has to be carried out. These values refer to annual mean radon gas concentrations, exactly speaking radon-222.

The limit for workplaces as a mean over one month working time, is set at 3000 Bq/m^3.

Measurements

The radon gas concentration measurements must be performed by recognised measuring laboratories. The Federal Office of Public Health recognises the laboratories provided the envisaged measuring system meets the state of the art and is linked to national or international comparison standards. The traceability is established by the Swiss National Institute for Metrology.

The radon gas concentration is determined with integrating passive dosemeters. A three month exposition is recommended during the heating period. The dosemeter should be placed in the deepest inhabited premise and in contact with normal breathing air. An additional measurement carried out in the cellar can give a complementary and redundant information.

Based on earlier investigations on winter-summer differences, the following formula has been adopted for the calculation of the annual mean A_0 out of measured concentration A_m:

$$A_o = A_m \frac{N_w + N_s}{1.12.\,N_w + 0.88.\,N_s}$$

where N_S is the exposition time in "summer" (April to September) and N_W the exposition time in "winter".

The measurements can be performed upon request from the house owner, any other person concerned or the Canton. The person concerned has a right to know the radon concentration measured in the house he is living in.

Protective Measures

If the limit value is exceeded, a person concerned can require that the necessary remedial work is carried out within three years. If this term expires without any work being done or should the proprietor refuse to undertake it, then the Cantons shall order the necessary remedial work to be executed. The time limit for completion of the work is three years at most, depending on the urgency of the particular case. The costs of remedial work shall be borne by the proprietor.

Radon Areas

The Cantons shall ensure that a sufficient number of measurements are made throughout their territory. This should allow to determine the areas with elevated radon gas concentrations and to adjust these continuously, on the basis of the measured data. The charts of radon areas shall be available for public consultation.

It is therefore very important to define criteria for the delimitation of radon areas. Because local geology is most of the time not so well known, it was decided to base the classification on measured concentrations in dwellings. In order to avoid as far as possible any misclassification, a minimal sample of 20houses per political community must be considered. This means that for Switzerland over 50'000 permanently occupied houses have to be analysed for radon. Nowadays some 8'000 buildings are registered in the radon database at the Radon Technical and Information Centre of the Federal Office of Public Health.

Since it is impossible to measure all communities at the same time, priorities can be set based on geological considerations, mainly involving estimated soil air permeability's.

Since the main aim is to find houses with high concentrations, single family houses and farmhouses are first selected. Older buildings, showing in general higher concentrations, are also preferred. If possible, houses with natural soil in the cellar are retained. Measurements are not performed higher than the first floor. All this, of course, will lead to a biased distribution of the radon concentrations with an overestimated component in the high concentration range.

The arithmetic mean of the radon concentrations in residential premises has been used since several years as a unit for the radon potential in a defined region. It will also be used in the future because it is easy to calculate and sensible to the presence of high concentrations. If, for a given community, a large enough number of houses has been measured, the classification is performed as follows:

Arithmetic Mean [Bq/m³]			**Radon Area**
residential premises		**Cellars**	
≤100	and	≤500	no
100-200	and	≤1000	?
>200	or	>1000	yes

If enough cellars are measured, their arithmetic mean is also taken into account as an additional condition. The following remarks have to be made:

- If a community is declared as not being a radon area, no preventive measures are necessary for new constructions. If the houses have been selected according to the above recommendations, it is unlikely to get a sample arithmetic mean below 100 Bq/m³ when the real mean is above 200 Bq/m³.

- If the classification is not possible, another 20 houses are measured. If the arithmetic mean is below 200 Bq/m³, the community is not considered as a radon area. Otherwise it has to be treated as radon area.
  In case of doubts, the community can be classified regarding the local geological findings.

- If a community is classified as radon area, measures must be taken so that, for new construction, the reference value is not exceeded. Most houses should be measured in order to find and mitigate those with very high radon content.
  The probability of classifying a community as radon area, when in fact it is not, is of a range of only 1 %o.

Radon Technical and Information Centre

The Radon Technical and Information Centre co-ordinates the radon activities in Switzerland and represents the Federal Office of Public Health. Radon activities can roughly be devided into scientific, public and international fields.

The main aim for the next years will be to find houses with elevated radon gas concentration and to carry out the necessary remedial work. The Cantons will be advised and assisted in performing of measuring campaigns. The criteria for delimitation of radon areas will be validated or adapted by results of measurements and building characteristics. New mitigation methods will be evaluated and tested in collaboration with construction experts.

The public at large shall be provided with regular information regarding radon and its harmful effects on health. House owners must be motivated to carry out remedial work even if the latter do have financial repercussions for them.

To allow proper remedial measures to be taken, the construction experts must know the different possibilities helping to lower the radon gas concentrations in the residential and recreational premises. Therefore, an efficient collaboration with educational establishments and the different professional associations has to be achieved. Faults and ineffective measures should be detected and avoided in time by carrying out regular evaluations of the effects of implemented measures.

There are still developments in the radon field. International contacts with radon responsible, research groups and organisations have to be improved, in order to adapt, as fast as possible, the very last findings to the local conditions.

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THE APPROACH OF THE RADON PROBLEM IN BELGIUM

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Abstract

The major items of the ongoing radon action programme in Belgium are described and discussed. Cost-benefit and multi-attribute analysing techniques are applied to select priorities for the governmental approach about radon.

1. Introduction

In Belgium, up to the end of the eighties, almost all activities in respect of radon were related to research projects supported by the Commission of the European Communities. Among others, a systematic investigation as to the radioactive content and exhalation rate of most commonly used building materials was carried out. Some small scale surveys were also conducted, indicating that the overall mean radon concentration was around 50 Bq/m^3 , with a significant higher mean value (80 Bq/m^3) in the south than in the north (40 Bq/m^3). In about 10000 houses - mainly situated in the southern part of Belgium - radon levels are expected to be in excess of 400 Bq/m^3. Meanwhile the Ministry of Public Health and in particular the Radiation Protection Department (RPD) followed the developments in neighbouring countries very closely. At the same time an important financial support was given to the assessment study on the radon-induced cancer risk in the Ardennes-Eifel region.

2. Radon action programme

By the end of 1993, the Minister of Public Health decided to launch a 5 year-programme on radon in homes. The major topics of this programme are :

1. Information of the public;
2. Mapping;
3. Training of, and information to architects and building contractors;
4. Mitigation and prevention;

5. Regulation and Control.

2.1 Information

Little concern and ignorance are the typical attitudes of the general population as to the radon health problem. One of the major challenges of the ongoing action programme is to inform the public and to improve its awareness of radon as a potential health risk. As a first step, a working group of the National Health Council, composed of radiation protection experts and social scientists, did formulate general criteria according to which information should be given to the public (1). The basic principle is that the information should allow everybody to take decisions based upon his own general value system.

Based upon these recommendations an information brochure was drafted. This is currently being tested upon its legibility and effectiveness in the pilot phase of the radon measuring campaign of the RPD. Meanwhile a network of Radon Centres has been set-up. Co-workers of these centres were (and still are) trained to inform and communicate with the public. In radon prone areas contact persons are looked for in every municipality.

2.2 Mapping

Detailed radon maps form an indispensable tool for the outlining of any radon policy. The major purpose of the measuring campaign of the RPD is to localize radon prone areas. Analysis of the initially available data indicated that the mean indoor concentration in Belgium is about 50 Bq/m and that some 10.000 houses are expected to have concentrations of 400 Bq/m^3 (the currently adopted action level) or more (2). As about all of these houses are expected to be situated in the southern provinces it was decided to perform about 90% of the scheduled 10.000 measurements there. In the northern regions, where radon levels are known to be low, no attention will be paid to the "natural" radon. The scheduled 1000 measurements will be concentrated in areas where, due to past or current industrial activities (mainly related to phosphates), enhanced levels of indoor radon may or could occur.

This measuring campaign is far from completed. In the pilot phase, conducted in 1995, measurements were performed in some 1000 randomly selected houses in 2 counties in the provinces of Luxemburg and Namur and in an (suspected) area in the province of Liège . Measurements did all start in the beginning of February and lasted for 3 months. In the autumn of 1995 all participants did receive a letter with their result, and information sessions were organized in the 3 selected areas. The results indicate that in some parts of these provinces up to 10% of the houses have radon concentrations above the action level. In about 2% of the investigated houses levels were in excess of 800 Bq/m^3. In all these houses control measurements have been performed. For these cases remediation has also been initiated. The neighbourhood of these high level houses is actually being investigated. More detailed measurements are in progress in the houses with levels between 400 and 800Bq/m^3. In 1996 the measuring campaign will be completed in the provinces of Luxemburg, Namur and Liège, while in 1997 the rest of the country will be addressed.

2.3 Training of, and information to architects and building contractors

An agreement has been reached with the Belgian Building Research Centre to include the training of and information to architects and building contractors in its routine tasks within 3 years. The effectiveness of different prevention and mitigation techniques will be studied in detail by this Centre.

2.4 Mitigation and prevention

Except for a few isolated cases and the initiative taken by the federal government for the houses with more than 800 Bq/m^3, no mitigation has been performed up to now. Since a few months however, householders living in dwellings in the Walloon region with levels in excess of 400 Bq/m^3 can - if they fulfill a number of conditions - obtain financial assistance for remedial work.

Contacts have been taken with the competent authorities of the Walloon region to set up a specific building code for radon prone areas and to ensure that future homes have precautions against radon.

2.5 Regulation and Control

The government considers it its duty to regularily evaluate the proficiency of any radon company in Belgium offering measurements, mitigation services, or being involved in building radon resistant constructions. Therefore appropriate protocols and an accreditation system are being prepared in collaboration with the responsible authorities at different levels.

3. Radon policy scenarios

In order to develop a rational and coherent approach and to select priorities for the governmental approach about radon, cost-benefit and multi-attribute analysis (MAA) were applied upon 4 scenarios (3). Three scenarios deal with remediation of existing situations (for levels > 1000 Bq/m^3,

> 400 Bq/m^3 and > 150 Bq/m^3) and one scenario studies the effect of preventing radon levels of more than 50 Bq/m^3 in new constructions. From the point of view of cost-benefit, all 4 scenarios are found to be highly justified. For the MAA cost, detriment, societal impact and individual perception were used as criteria. As potential government strategies the following alternatives were put forward : pay no attention at all; provide information sheets, offering risk quantifying opportunities and practical references; organise measuring and information campaigns; offer technical and financial sustenance for remediation actions; draw up specific building regulations and an action level for existing dwellings.

The result for the scenario >1000 Bq/m^3 showed that remedial actions remain highly justified. The preference for action is due to the fact that a lot of lung cancers are prevented in a small group of highly exposed persons. For the scenario > 400 Bq/m^3 on the contrary remedial actions are less justified and to draw up regulations is the most recommended policy.

4. Remark

Up to now no initiatives have been taken to systematically investigate radon at work or in schools. Surveys performed in some 1000 schools in the past by the University Ghent in the provinces of Luxemburg and Liège at the demand of the authorities over there , indicated quite clearly that radon in schools may sometimes reach high levels. Taking into account the results of the measurements in private dwellings this is not unexpected, as many of the schools in these provinces are very small and from the point of construction are not different from ordinary houses.

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MONITORING OF RADON AT WORKPLACES - FINNISH APPROACH

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Abstract
Radon and other natural radioactivity are monitored according to Finland's Radiation Act, which took effect in 1992. Since 1992 STUK has contacted 8000 private and municipal employeers and asked them to measure radon concentrations at workplaces where high radon concentrations were assumed to exist. Up to the end of 1995, 5400 radon measurements had been made at workplaces, the basic measurement method being a one-month integrating measurement. The highest radon concentrations were detected in municipal workplaces, e.g. schools, day nurseries and local government offices. About 300 orders to reduce radon concentrations were given. To date, about one-third of these have taken measures to reduce radon concentration. The mean decreace in radon concentrations is 1500 Bq/m^3.

Key words: Radon, workplace

1. History of radon measurements in Finland

The first workplace radon measurements made by the Finnish Centre for Radiation and Nuclear Safety (STUK) were on an underground excavation in the Helsinki area. The year was 1972. It was suspected that the workers had been exposed to high radon concentrations during excavation. The measured radon concentrations were between 4000 and 7000 Bq/m^3.

In the 1970s, however, the main focus was on measuring radon in mines. At that time, there were about 20 underground mines in Finland and the number of miners in them was about 1300. Later, measurements were also increasingly made in underground excavations. Occasionally measurements were also made in underground maintenance rooms, civil-defence shelters, underground control rooms and even in some offices where high radon concentrations were suspected of occurring.
Regulations for controlling radon in mines were issued in 1975 and for controlling radon in underground excavations in 1986. The Radiation Act then in effect was not applied to natural radiation, and, from the regulatory point of view, the radon monitoring did not cover all the different types of workplaces.

Extensive radon measurements in dwellings were started in the early 1980s and to date about 50 000 such measurements have been made, mainly by STUK. The country-wide coverage of these measurements has enabled all the most radon-prone areas in Finland to be identified.

The monitoring of radon at above-ground workplaces gained momentum when the new Radiation Act, which stipulates that radon at workplaces as well as other natural radiation must be monitored, took effect on January 1, 1992. The limits for radon concentrations at workplaces are laid down in Radiation Safety Guide ST 1.2 issued by STUK. The limit for radon concentrations (action level) at workplaces has been set at 400 Bq/m^3, averaged over the total number of annual working hours. Steps must be taken to reduce the concentration if it exceeds 400 Bq/m^3.

For comparison, the United Kingdom has also set a limit of 400 Bq/m^3 on exposure of workers to radon daughters expressed as a radon concentration [3,4]. The same limit is used in Sweden [7].

In its publication "Protection Against Radon-222 at Home and at Work", the ICRP recommends that the action level for radon at workplaces should be set by the national authorities within a range of 500 to 1500 Bq/m^3 [8]. The IAEA recommends that the action level for remedial measures at workplaces should be 1000 Bq/m^3 [9].

The data used in this paper are almost the same as in Annanmäki et al. [1], which presented the results of 4500 radon measurements made at workplaces. (Very similar data were also used in Oksanen et al. [6].) That paper reported that the highest radon concentrations were found in municipal workplaces, e.g. in schools, day nurseries and offices in the areas classified as the most radon-prone in Finland. The mean radon concentration in municipal workplaces was 510 Bq/m^3, as against 260 Bq/m^3 in the premises of privately owned companies.

2. Tools for radon monitoring

Monitoring is focused on radon-prone areas which have been identified on the basis of radon concentrations measured in detached houses [2]. To facilitate monitoring of radon-prone areas, the 455 municipalities of Finland were grouped into four categories. The classification was based on 25 000 radon measurements made earlier in detached one-family homes [2].

The municipalities where the highest radon concentrations were measured were put in category I, which comprises those where more than 25% of the radon concentrations measured in dwellings exceeded 400 Bq/m^3. The corresponding percentages exceeding 400 Bq/m^3 in categories II, III and IV were 10-25%, 1-10% and < 1%, respectively. There were 14 municipalities in category I, 68 in category II, 154 in category III and 224 in category IV.

At first it was thought that radon could be monitored by simply informing employers through articles published in journals and that this information would arouse their interest in the subject. This did not work out, however. Therefore a more direct approach had to be adopted.

During 1992-94 STUK contacted 8000 private and municipal employers in category I and II municipalities and asked them to measure radon concentrations at workplaces where high radon concentrations were assumed to exist.

It emerged that there was no need to measure radon concentrations in about two-thirds of the workplaces. Typical reasons for exclusion were:

- the workplace was situated in the upper floors of the building;
- the company had no employees (the owner being the only worker); and
- most of the work was done elsewhere (truck drivers, hired cleaners, building workers, etc).

By the end of 1995, about 5400 radon measurements has been made at workplaces, the basic measurement method being one-month integrating measurement using track-etch detectors [5].

3. Results

The arithmetic mean of all the workplace measurements was 270 Bq/m^3, and the maximum value measured was 16 000 Bq/m^3. In 10% of the results the radon concentration was higher than 400 Bq/m^3, leading to a re-test, remedial action or a specific request to show to the competent authority that the radon concentration during working hours was less than 400 Bq/m^3.

The number of measurements made in a building depended on its size. Usually, only one measurement was made per building. However, when the data were analysed all the results had the same weight. Note that one result from a ground-floor room does not necessarily represent the mean radon concentration of the whole building, especially in the case of an apartment building.

The highest radon concentrations were measured in local government workplaces, e.g. schools, day nurseries and local government offices. The arithmetic mean of the measured radon concentrations in these was 510 Bq/m^3, which was twice that found in the premises of privately owned companies in the same areas, i.e. 260 Bq/m^3.

The radon measurement data for different types of workplaces are summarised in Table 1. The results are largely the same as those presented earlier in Annanmäki et al. [1].

4. Remedial measures

By the end of 1994, about 300 orders to reduce radon concentration had been issued. About one-third of these have already been performed. The mean decrease in radon concentrations was 1500 Bq/m^3.

The methods used to reduce radon concentrations were:

- at sites with permeable soil and very high concentrations, one or more radon-wells were built around the building (the concept "radon well" refers to depressurization of the soil near the building);
- sub-floor depressurization;
- installing a new ventilation system and modifying or upgrading the old one;
- sealing, which was sufficient in some cases but was usually combined with other countermeasures; or
- assigning the premises a new function.

5. Conclusions

The radon concentrations at workplaces in the municipalities classified in category I were higher than those at the workplaces in the municipalities in category II, as was expected.

Most of the measurements were made in permanently occupied ground-floor rooms. The results obtained are therefore not representative of Finnish workplaces, and not even of those in radon-prone areas.

When a building was mechanically ventilated during working hours only, the radon concentration during working hours was about half the mean concentration over the long time period. Therefore an integrating measurement may highly overestimate the actual radon concentration during working hours.

The radon concentration limit (action level) of 400 Bq/m^3 did not entail an unreasonable degree of remedial action and was found to be suitable for Finnish conditions.

To make things easy we suggest that the limits be given in radon concentrations and that all measurements be measurements of radon gas concentrations.

It was found convenient to apply the same action level (400 Bq/m^3) to workplaces and dwellings.

Table 1. The radon measurement data for different types of workplaces. The table shows the arithmetic mean (AM), the number of measurements (N) and the percentages of the results exceeding 300 Bq/m^3. If the result of the first measurement was higher than 300 Bq/m^3, further actions were required. Depending on the concentration, those were a new measurement during an other season, assessment of radon concentration during working hours or remedial action. The results are shown separately for public and private premises.

	AM Bq/m^3	**N**	**Per cent exceeding 300 Bq/m^3**
Municipalities in category I			
Local government workplaces	505	426	25 %
Schools and day nurseries	531	271	34 %
Other	460	155	37 %
Businesses	255	3050	19 %
Municipalities in category II			
Local government workplaces	290	995	18 %
Schools and day nurseries	294	595	19 %
Other	284	400	17 %
Businesses	171	83	12 %

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ELÉMENTS D'INFORMATION SUR LA QUESTION DU RADON DOMESTIQUE EN FRANCE

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Résumé

Après avoir décrit le contexte français, on présente ici les données récentes sur l'avancement des campagnes de mesure du radon et sur des études de perception par la population du risque qu'il représente.

En France, la tendance est d'intégrer la question des risques entraînés par le radon dans celle de la pollution intérieure des locaux d'habitation et donc de privilégier les actions d'éducation et d'information par rapport aux approches réglementaires.

1) Le contexte national

Le Conseil Supérieur d'Hygiène Publique de France (CSHPF) a établi en 1989 un document sur le risque dû au radon et sur sa gestion intitulé « avis sur les risques liés à la présence de radon dans les habitations et l'eau » [CSHPF 1989]. Ses principales recommandations étaient les suivantes ; d'une part que soient développées des campagnes de mesure des niveaux de radon dans l'ensemble des habitations du pays, d'autre part que les études épidémiologiques sur l'impact sanitaire du radon soient poursuivies et enfin, que soient considérées des techniques simples de réduction de la concentration en radon dans les habitations où une action s'avère nécessaire.

Plusieurs organismes sont impliqués dans l'évaluation et la gestion d'un tel risque.

Au niveau central du Ministère de la Santé, un Bureau de Radioprotection a été récemment créé à la Direction Générale de la Santé (DGS). Une de ses missions est de prendre en charge le problème radon. Au niveau local, les Ingénieurs Sanitaires des Services de l'Environnement des DDASS (Direction Départementale des Affaires Sociales et de la Santé) sont situés en première ligne pour répondre aux questions qui se posent quand de fortes concentrations sont rencontrées (la question des écoles est parfois posée). Ils peuvent être sollicités aussi bien par des particuliers que par les responsables locaux. Ils ont en charge la réalisation pratique de la campagne nationale de mesure du radon dans les habitations de leur département. L'Institut de Protection et de Sûreté Nucléaire (IPSN) et l'Office pour la Protection contre les Rayonnements Ionisants (OPRI) les assistent dans cette tâche. Organisme chargé d'une mission de recherche et d'expertise dans tous les domaines concernant les besoins de protection et de sûreté nucléaire, l'IPSN, par sa participation aux études épidémiologiques aussi bien chez les mineurs d'uranium qu'en population générale, contribue à l'évaluation du risque lié au radon. Il prend également part à l'acquisition et à la diffusion des connaissances scientifiques relatives à la dosimétrie, à la mesure et à la réduction de l'exposition au radon dans les habitations.

2) La campagne nationale

Des études expérimentales de terrain avaient déjà été conduites par l'IPSN durant les années 80 afin de tester les techniques de mesure et les stratégies d'échantillonnage. La campagne nationale proprement dite a été lancée en 1992 en collaboration avec la DGS afin d'étendre les mesures dans l'habitat privé français à tout le territoire, sur la base des 96 départements métropolitains.

Le protocole de recueil des données de la campagne lancée en 1992 comporte le découpage du territoire en carrés de 7 km de côté, avec au moins une mesure qui doit s'effectuer dans la commune la plus importante. L'ingénieur sanitaire du Service de l'Environnement de chaque département est responsable de la conduite des mesures. Le maire de chaque commune concernée se charge de trouver un volontaire. Un dosimètre est posé durant deux mois dans la pièce la plus fréquentée (chambre ou salon) de l'habitation et l'ingénieur remplit sur place un questionnaire sur les caractéristiques que présente cette habitation. De 50 à 200 mesures par département ont ainsi pu être recueillies.

Des résultats de mesures seront disponibles pour tous les départements durant les premiers mois de 1996. Il sera ainsi constitué un échantillon d'environ 10 000 mesures, soit une habitation pour 2070 résidences principales en France. Une analyse a été effectuée en novembre 1995 sur 62 départements (6878 mesures). La moyenne des niveaux de radon dans les habitations pondérées par le nombre d'habitants de chaque département est de 68 $Bq.m^{-3}$. Dans 5,9 % des logements la concentration de radon mesurée dépasse 200 $Bq.m^{-3}$ et elle est supérieure à 400 $Bq.m^{-3}$ dans 1,8 % des habitations [LEADS 1995]. Ces valeurs sont susceptibles d'être modifiées par les résultats à venir, ainsi que par l'application de différents facteurs de correction tels que les variations saisonnières, la standardisation en fonction des caractéristiques et de la localisation du logement, ou la prise en compte des biais de recueil [VERGER 1993]. La figure n° 1 présente les résultats bruts des campagnes de mesure à la date du 07 mars 1996 portant sur 88 départements. Une caractéristique de la France est de présenter une grande variabilité des niveaux moyens de radon selon les régions (figure n° 1). Certains départements présentent des moyennes supérieures à 150 $Bq.m^{-3}$ (départements du Limousin, départements corses, Puy-de-Dôme, Cantal, Haute-Loire, Territoire-de-Belfort, Loire, Lozère), alors que pour le département des Landes la moyenne est de 28 $Bq.m^{-3}$. La définition de « zones » mieux ciblées pourrait faire apparaître des contrastes encore plus importants. Enfin, certaines habitations dans lesquelles on trouve plus

de 1000 $Bq.m^{-3}$ ont été recensées, et leur nombre doit avoisiner la centaine de milliers. Les valeurs élevées se retrouvent essentiellement dans les régions riches en sols volcaniques et granitiques telles que le Massif Central, la Bretagne ou la Corse.
L'IPSN envisage de lancer de nouvelles campagnes de mesures durant l'année 1996 afin soit de compléter la campagne pour certains départements, soit de mieux caractériser certaines zones à risque, notamment dans les régions citées plus haut.

3) Les attitudes du public à l'égard du risque

Pour une meilleure compréhension des attitudes du public à l'égard des risques, des enquêtes sur la perception des risques et de la sécurité sont régulièrement réalisées par l'IPSN [SYMLOG 1992, LSEES 1995]. Ces enquêtes comportent quelques questions sur le radon qui aident à estimer le niveau de connaissance et les attitudes du public à ce sujet, et à identifier les relais d'informations crédibles.

niveau de connaissance

L'enquête de décembre 1995 montre que le public méconnaît le radon et les risques qu'il représente pour la santé, puisque seulement 21 % des personnes interrogées répondent en avoir déjà entendu parler. Moins du tiers de ces dernières pense être personnellement concerné par ce problème.

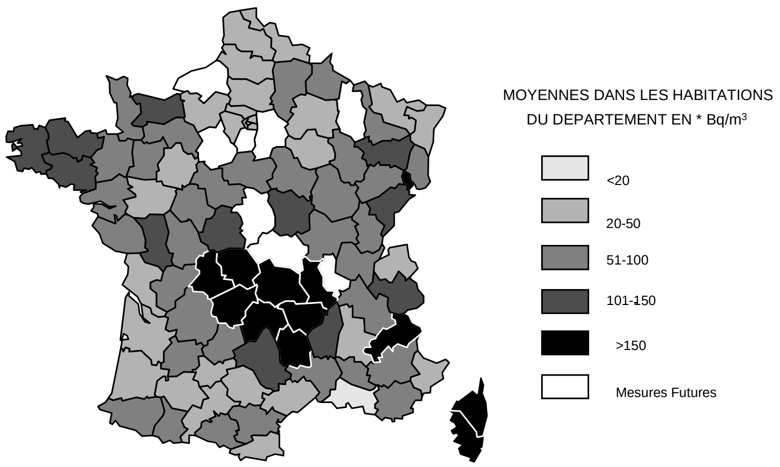
hiérarchisation

Le radon se situe très bas dans l'échelle des risques perçus par le public puisque, dans une comparaison hiérarchique de la perception des risques pour la santé, le radon vient loin derrière les déchets nucléaires, le trou de la couche d'ozone, l'exposition au stress ou les techniques de stérilisation des aliments par irradiation (figure n°2). On note cependant qu'il n'y a pas eu, en France, de campagne d'information à grande échelle, soit du grand public, soit de ses relais d'information et d'opinion.

crédibilité

Le sondage de septembre 1995 montre que 53 % des gens pensent qu'on ne leur dit pas la vérité sur l'irradiation d'origine naturelle (figure n° 3).

CAMPAGNE NATIONALE DE MESURE DU RADON DANS LES HABITATIONS FRANCAISES

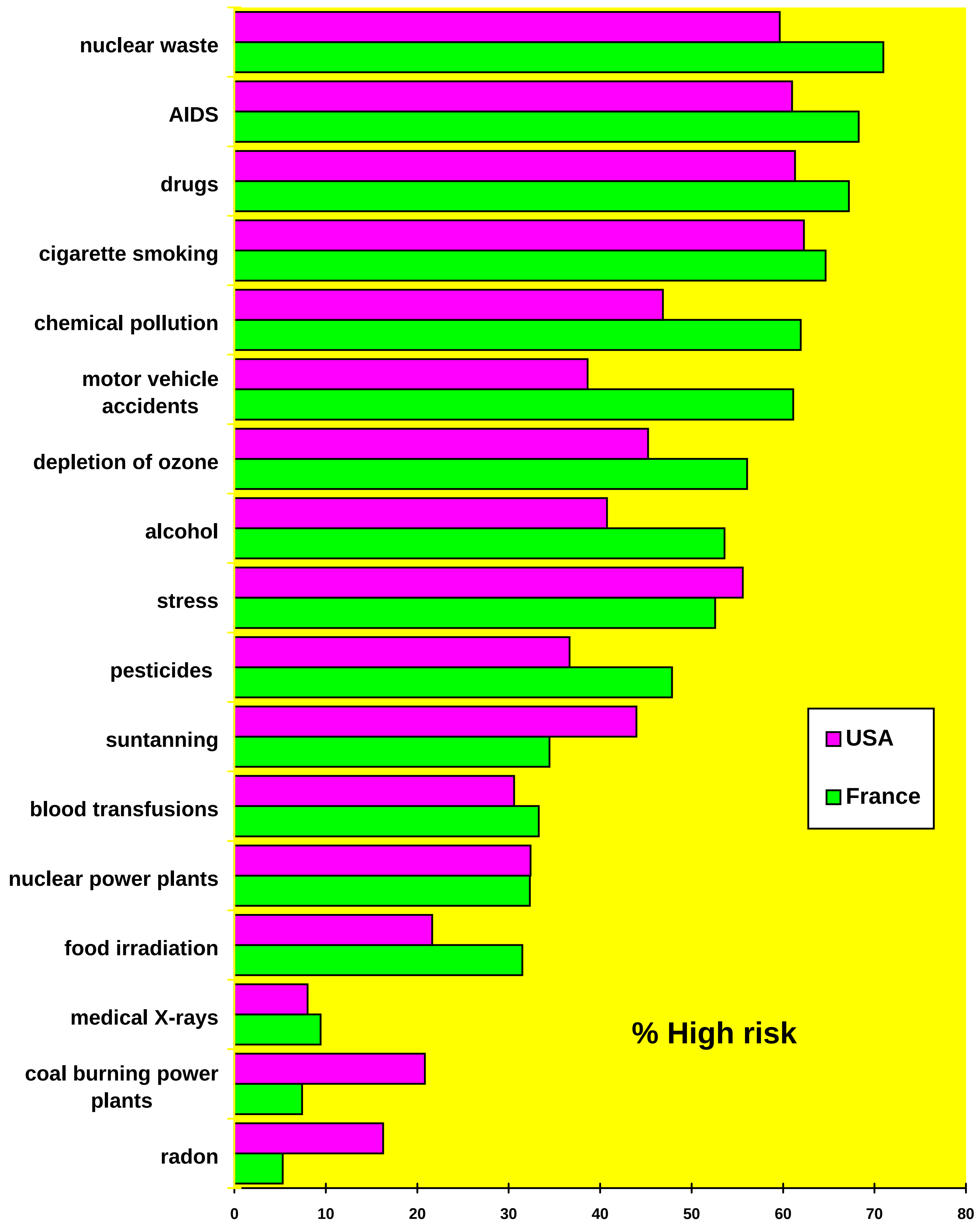


MOYENNE DE LA CONCENTRATION EN RADON DANS L'AIR DES HABITATIONS

*1 becquerel (Bq) = 1 désintégration par seconde

Bilan IPSN/SEGR de février 1996 : J.P. Gambard, Ph. Pirard, F. Lacaton

Figure n°1 : cartographie du radon en France



SYMLOG-BVA, Décembre 1992
DECISON RESEARCH-O'NEIL, Décembre 1992

Figure n° 2 : comparaison hiérarchique France USA de la perception des risques

"Dans chacun des domaines suivants, estimez-vous que l'on dit la vérité sur les dangers qu'il représente pour la population ? "

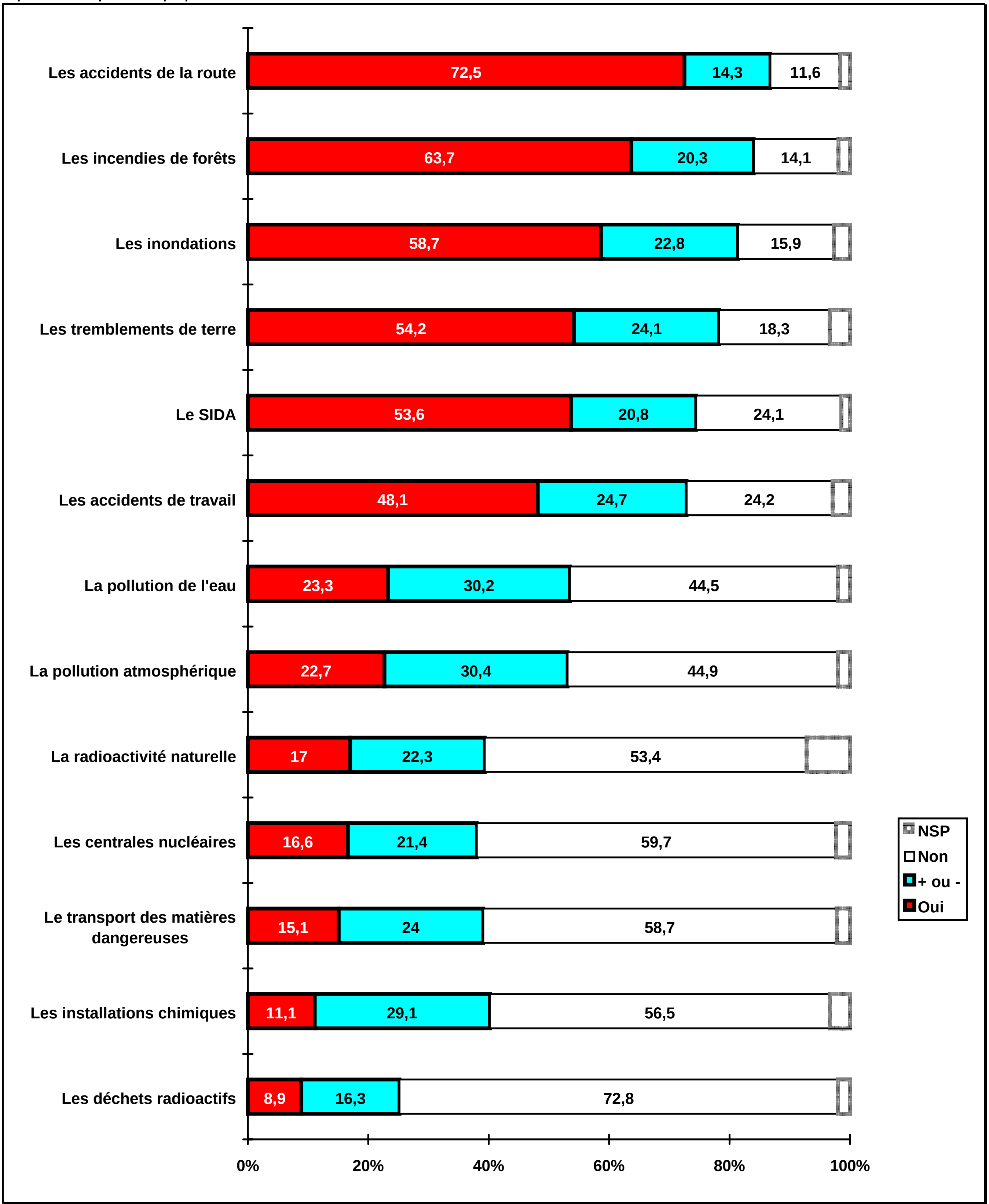


Figure n°3 : vérité dite sur les dangers

relais d'information

Pour s'informer sur la radiatioactivité naturelle les personnes interrogées au cours l'enquête IPSN s'adresseraient d'abord à leur médecin (25,4 %), puis aux services santé du département (20,1 %)(figure n° 4). Ils constituent donc des relais sur lesquels il sera possible de s'appuyer pour informer le public.

"Si vous aviez besoin de vous informer sur la radioactivité naturelle dans votre région, vous vous adresseriez d'abord":

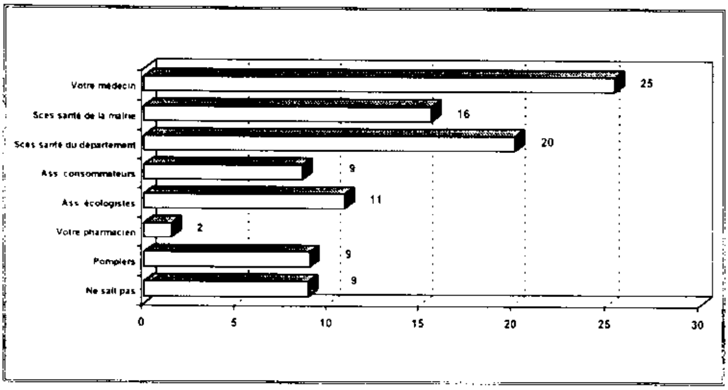


Fig. 4. informateur privilégié sur la radioactivité naturelle

attitude face aux contre-mesures

59,3% des personnes interrogées se déclarent prêtes à adopter une attitude active face à la réduction du risque en cas de résultats élevés de mesures de radon dans leur habitat. 33,8 % s'emploieraient à améliorer la ventilation et 25,5 % entreprendraient des travaux (figure n° 5).

4) Les actions d'information actuelles

Indépendamment des difficultés techniques et organisationnelles, les campagnes nationales nécessitent d'être accompagnées d'une politique de communication donnant des informations sur leurs raisons d'être, sur le risque consécutif à une exposition au radon et sur les principes de réduction de ce risque.

En tant que responsables de la campagne nationale, l'IPSN et les Services de l'Environnement des DDASS sont les premiers informateurs du public. Cette campagne est un support d'information à ne pas négliger (communications aux Préfets, formation et soutien des ingénieurs sanitaires, communication au public

"Si la concentration de radon dans votre habitation est élevée, que faites-vous?"

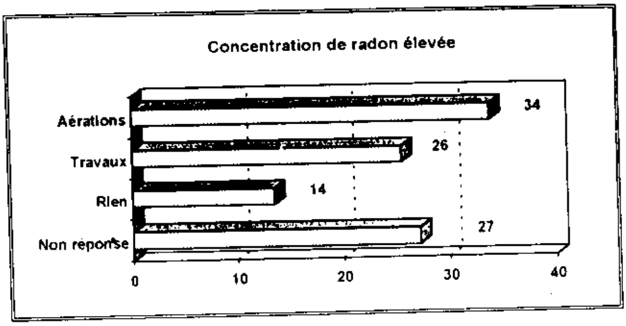


Fig. 5. Acceptabilitié des mesures de réduction du risque

par l'intermédiaire de la presse locale). L'IPSN informe de plus le public et les différents corps techniques au moyen de plaquettes sur le radon, de dossiers de presse et d'articles de vulgarisation [SEGR 1993, PIRARD 1995]. Le message principal est que des solutions techniques simples peuvent le plus souvent réduire une exposition à un niveau acceptable.

5) Conclusion

La maîtrise du risque lié au radon nécessite la mise en place d'actions variées dont l'efficacité doit être régulièrement évaluée. Elle s'inscrit dans le long terme. On a présenté ici deux aspects liés aux questions du radon dans l'habitat. D'autres travaux sont en cours, par exemple en épidémiologie ou sur l'optimisation des contre-mesures.

La phase de la campagne nationale de mesure du radon dans les habitations privées qui s'achève a permis de mieux cerner l'étendue et surtout la répartition du risque lié en France. Au vu du niveau d'information largement insuffisant du public au sujet du risque lié au radon et des retours d'expérience des politiques déjà mises en oeuvre dans d'autres pays, la conclusion est que la mise en place d'une politique active à l'égard du radon en France nécessitera une implication forte des acteurs concernés.

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Indoor radon: experiences and prospects in Italy

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Abstract
The knowledge about indoor radon concentration in the Italian dwellings and work places is briefly outlined. The National Survey on natural radioactivity in the Italian dwellings came to the conclusion that the average radon concentration is about 75 Bq/m^3 and the average gamma absorbed dose rate in air about 105 nGy/h. Considering the reference levels recommended by the E.U., about 1% of the Italian dwellings exceeds 400 Bq/m^3 and about 5% 200 Bq/m^3. At the moment in the country neither regulations nor recommendations on radon indoors are available. In the paper a proposal for a possible future recommendation is drawn.

1. Introduction

The geological nature of the Italian territory is such that elevated values of radon concentrations indoors could have been expected. In fact, two tertiary orogenic ranges cross the country: the Alps from East to West and the Apennines from North to South. The former are made of crystalline and metamorphic rocks plus sedimentary formations, the latter present a lithologic structure similar to these sedimentary formations. In both the ranges, the sedimentary formations show some tectonic mobility, strong seismicity and active faulting and folding. Finally, along the Thyrrenian coast and eastern Sicily, effusive and explosive materials, as well as small volcanoes, are present (1) .

In Italy, both the geology and hydrogeology of the territory have been investigated somewhere, using radon diffusion and emanation from the soil and these results confirmed that high radon concentrations indoors were expected. However, till now a punctual and systematic geological investigation on the Italian territory to this end has not been conducted, so that radon prone areas are not thoroughly identified.

In the eighties, many experimental surveys were set up in Italy on indoor radon, both in domestic environments and in peculiar working environments (mines, spas, etc.).

The surveys on radon concentration in domestic environments involved only a limited number of houses and the sampling procedure was not statistically representative. Their aims were mainly to identify some hot spots, to evaluate the mean radon concentrations in some zones, to identify the main sources of radon indoors, to investigate their behaviour inside the buildings, to test a methodology for a national survey, etc. (see e.g. 2, 3, 4, 5). These studies agreed in recognising that also in Italy the main source of radon concentration indoors is the soil, but that in some areas a non-negligible contribution comes from some natural building materials, like tuff and pozzolana (see, e.g. 2, 5). This fact stresses the importance of a geological investigation to single out high radon areas (6). The high activity content of some building materials, due to the presence of uranium and thorium series, had been highlighted by previous measurements and correlation was found between indoor radon and absorbed gamma dose rate in air in those dwellings where building materials play an important role as indoor radon source (5). Radon concentrations measured over the country showed a great variability and the correlation with the results of a previous gamma outdoor survey (7) was rather weak. This could be attributed to the presence of high-permeable soil in some areas. Finally, a good acceptance by inhabitants to collaborate in the frame of a radon survey in dwellings was experienced in most of the cases.

As regards working environment, Italian studies were devoted mainly to spas, underground non-uranium mines and deep caves (1), whereas only few measurements were conducted in the eighties on working places like offices, schools, etc.

2. The Italian national survey on natural radioactivity in dwellings

In 1989 a national survey on the exposure of the Italian population to natural radioactivity indoors was organised by ANPA and ISS in collaboration with local health authorities and laboratories. This survey had two main goals. First, to evaluate the mean value of indoor radon concentration and gamma absorbed dose rate in air by using a statistically representative sample, so that the average health risk of the population could be assessed. Secondly, to know the percentage of the Italian dwellings exceeding some reference levels to be fixed.

A sample of 5000 dwellings was chosen, with a two stage stratified sampling procedure (first stratum the 21 administrative districts - "Regions" - in which the Italian territory is divided, second stratum the municipalities with less or more than 10^5 inhabitants). In this way, the results of the survey would also have been representative at regional levels. The sampling proportion was one out of 4000 dwellings (8). ANPA and ISS proposed the survey to the health authorities of the 21 Regions and 19 accepted to conduct it on their territory. The local health services and radioactivity control laboratories were charged to select the dwellings and to prepare, to distribute, to collect and to process the dosemeters. ANPA and ISS chose and tested the radon measurement technique (passive dosemeters with track-etch detectors LR 115 and CR 39), prepared the measurement protocols, educational materials for both authorities and families and questionnaires to be filled on the characteristics of the dwellings and the composition and habits of the families. A careful quality assurance procedure of the various steps of the survey was set, in order to check the sample representativeness, the consistency of the data collected through the questionnaire and the quality of the radon measurements. These goals were pursued for the sampling representativeness by means of the comparison between the characteristics of the sample and those obtained from the population census, for the consistency of the data in the questionnaire performing crossed analyses of some answers and for the radon measurement quality by means of international intercomparisons of the prototypes, checks on the dosemeter assembly, national intercomparisons between regional laboratories and statistical analyses of the results of the two detectors in each room, checking their coherence (9). Final results were released in each Region generally during a meeting opened to local collaborators, authorities, families involved, general public and mass media.

The survey was completed in 1994 with a satisfactory acceptance (75%), most probably due to the door-to-door approach to the families.

The average radon concentration turned out to be relatively high (~75 Bq/m^3) and confirmed the already evidenced high variability throughout the territory (regional averages range from 20 to 120 Bq/m^3). Assuming a cosmic ray contribution of 32 nGy/h (6, 10) the average gamma absorbed dose rate in air resulted 105 nGy/h (with regional averages between 40 and more than 210 nGy/h) (1, 9). In some Regions the radon concentration versus the storey of the dwellings (decreasing significantly only from the ground floor to the first floor) and the higher levels of gamma absorbed dose rate in air supported the non-negligible contribution of building materials to the radon concentration measured. Two other useful conclusions of this survey were the assessment of the average occupancy factors of the Italian dwellings (the first assessment available) necessary for the dose calculations, and the experience of the feasibility of a national health and research project conducted in collaboration between Central Institutions and local structures (9).

The average radon 222 concentration measured in Italy implies that the average annual lung cancer risk for chronic exposure of the Italian population is about $7.5 \cdot 10^{-5}$. This evaluation is obtained using the last

ICRP (11) lung fatality coefficient of 3.10^{-4} per WLM and the assumption of an equilibrium factor of 0.4 and an average occupancy factor of the dwellings of 0.6. This fatality risk corresponds to a "conventional" annual dose of about 1.5mSv; this conventional conversion, as it is well known, is a mean to make the lung cancer risk from radon comparable to the risks from other sources of ionising radiations.

To this risk an average annual fatal cancer risk of about 2.10^{-5} should be added, if the dose contribution to the effective dose (~0.4 mSv) of the gamma absorbed dose rate in air (105nGy/h) is considered. This risk was calculated using the last ICRP dose conversion factors (12) and the coefficient for adults of 0.7 Sv/Gy (13). Some further hypotheses were made to complete the dose assessment with the contribution from the "indoors elsewhere" (9).

Following the national survey, in some Regions the indoor radon measurements were extended to other dwellings mainly in hot spot areas, or to some particular working environments like schools, kindergartens, etc. (1). At the same time also other research groups continued their studies on indoor radon in domestic environments. Finally, some investigations began in working environments, such as offices, public buildings, etc.

3. The regulatory situation: state of the art and proposals

Italy is still regulated by a nuclear law dating 1964, which does not cope with radon indoors, but only with radon in mines, due to the year of its promulgation. A new law has been recently published, which complies with the 1980 and 1984 European Directives, that is the European Basic Safety Standards, and other Euratom Directives. It will be effective on January 1st, 1996.

As regards radon indoors the new law does not introduce any change: only radon in mines is regulated and the entire problem of natural radioactivity in domestic and work environments is postponed to a future decree to be promulgated. Moreover, the E.U. 1990 Recommendation of radon in buildings (14) has not yet been adopted in Italy and therefore at the moment in the country neither regulations nor recommendations on radon indoors are available. In the following a preliminary proposals of the authors is presented.

As far as the domestic environment is concerned, the problem the Authorities have to face is the choice of the reference levels. As it is well known the 1990 Recommendation (14) quotes two reference levels: 400 Bq/m^3 for existing dwellings and 200 Bq/m^3 for future constructions. The national survey revealed that in Italy about 1% of the dwellings exceeds the first level and about 5% the second level, but in some

Regions this last percentage is up to about 10%. In the author's opinion, the choice of two different reference levels, for existing buildings and the future ones, would not be understood both by the population and the Authorities and would generate a strong debate (1). Therefore two proposals could be put forward. The first one to fix a single value of 400 Bq/m^3 both for new and old dwellings for the whole country, the second one to fix a range of levels from 200 to 400 Bq/m^3, so that the Authorities of each Region could be free to make their own choice, balancing the severity of the radon problem on the territory of the Region, with its own socio-economical situation. If this last solution was chosen, the obvious goal would be to make the higher reference level coincide or become closer to the lower one in the future. However, neither sufficient analyses nor investigations have been yet made by the Italian engineers and architects on the remedies suitable for peculiar building characteristics of the country, especially for multistorey flat blocks. This information should be available prior to making any sound choice.

For the work environment, efforts should be made to carry out remedial actions in order to lower the indoor radon concentration down to a reference level, chosen by the Authorities, as the level above which the radiation protection regulation should apply.

Moreover, authors are firmly convinced that the future Italian recommendation on natural radioactivity indoors should include financial incentives to the families to promote remediation and a limitation in the use of building materials. This limitation could foresee the application of a formula (see e.g. 15) to regulate both radioactivity concentration and radon emanation from building materials. This need came out clear in the analysis of the results of the measurements of the national survey: as previously quoted, in some zones the contribution of building materials both to radon concentrations indoors and to the total effective dose, due to their gamma irradiation, appeared evident.

Finally, a correct strategy of public information is absolutely needed, considering the extremely important role of mass media and the frequent tendency of people to perceive risk as significantly different from "real" risk. Correct information develops confidence towards Health Authorities and National and International Institutions and enhances the cultural level of a society, allowing the involvement of public in health choices. This approach was used during the Italian National Survey and resulted in a good public consensus towards the survey. It implied the decision of face-to-face contact with the families, the organisation of seminars for all the personnel involved as well as the above mentioned public meetings at the end of the survey in many Regions, the preparation of information materials for the families and the Health Authorities. The final information to families was given according to a standard format and this proved to be particularly useful to avoid contrasting approaches. This experience showed that in this way a fruitful relation can be developed with the population and the mass media come up to the expectations.

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THE RADON POLICY IN THE GRAND-DUCHY OF LUXEMBOURG

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Abstract

Currently 5000 long term integrated radon gas measurements have been realized in about 3200 dwellings in Luxembourg, covering nearly 3% of the dwellings in the country. The North of the country can be considered as a radon prone area, as more than 1 % of the monitored dwellings have a radon concentration exceeding ten times the national average value. An action level of 150 Bq/m^3 for radon in dwellings is recommended by the Ministry of Health. Some initiatives have been taken to face the problem: at the request of the householders long term integrated radon gas measurements are carried out in homes; all radon measurements are free of charge; householders who decide to take preventive measures to reduce radon in their home may get technical advice and financial support from the Ministry of Housing.

In 1989, the Ministry of Health, Radiation Protection Department, started a nationwide survey program for radon in dwellings. Using solid state nuclear track detectors from the Karlsruhe type, radon gas measurements are carried out mainly in family houses, some in schools and in workplaces.

Using a standard measurement protocol, 5000 long term integrated radon gas measurements have currently been realized in about 3200 dwellings. The detectors were mainly exposed in autumn and in winter time for a 3 month period. In addition to these measurements, information on house features, soil characteristics and the underlying lithologies were gathered.

Only a very small part of the radon measurements were carried out at the request of householders; more than 95 % of the radon detectors have been randomly distributed throughout the country with the help of the local voluntary fire brigades.

Up to this day, the screening Program covers nearly 3% of all Luxembourg dwellings, with 9% of the measured dwellings in the North of the country and 2 % in the South.

The analysis of the radon data allows a fairly good view of the variation in radon levels across our country. In accordance with the recommendations of ICRP 65, the North of the country can be considered as a radon prone area as more than 1 % of the dwellings have a radon concentration exceeding ten times the national average value. The three-dimensional map in Figure 1 clearly indicates what areas of the northern part of the country can be considered as radon affected areas.

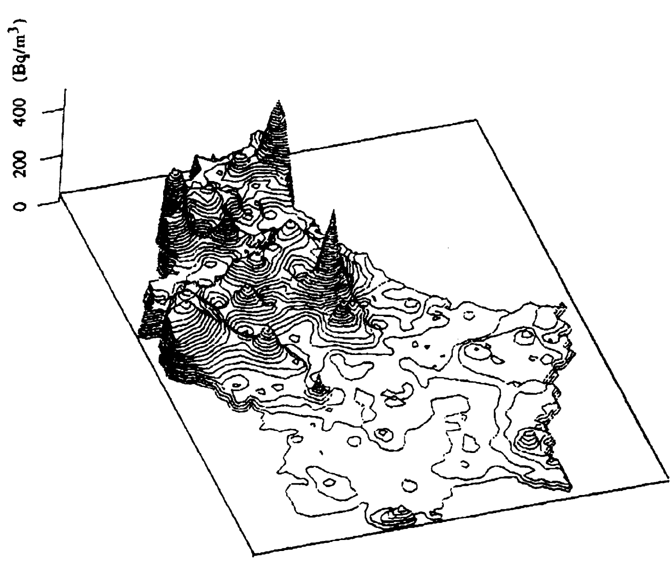

Figure 1: Surface map of radon in Luxembourg dwellings

The North of the country is situated on Palaeozoic lithologies and is part of the French-Belgian Ardennes, whereas the southern part of the country is situated on younger Mesozoic bedrocks. The difference in radon concentration in dwellings between these two regions may be partly explained by the difference in folding and dislocation of the bedrocks leading to differences in the radon availability.

Table 1 provides a summary of the radon data resulting from the national survey.

	Arith. Mean (Bq/m^3)	Geom. Mean (Bq/m^3)	% of houses > 150 Bq/m^3	% of houses > 400 Bq/m^3	% of houses > 800 Bq/m^3
Luxembourg	113	75	16.2	3.7	0.8
South	74	57	6.3	0.7	0.1
North	212	148	40.1	10.7	2.5

In the North, the mean radon gas concentration in dwellings is about 150 Bq/m^3 (geometric mean}, with maximum values up to 2000 Bq/m^3; 12 % of the Luxembourg population is living in this radon affected area.
The analysis of the radon data suggests, that 16 % or about 18000 Luxembourg homes are exceeding the action level of 150 Bq/m^3 recommended by the Ministry of Health.
This is certainly an overestimation because indoor measurements in towns with low radon concentrations in dwellings are largely under-represented and older buildings with enhanced radon levels may be over-represented.

Although the action level of 150 Bq/m^3 recommended by the Minister of Health is rather low, radon is not considered as a major issue of Public Health policy.
Regarding lung cancer risk, not radon, but the smoking habits of the population as well as the interaction of smoking and radon are considered as the main carcinogen.
Nevertheless there exists from a scientific point of view a clear evidence for the role of radon in inducing lung cancer and for this reason some measures have been taken by the Government to face the problem:

- At the request of the householders long term integrated radon gas measurements are carried out in homes by the Radiation Protection Department. These measurements are free of charge. Detectors are dispatched by post, occasionally by personal visit, return being postfree. Householders get an information leaflet with instructions concerning the correct installation of the detectors. They are asked to complete a questionnaire about exposure time, location of the detector and house features. One problem related to this way of distribution is the lack of control of the proper handling and the correct exposure conditions of the detectors.

The results of the radon measurements are automatically communicated to householders together with an appreciation of the detected radon levels. When exceeding the action level, an information leaflet about potential remedial measures is joined to the results.

The results of these measurements are absolutely confidential.

In practice, this surveying technique works well, but very few householders take the initiative to have their house monitored. Actually, only 10-20 indoor radon gas measurements per year are carried out upon request from householders.

- Householders who decide to take preventive measures in their home may get technical advice from the Ministry of Housing. Actually, only few householders availed themselves of this opportunity. This lack of feedback makes it difficult to gain practical experience on the effectiveness of the different techniques to reduce radon levels in existing houses and to prevent high radon concentrations in future houses.

- Householders taking preventive measures to reduce radon in their home may get financial support from the Ministry of Housing.
In 1979 the Government created a legal framework of premiums and subsidies granted to house owners for the renovation of their dwellings. At that time, this financial support aimed the amelioration of the heating systems, the sanitary and electric installations, the roofing, the replacement of windows etc. In 1994 the decision was taken to extend this legal frame work also on remedial measures undertaken by house owners wishing to improve the sanitary conditions by reducing radon in their homes.

The characteristics of this legal framework are as follows:

- before the preventive measures are taken, the radon concentration must have exceeded the recommended action level;
- after the remedial actions have been taken, the radon gas concentration must fall below the action limit or must have been reduced at least by 70%;
- the reduction of radon in the dwelling must be certified by long exposure-time measurements carried out by the Radiation Protection Department from the Ministry of Health.

The reduction factor of 70% has been introduced because in some houses with initially very high radon levels, it may be impossible to reach the action level, even if the corrective measures have been carried out properly.

Some other conditions must be fulfilled to get this financial support:

- the house must have been built before 1994,
- this financial support is only granted for the main residence,
- this support is only granted once for the same house and for the same house owner;
- only part of the global costs are taken into account for calculating the granted amount of money;
- the amount of the financial support is related to the financial situation of the house owner;
- the maximum amount available for remediation is limited to 70000 Belgian francs;
- work carried out by the house owner himself is taken into account and rewarded by half the commercial price.

One disadvantage of this framework is that this support is only granted once for the same house and for the same house owner. On the one side, house owners who already got this support in the past cannot benefit a second time. On the other side, house owners who are going to ameliorate older homes prefer spending the allocated money for other remedial actions than those related to radon.

In practice only few house owners requested this financial support and in most cases the financial situation of the house owners was such that they could not fulfil the requirements for obtaining this support.
For future buildings, actions may more easily be taken during the construction stage to event radon entering buildings. But it is not clear in what defined geographical areas preventive measures should be taken. For this purpose a more detailed risk mapping could help to identify radon prone areas, thus helping the authorities to fix the technical conditions for new constructions in precise areas. First results show however that the undertaking of this project is not evident.

Much effort has been undertaken in the field of radon, but practice shows that, although the public is very concerned about radiation arising from artificial radioactivity, problems related to radon are of much less concern. Information campaigns do not change anything about this unconcern because naturally occurring radiation seems not to be perceived by the public as a potential hazard.

In the light of this experience, the radon policy should perhaps be reassessed. For uranium miners the relationship between radon exposure and risk seems to be obvious.
It seems less evident to quantify this relationship for the exposure of the population.

Have the costs of this radon policy been adequately compared to the benefits in term of risk reduction? Has the current radon policy at all an influence on the collective dose?
Should not radon policy target the very high individual doses rather than try to influence the

collective dose? Are the costs for reducing radon in homes always justified compared to the overwhelming risk induced by smoking, considering that smoking is the origin in about 90 % of all lung cancers?

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RADON AND RADON POLICY: THE DUTCH SITUATION

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Abstract

The development of the Dutch policy for addressing the problem of exposure to radon in dwellings is described. The emphasis of this description is on the role the research programme on natural radioactivity as launched by the Dutch Government has played in the formulation of this policy. Furthermore, this policy is outlined in view of the Dutch environmental policy and general system of risk assessment and management. Finally a short review is given of governmental strategies in communication of radon risk to the general public and to groups involved like the local government and the building industry.

1 Introduction

Radon is a major pollutant of indoor air for most European countries. In the Netherlands, radon concentrations are considered to be relatively low. During the 1984 Dutch radon survey (about 1000 dwellings) an average concentration of 29 Bq m^{-3} was found. In the Dutch situation, radon is estimated (based on the risk evaluation of the ICRP) to cause about 900 deadly lung cancers per year among the 15 million inhabitants. This is about two thirds of the number of people killed in car accidents. It is expected that the exposure to radon will gradually increase due to the replacement of old houses by new ones with reduced ventilation to reduce energy consumption and to the use of building materials made from industrial rest products that are often enhanced in natural radioactivity. In recently built and renovated houses in the Netherlands concentrations of 50 Bq m^{-3} or higher are not exceptional any more.

As a result of the findings in Sweden and the United States that in some dwellings exposure to indoor radon concentration may result in a radiation dose to the occupants higher than dose limits set for radiological workers, the Dutch government became more and more alert to the possible risk associated with natural radioactivity. To assess these risks and to provide a scientific framework for policy development to reduce these risks the Dutch Government launched a trilogy of research programmes the first of which started in 1982.

This paper presents an historical overview of these research programmes initiated by the Dutch government and the ways the results of these programmes influenced Dutch policy on radon and have finally culminated in the recently formulated aims to reduce indoor radon concentrations in the Netherlands.

2 Radon research programmes

One of the aims of governmental policy in the Netherlands is to constrain the radiation dose to the general public within acceptable boundaries. According to the Dutch government, to achieve this aim, research on a national level and participation in international research activities is fundamental [Ho84, Ra86].

2.1 SAWORA (1982-1986)

To provide a scientific basis for governmental policy on natural radiation the Dutch government started the research programme SAWORA (Radiation aspects of the indoor environment and related radioecological problems) in the beginning of 1982. This programme was conducted by about ten university laboratories and research institutes and mainly aimed at determinating the level of the natural radiation background due to both external radiation and due to radon in and around houses. Although the natural radiation levels in the Netherlands were found to be relatively low, first estimates indicated that about 4% of the lung cancer mortally might be due to radon and the government acknowledged natural radioactivity as a potential problem for human health and the environment [Bo88].

2.2 RENA (1987-1990)

To follow up the SAWORA programme the research and policy development programme RENA (Controllable forms of natural background radiation) was initiated in 1987. In contrast with the SAWORA programme that was intended to make an inventory of the potential problem the RENA programme had is emphasis on problem solving. The research in this programme was directed at identification of sources by using newly-developed sensitive measurement equipment, modelling of radon entry routes and searching for and testing of means to lower radiation risks.

2.3 STRATEGO (1991-1995)

The SAWORA and RENA programmes led to a significant increase in knowledge on the natural radiation environment in the Netherlands. However it was stated that some uncertainties and lacunas in this knowledge still remained [Va92]. The transport mechanisms of radon in soil and houses were only partly understood; reduction techniques for indoor radon concentrations were not effective and reliable in all cases; the indoor radon situation in buildings others than dwellings still had to be assessed and also for some reduction measures a cost-benefit analysis still had to be made in order to select the most promising and acceptable mitigation techniques. For this the STRATEGO (Radiation in relation to buildings) programme was started in 1991. This programme focusses on implementation of measures for protection against radiation in dwellings as well as on research for possibilities for additional policy in the next decade.

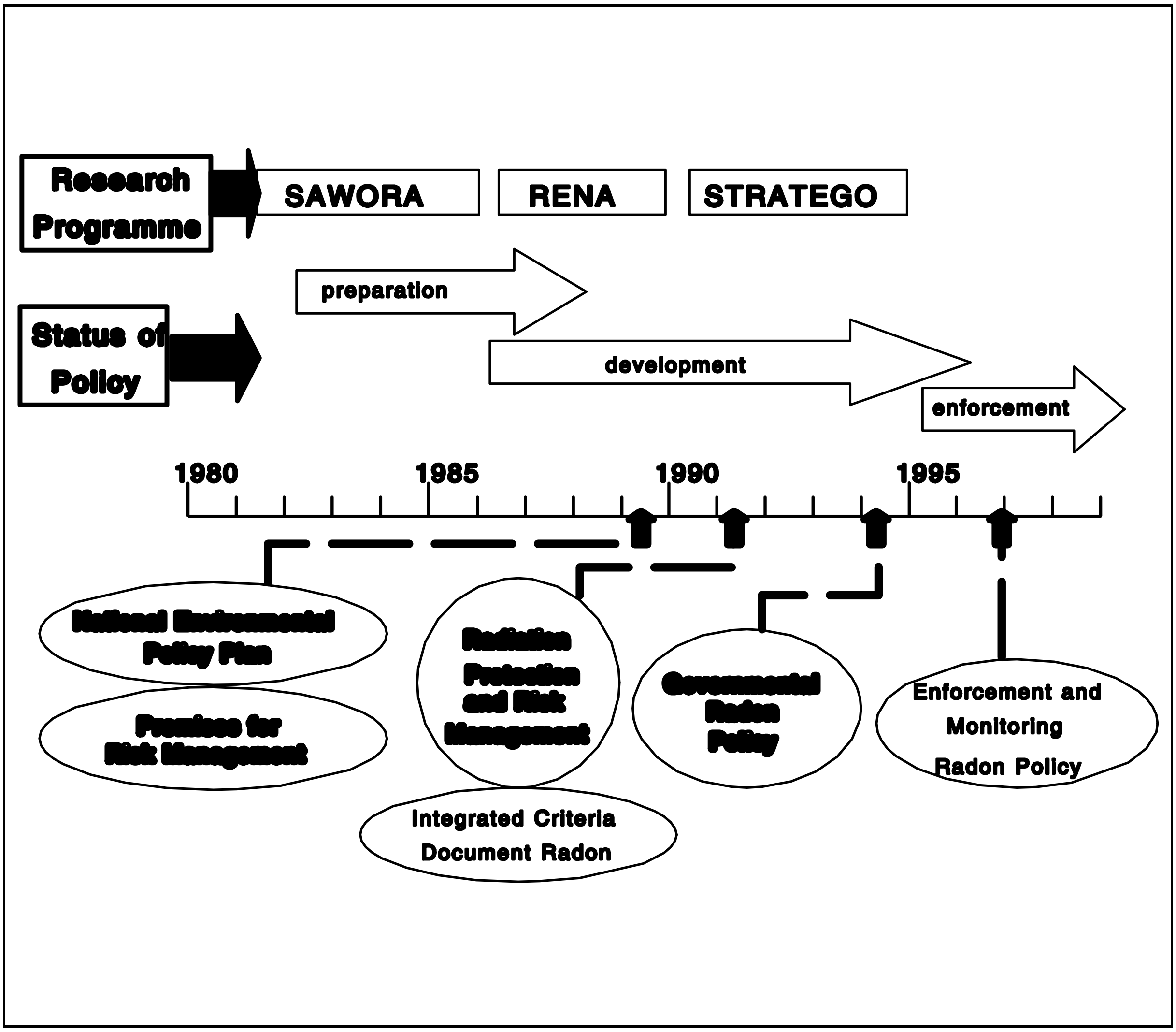

Figure 1. Overview of the governmental radon research programmes, radon policy and radon policy related documents in the Netherlands.

3 Radon policy

The Dutch policy on radon in the last fifteen years first went to a stage of preparation (assessment of the problem) and a stage of development (assessment of possible solutions). At the moment the contours of a third stage emerge that could be denoted by enforcement (assessment of implemented policy). An overview of these stages in relation with the research programmes is given in figure 1.

Actually, the real starting point of active policy development was when, in 1989, the Dutch goverment issued the National Environmental Policy Plan (NEPP) [Na89]. The medium term environmental policy strategy stated in this document is based on the concept of sustainable technology as described by the World Commission on Environment and Development (Commission Brundtland). This NEPP was the governmental response to an integrative scientific survey of the environment that gave an overview of environmental problems in the next decades [Co88]. Sustainable technology is intended to be implanted by closure of the circulation cycle of substances; reduction of and more efficient use of energy and improvement of quality of production processes to extend the economical life time of products.

As an annex to the NEPP a system of risk management was issued in the memorandum "Premises for risk management, Risk limits in the context of environmental policy" [Pr90]. This system applies to risks of human activities (so-called sources) that have a negative effect on the environment. The system is based on the definition of risks limits. This approach facilitates the comparison of different risks for various sources, and enables treatment of radiation risks in a similar manner as risks due to exposure to chemical or other agents. In the risk management system three limits are formulated. The maximum tolerable risk limit for early death for all sources is established at 10^{-5} y^{-1}. For exposure to each single source a maximum risk level is set at 10^{-6} y^{-1} and the risk due to a single source is considered to be negligible if it does not exceed 10^{-8} y^{-1}.

Between maximum tolerable and negligible risk lies a "grey" area in which risks have to be reduce as much as possible [Bo88]. As long as the risk is not negligible measures have to be taken if the disadvantages and risks outweigh the advantages of the relevant activity (ALARA). These measures should preferentially be directed against the source and only when this is not possible or very uneconomical, risk reduction measures may be taken to reduce the effect.

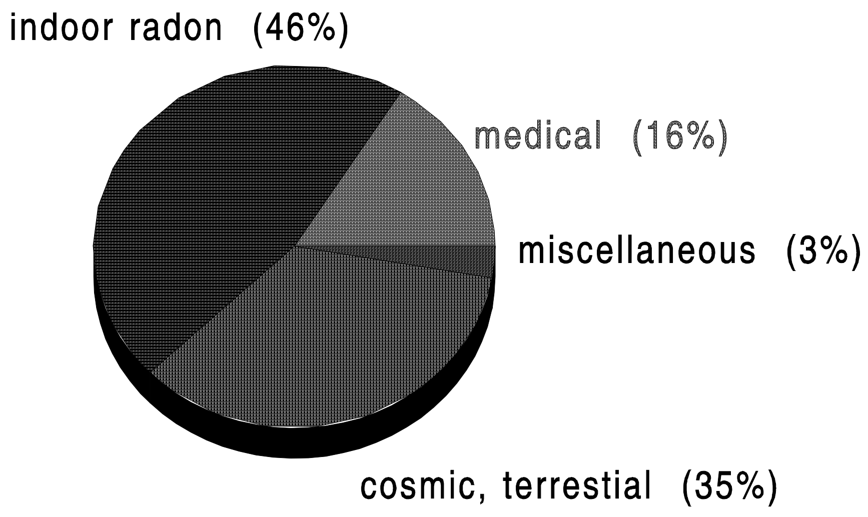

Figure 2: Contribution of various sources to the total annual radiation dose (about 2.5 mSv) in the Netherlands. Miscellaneous comprises:
funct.applications (0.5%); process industry (0.6%); radiological work (<0.1%) and others (1.9%)

NEPP states the policy for so called priority substances for which documents with basic information on the substance (integrated criteria documents) were or are being made. This policy is to reach for each priority substance a risk level smaller than the maximum tolerable risk in the year 2000 and trying to reach negligible risks whenever possible. The criteria document for radon [In91] - being one of the priority substances - was issued in 1991.

A system for radiation protection and risk management that followed the lines of the legislation formulated in NEPP was also published in 1990 [Ra90a]. This system aims at "protecting the environment, members of the general public and workers against the negative effects of exposure to ionizing radiation". In accordance with ICRP-60 [IC91], four sources of ionizing radiation are distinguished (see also figure 2): 1) functional applications; 2) non-nuclear industry; 3) sources connected to the living environment (dwellings and building techniques) and 4) other natural sources (cosmic rays, ^{40}K). For the first two sources the system of risk limits will be applied. Risks due to the last source are considered to be totally uncontrollable and these risks will not be subject to the risk management system. The risk due to the third source are regarded to be only partly controllable and application of the risk limits is considered less suitable. It was stated that the additional radiation risk related to the living environment is 2.5 10^{-5} y^{-1} (a risk factor for early death of 2.5% per sievert is assumed) and thus exceeds the maximum tolerable risk limit. The relatively high risk of especially radon in the living environment as compared to the risk of other agents, combined with the trend of increasing indoor radon concentrations in future has led the government to give priority to the formulation for legislation aimed at reduction of this risk. With respect to building materials it was stated that a so called stand-still principle would be applied. This principle should prevent the increase of radon concentrations and gamma radiation from building materials and does not permit radiation levels, due to building materials, in new buildings (including replacements) to exceed those presently found in dwellings built after 1945. For this, specific reference levels which were regarded as inevitable were set for concrete, bricks, gypsum blocks, sand-lime bricks and aerated concrete [No90]. To assess if new varieties of these construction materials comply with these levels a calculation procedure was developed to estimate the dose resulting from application of the materials [Ac84, Ra90b]. In [Ra90a] new legislation concerning both building materials and practice was announced after more research on the cost-effectiveness of reduction measures (as part of the STRATEGO programme) and after publication of the integrated criteria document for radon.

This criteria document for radon [In91] was published in 1991 and contained an overview of the knowledge on radon at that moment. It is estimated that radon causes about 900 deadly lung cancers per year (15 million inhabitants; estimated uncertainty range 450-1800). In [In91] it is argued that the risk due to radon has a component inherently linked with nature (e.g. outside radon) and a component due to human interaction with nature (building materials and practice); the first component is considered to be uncontrollable and the second component is considered to be only partly controllable. It is stated that the controllable part should be reduced but that knowledge on the cost-benefit ratio of various countermeasures is insufficient and requires further research.

The most recent aims of the policy of the Dutch Government on radon are formulated in the "Governmental Radon Policy" [Go94] that was made public in 1994. These aims are:

1) To modify the present building practice in such a way that the average radon concentration in newly built houses is less than 20 Bq m^{-3} (without modification of building practice this concentration is estimated from trend analysis calculations to become 40 Bq m^{-3} in the year 2005);

2) To adjust existing houses in such a way that the average radon concentration will not exceed 20 Bq m^{-3} (without adjustment this concentration is estimated from trend analysis calculations to become 32 Bq m^{-3} in the year 2005);

3) To prevent that the average contribution of building materials to the total radiation dose exceeds the average contribution as measured in 1984, namely 0.7 mSv per year. In 1996, after completion of a joint programme of government and the building community, a long term reduction aim will be formulated for building materials. This will probably involve standards that restrict the exhalation of radon from building materials (maximum allowable level). This aim will be formulated in the context of other policy of the Dutch government concerning, recycling, waste products, granular raw materials for building products. Furthermore, also economical considerations will be taken in to account.

The first two aims are based on results of model calculations during the RENA programme that showed that such a reduction is feasible if two measures against radon entry from the soil are taken in combination [Ba90]. These two measures are to increase the ventilation rate of the crawl space and to decrease the air permeability of the ground floor. At the moment the actual effectiveness of these two measures is being tested in a large scale study in recently built houses (as part of the STRATEGO programme).

To achieve these aims the Dutch government foresees a gradual modification of the current building practice and the usage of current building materials. According to the Dutch government these modifications will have to be implemented gradually taking into account the restriction that they should not lead to major irregularities in the market mechanisms concerning building. Moreover, product standards for building materials also need notification of the European Union. It is likely that remedial actions to reduce radon concentrations in existing houses will be combined with other curative interventions, for instance measures against humidity. Such measures should also relate to the existing Dutch Housing Act. Building codes may provide an instrument to enforce certain measures e.g. by requiring certain crawl space ventilation and/or ground floor permeability standards.
Short term Dutch policy aims at consolidating the already formulated aims for houses and the to be formulated aim for building materials into guidelines and performance requirements for the building practice. A policy document "Enforcement and monitoring radon policy" is announced for publication in 1996.

4. Communication strategies

Although the public generally tends to react strongly to hazards connected with ionizing radiation (storing nuclear waste, Chernobyl accident) [Dr93], the public perception of risk related to radon is low and not in accordance with the perception of this risk by most experts [Me94a, Me94b]. In the Netherlands public attention to the radon problem is also relatively small. An important reason for this is probably that the risks of exposure to radon has never been broadly communicated by the Dutch government to the general public. In [Go94] it is stated that radon is a great health risk that at the moment can only be reduced in a limited sense. Furthermore, the willingness to take measures (which involves a financial effort) is hindered by a lack of positive effects that are directly visible. It is foreseen that this might pose a problem for enforcing radon policy, not only for owners and users of buildings but also for the building industry. It is also stated that by careful communication if the risks, unnecessary distress amongst home owners and users should be avoided.

With respect to proposed regulations for building, the government has frequently stated that whatever these regulations, they must be accepted and understood by all parties involved, meaning that extra attention has to be paid to public relations in order to provide ample background information to the groups involved (manufacturers of building products, architects, builders, etc.) [Va92, Ju94]. The government sees discussions about monitoring and enforcement of radon policy with these groups as an integral part of its risk communication. Indeed, the recent aim about the contribution of building materials to the total radiation dose is a result of such a discussion.

An other example of direct communication with groups involved is the circular letter that was send recently by the Minister of Housing, Physical Planning and Environment to the local political authorities [Ra94]. This letter mentioned the recent finding that at some locations in the Netherlands radium concentrations in the soil were enhanced due to heightening of land with spoil and silt that had been contaminated by discharges of the process industry. It was stated that in houses built on these locations elevated radon concentration might be expected. The circular letter contained guidelines how to deal with suspect sites.

5. Discussion

The interaction between governmental policy and radon research has evaluated in time. In the beginning, during the definition of the SAWORA-programme, it was evident that little was known and to answer the question from the government namely an assessment of the national situation on natural radiation, researchers defined to a large extend the research programme. Measurements techniques were assessed and developed and, in good collaboration with the government, the research programme was carried out.

At the conclusion of the SAWORA programme researchers were still invited to participate in the discussion on the definition of the second national research programme RENA. Contrary to SAWORA, the steering board for the programme was almost exclusively the domain of governmental civil servants. The programme was kept more strict to the questions directly relevant to short time governmental policy and it was already difficult to obtain funding for more fundamental questions that were raised at the end of the SAWORA epoque.

In the present programme STRATEGO there is virtually no space for basic research anymore. Research that is carried out at the moment restricts itself to assessment studies and measurements made by engineering companies. The argument for this attitude given by the policy makers is that radon policy is in the implementation phase (the third stage in the environmental policy life cycle). However, in contrast with the definition by the former Dutch Minister of Housing, Physical Planning and Environment, Winsemius, who allowed a repetition of the cycle since new basic questions emerge in time, for the present policy makers there seems only room for research devoted to implementation questions.

To our opinion this emphasis on implementation is unwise especially in the light of the quite ambitious reduction aims of the government. We believe that to reach these aims basic research on both efficient radon reduction techniques and on low radon building materials is needed. Furthermore, a broad, integrated and multi-disciplinary approach is needed [De95] to avoid that a countermeasures against radon produces adverse effects with respect to other aspects of the indoor environment e.g. moisture, energy consumption, other indoor air pollutants etc. We also think it is advisable that the building industry participates actively in new developments to set the boundary conditions concerning manufacturing processes of building products and economical feasibility of proposed solutions.

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EXPOSURE AND LEGAL STATUS OF RADON IN POLAND

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Abstract

Measurement of radon and potential alpha energy concentrations in non-uranium mines had been initiated in Poland in the late sixties, and continued for ab. 30 years since. (Inst. Occ. Med., Lodz). Already at the early stages passive integrating methods (track etching) were introduced. As a result, mean concentrations of Rn and its daughters in the air of mines have been reduced over the years by an order of magnitude.

There has been a controversy in Poland in recent years related to assessment of the exposure to radon daughters in mines using different methods of measurements but mostly different sampling strategies (short vs. long-term measurements, selection of the sites etc.). We believe strongly that integrating methods and distribution of dosemeters among miners and preselected sites provides the least biased results.

Optimisation of protection and limitation of the exposure in mines require following factors to be taken into account:

1. Widespread and worker-oriented measurements in all mines, irrespective of mean concentrations, are economically not feasible.
2. There is, as a rule, a wide variation of the concentrations (potential alpha energy) over time and space in mines; the frequency distribution is grossly skewed and may be approximated by a log-normal distribution with a geometric standard-deviation (GSD) ranging up to 3.
3. Selection of mines, with significant exposure, to be monitored must be based upon probabilistic criteria (a given probability to exceed a preselected exposure constraint).

Current regulations in Poland do not conform with these requirements and need modification. One should aim at elaborating respective international criteria and quidelines in this field.

Intervention levels for radon concentrations in old and new houses will be based upon ICRP and BSS recommendations (200 and 400 Bq/m^3 in new and old houses, respectively). There is still a need to delineate the radon prone areas.

Procedures for attestation and intercomparison of methods for determination of radon and potential alpha energy concentrations at home and work should be worked out and given legal status.

1. History and development of radon studies in Poland

First, exploratory studies of exposure to radon had been initiated in this country in the years 1966-68 [1]. They were concerned with evaluation of the potential alpha energy concentration in selected underground mines of metal ores, coal and other raw-materials. The studies have shown that substantial exposure existed in old mines where pyrites as well as copper, iron, zinc and lead ores had been recovered. The average concentrations oscillated around 1 WL and rose quickly up to 30 WL when ventilation disturbances occurred. Occupational exposure of such magnitude called for various technical and organisational measures in radiological protection, such as:

1. Screening of the concentrations in all underground mines in the country [2].
2. Organisation and training in respective measurements of in-mine services, responsible for daily control of the working environment.
3. Selection of optimal methods for radon and daughters control and principles of interpretation of the forthcoming results from the standpoint of radiological protection.
4. Design and manufacture of a simple, battery operated, robust device for short-term measurements of radon daughters, satisfying the needs of in-mine services.
5. Elaboration of and practical implementation of a system of exposure evaluation by means of an integrating device; for all possible reasons the choice made resulted in elaboration of a method employing a passive track-etch detector [3].

These actions as well as closure of some old, poorly ventilated metal-ore mines plus development of a number of modern, very well ventilated ones gradually lead to reduction of the exposure in metal-ore recovery. The trend is demonstrated in fig. 1.

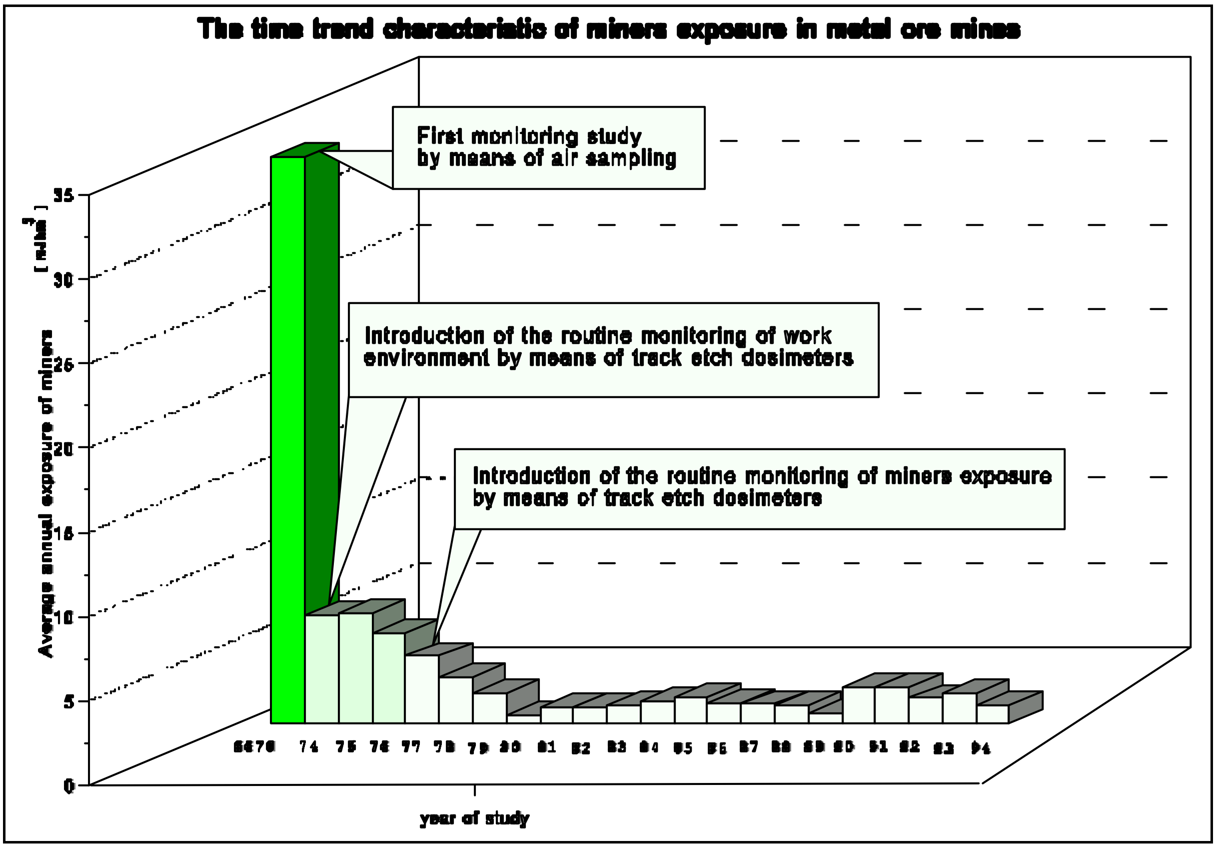

Fig. 1. Mean exposure to radon daughters in metal-ore mining in Poland in the period 1966-1994.

In the late sixties first studies had been initiated on radon concentrations in houses and apartments. This exploration had been conducted on a minor scale [4] but culminated in creation of a system aimed at the control of radioactivity of building materials [5], particularly with regard to construction of multifamily houses, utilising prefabricated elements containing fly ashes as one of the constituents. The system proved quite effective in elimination of those constituents with sum of radium, thorium and potassium activity concentrations, exceeding a predetermined level for which annual effective dose would amount to about 1 mSv and additionally the radium activity concentration of 185 $Bqkg^{-1}$.

2. Current evaluation of occupational and public exposure to radon daughters in Poland

The dominant occupational exposure to radon daughters in Poland has ben localised in various non-uranium underground mines. In 1992 there were altogether 94 such mines, employing ~ 270 thousand miners. These are predominantly very large enterprises with several thousand miners each. All the mines were surveyed for potential alpha energy concentration in the working environment. In each mine a representative group of workers had been selected who were provided with passive track-etch detectors, fixed to the helmets [6,7]. The measurements covered monthly periods at least four times in a year.

From monthly frequency distributions of recorded exposures the expected yearly distributions were computed, utilising a special simulation procedure. This enabled estimates of percentages of miners most likely exceeding yearly exposure of a given magnitude [8]. The most complete set of the data was obtained in 1992 and they are presented in table no 1 for mines of three categories (acc. to the mined raw material) [9].

Table 1. Characteristics of miners exposure to radon daughters in Poland in 1992.

CHARACTERISTIC OF MINES		RAW MATERIALS RECOVERED		
		COAL	METAL-ORE	OTHER RAW-MATERIALS
Number of mines		71	10	13
Number of miners		246580	17820	3080
Average annual exposure [WLM]		0,53	0,47	0,50
Number of miners in relevant ranges of annual exposure	[WLM]			
	<0 - 0,1>	27058	664	89
	(0,1 - 0,5>	112710	10008	2117
	(0,5 - 1,5>	97034	6883	738
	(1,5 - 3,5>	9778	265	124
	>3,5	0	0	12

Among individual mines the average exposure was varied. There are some where probability of exceeding yearly exposure of 1.5 WLM is very small or practically non existent; on the other hand there are mines where one half of the workers may surpass this level. This implies, of course, a necessity to classify the mines from the standpoint of the type and frequency of the monitoring as well as the monitoring strategy to be applied, both when working environment characteristics and individual exposure is concerned [10].

Significant occupational exposure at work was found also in several radon-rich spas [11,12]. The population of workers did not exceed 0.5 WLM per year and simple remedial action (intensified ventilation) reduced the exposure by a large factor.

Public exposure to radon in houses in Poland has not yet been sufficiently surveyed and presented. In spite of relatively early initiated explorations of the problem an essential factor in the sketchy knowledge acquired has been a lack of a comprehensive monitoring programme [13]. Numerous institutions have been surveying various regions of the country without clear prior identification of the affected (radon prone) areas.

Acc. to the available sources [14], on basis of the studies aiming at creation of a radiological map of Poland, it has been estimated that ~ 41 % of the effective per caput dose from natural sources comes from radon-daughters. From the limited data it was concluded that contribution of radon daughters to the mean effective annual per caput dose in Poland amounts to 1.4 mSv.

From the somewhat fragmentary data at hand on radon concentrations in houses and geological structure of Poland, where most of the lowland regions, dominating in the country, are situated on sedimentary rocks, sands, clay etc it appears that-apart from some, rather limited areas of mountainous character (Sudety, Beskidy; in general but not exclusively the most southern belt of the country) - the radon problem in houses does not appear as calling for intensive surveys or substantial probability of remedial actions. In selected areas, however, with expected or diagnosed higher concentrations of natural radioactivity in geological formations, the affected areas should be delineated and surveyed.

The open-air concentrations of radon have been thoroughly studied (343 points, covering the country, measurements utilising track etch detectors exposed for two 6 month cycles). The mean concentrations varied from 1.2 to 8.6 Bqm^{-3} and the country - wide mean amounted to 4.4 Bqm^{-3} [14].

3. Legal status in Poland of radon exposure at work

In spite of the fact that infrastructure in radiological protection has been in existence in Poland for a very long time the radon problem did not so far find proper legal regulation. In the atomic law of 1986 the only reflection of the problem had been an annual limit of intake for potential alpha energy from radon daughters of 0.02 J. A secondary act of 1986 specified an authorised annual limit of exposure to daughters at 3.5 WLM.

The same act introduced requirements related to the control of working environment, individual exposure measurements and specified - rather in a general way - the methods for the measurements, to be applied. The act served also as a general legal background for establishing instructions and guidance related to the strategy of the monitoring. However, in course of development the latter became different among mines where specific raw materials are being mined. This fact precluded the same procedures to be applied in mines of various technological profiles and administrative subordination. For instance, in coal mining the monitoring of the working environment had been based mainly on short term (air-aspiration of few min duration) radiometric measurements at predetermined sites in the mines. In other mines the evaluation of exposure has been based mainly on track-etched detectors, carried by representative miners there. The environmental monitoring as well as prophylactic and remedial measures were dealt with rather independently from assessment of occupational exposure of the workers.

This situation was rather abnormal and at the opportunity of modifying the general mining law in 1994-95 the radon problem was dealt with by the Ministry of Industry; as you will see shortly in a rather inopportune way. The accepted solutions - in our mind - are seriously unsatisfactory.

A classification of mining spaces has been formulated, dividing the entire working environment into areas characterised by specific levels of exposure. The areas were classified as those of so called category A and B. The latter cannot be interpreted as those corresponding strictly to those classified as <u>supervised</u> and <u>controlled</u> areas acc. to the ICRP. An inspection level was established of 400 Bqm^{-3} of Rn at ~ 0.4 equilibrium factor (a stipulated effective dose of 2 mSv/year), and lower boundaries of categories A and B at 5 and 20 mSv/year, respectively. The main issue here relates to the definition of the areas "as those where there is a possibility that miners may receive a dose exceeding ...". The act does not explain what this statement means and leaves free ground to all possible interpretations. It is well known that distribution frequency of instantaneous concentrations and of annual exposures is a highly skewed one, with a long tail towards high concentrations or exposures. A small proportion of miners may receive exposures much in excess of the median or the mode. This is a general characteristics of the mining environment and applies to a wide range of average concentrations. Therefore, such a classification appears gravely unsatisfactory. Other inadequacies of the act include:

a. nothing is being said directly about convention linking exposure to the effective dose, however, from the numbers given one can show that the ratio of 1.25 mSv per mJhm^{-3} is not the same as accepted by the ICRP [15]. This difference is unnecesary and may required create confusion,

b. introduction of obligatory personal dosimetry at possibility of effective doses > 20 mSv/a is at variance with practice in other areas of occupational exposure to ionizing radiation and with the international postulates [15,16],

c. recommended or prescribed methods for monitoring of the environment in category A and B are those based on short term measurements, what is an archaic proposition. From the nature of the concentration distribution it follows that the calculated means should be systematically lower than the real ones. This is so because high values from the tail of a log-normal distribution will be rarely encountered, however, they influence substantially the real mean.

In summary, the solutions proposed in this act are not consistent with ICRP Publ. 65, the Basic Safety Standards and forthcoming EC regulations.

In a survey of 1994 [17] using short spot-type measurements a separate set of data on exposure in the mines was obtained. The concentrations found were in general substantially lower than those found in 1992 (and previous years) employing the track etch detectors for long term assessment of integrated exposure. We believe that this discrepancy may be hypothetically linked to two factors:

1. Inherent difference in evaluation of exposure (characterized by a log normal distribution of concentrations over time and space) between short-term and integrating methods,
2. To possible subjective element playing role in selection of sites for short-term measurements [18,19].

   The issue is still unresolved and subject of forthcoming multilaboratory studies.

4. Legal status of the radon-in-house problem

In 1988 it was established within the framework of the atomic Law Act, that mean equivalent radon concentration in buildings, occupied by people and constructed after Jan 1 1995, should not exceed 100 Bqm^{-3}. However, it became apparent in 1993 that there is no material background for implementation of this legal requirement [13]. The date after which the radon concentrations shall be checked, and juxtaposed to the postulated values, has been shifted by two years. At the same time the action levels were modified to 200 Bqm^{-3} and 400 Bqm^{-3} for the new and the existing houses, respectively. The quantity was also redefined as corresponding to pure radon concentration per unit volume (irrespective of the degree of equilibrium with the daughters).

There is still a myriad of legal and organisational problems left unsolved, namely, who is supposed to order the measurements, who will pay for them and what will be the respective source of money, who will cover the expenses of remedial action, how to authorise measuring institutions (governmental, private), and finally should the measurements be obligatory (the private house or apartment is constitutionally protected from illegal intrusion).

5. Methodological problems of exposure assessment

Evaluation of exposure to ionizing radiation is generally well founded, however, there are specific problems in mines, which have been tackled with already above, relating to highly variable concentrations of Rn, variable equilibrium levels etc. The distribution frequency of potential alpha energy may be usually described as log normal with large geometric standard deviation, reaching values of up to 3 [20]. Interpretation of single selected values given as reference levels, e.g. 500, 1000 or 1500 Bqm^{-3}, for inclusion of the area as that in which the exposure should be treated as occupational, is therefore extremely difficult. What proportion of workers in an area to be classified should exceed a value of exposures derived from a Rn concentration of 1000 Bqm^{-3} to require treatment of the employed miners as occupationally exposed?

Another problem relates to the strategy of the monitoring. Short term measurements of radon or potential alpha energy concentrations do not provide, unless they cover a substantial part of the working time, satisfactory assessment of mean exposure, even at a given point in space. There are arguments [18,21,22,23] that this technique rather minimalises the exposure. We believe that utilisation of integrating methods, active or passive, is much better suited to the purpose. This postulate has found also acknowledgement in the ICRP Publ. 65 [15].

From the economic and logistic point of view it seems very unlikely that implementation of individual dosimetry for Rndp in non-uranium mines for all miners could be a fact in near future. However, an intermediate solution is to provide selected groups of miners with, passive track-etch detectors. Additionally a number of stationary point measurements in mines can also be made giving an insight into the spatial distribution of mean effective alpha energy concentrations in a large mine. The technique of evaluation is well at hand but needs careful quality assessment and quality control.

From the Polish experience it appears that external audits must play a significant role in overseeing, substantiating and evaluating the measurements performed by in-mine services. In Poland this is now a problem of financial and organisational nature.

One of the most important aspects of the radon problem is quality assessment and quality control. Gradually it has become a common knowledge, that without attestation of measurement and calibration procedures, accreditation acc. to ISO normative and periodic intercalibrations, the problem cannot be properly solved. A respective system is now in Poland in statu nascendi. Over the years several Polish laboratories have been taking part in international intercomparisons [24].

6. Further studies and general perspective

We believe that further activity in restraining exposure to excessive levels of radon daughters in Poland should concentrate on the following issues:

1. Modelling local legal requirements upon international principles (ICRP, BSS, European Union).
2. Further development of economic, accurate and precise methods enabling assessment of exposure by integrating methods, particularly by a parallel but separate measurements of the concentrations of radon and potential alpha energy of the daughters using a single device [25].
3. Development of optimal monitoring strategies for assessment of the exposure in non-uranium mines and proper selection of probabilistic criteria for categorization of mines.
4. Development and implementation of an intercalibration and attestation system for radon etc measurements.
5. In longer time perspective identification of radon prone areas, with systematic screening therein of radon exposure in houses.
6. Epidemiologic studies of lung cancer incidence (or mortality) among workers employed in mines with substantial concentrations of the potential alpha energy of radon daughters.

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RADON STUDIES IN UKRAINE: RESULTS AND PLANS OF FUTURE RESEARCHES.

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Abstract
Since 1986 studies on natural radioactivity problems have been conducting in Research Center for Radiation Medicine, Health Ministry of Ukraine. Frameworks of the studies include following directions: investigations of radon and radon daughters levels in houses, natural radioactivity of drinking water and of building materials. Volumes of investigations on every direction were determined by contribution of relevant components to the total irradiation dose.
Radon as most significant dose forming factor have been paid most attention. Integral method on the base of the passive diffusion track radonmeter was adopted as basic method for measuring radon. Nitrate cellulose radon film LR-115 II (Kodak-Pathe, France) or its analogues were used as detectors. Our own radon chamber was used for calibration.
Different types of living premises were studied throughout Ukraine. Seasonal variations of radon as well as a number of other factors influencing radon concentration were taken into account during data processing.
More than 6000 radon measurements with exposure time of about 1 month were conducted. Variations of average levels of radon effective equivalent concentration (EEC) obtained for all of 26 regions of Ukraine were found to be from 29 to 171 Bq $\cdot m^{-3}$. Results demonstrated high heterogeneity. To determine radon EEC we used equilibrium factor of F=0.45 recommended by ICRP 50. Average weighted effective dose from all natural sources in Ukraine was estimated to be about 4.2 mSv $\cdot a^{-1}$, 79% of which is due to radon.
Laboratory is provided with the equipment for measuring radon on the base of other methods. At the same time this equipment are utilized for solving a number of accompanying problems such as follows: continuous control of radon levels on the base of radon monitors AlphaGuard, RM-3, Eat Ease, Honey Well; charcoal based integral liquid scintillation counting (LSC) method; absolute radon measurement method based on LSC and Teflon vials coated with thermoplastic scintillator (Lucas chamber).
In our laboratory we worked out and developed LSC based precise ultra-sensitive methods of radon and thoron daughters determination. Investigations started aiming at determination radon daughters equilibrium factor, specific conditions in Ukraine being taken into account, as well as finding out portion of thoron daughters in forming population irradiation doses.
Future epidemiological studies with the participation of specialists of other countries are planned in accordance with international scientific programs.

INTRODUCTION

Since 1986 studies on natural radioactivity problems have been conducting in Research Center for Radiation Medicine, Health Ministry of Ukraine. Frameworks of the studies include following directions: investigations of radon and radon daughters levels in houses, natural radioactivity of drinking water and of building materials. Radon as most significant dose forming factor usually have been paid most attention. Seasonal variation, type and behavior of radon source, air ventilation as well as some other factors have contributed differently to radon EEC. Thoron daughters as a significant dose contributors are under investigation because of high variation of ^{232}Th concentration in building materials and soil in Ukraine.

METHODS

Radon measurements. Radon studies were carried for buildings of different types taking into account storey, building materials used, architectural peculiarities and many other factors. We used passive diffusion chambers method (See Fig.1) as a main method for radon measurements. Cellulose nitrate film LR-115 II (Kodak-Pathe, France) or analogous DNC (Preslavl-Zalessky, Russia) were used for continuous radon determination. Detector exposure is followed by standard etching procedure (NaOH solution). We used for radon track counting spark counter (“AIST” designed in Khlopin Radium Institute, Sent-Petersburg, Russia). Minimum detectable activity for radon gas was 8 Bq·m^{-3} for LR-115 II and 13 Bq·m^{-3} for DNC respectively for 30% confident interval and 30 days exposure time.

Our own radon atmosphere chamber was used for calibration of equipment. Radon measurement method based on LSC and Teflon vials coated with thermoplastic scintillator (Lucas chamber) are applicable as reference methods based on absolute measurements [1].

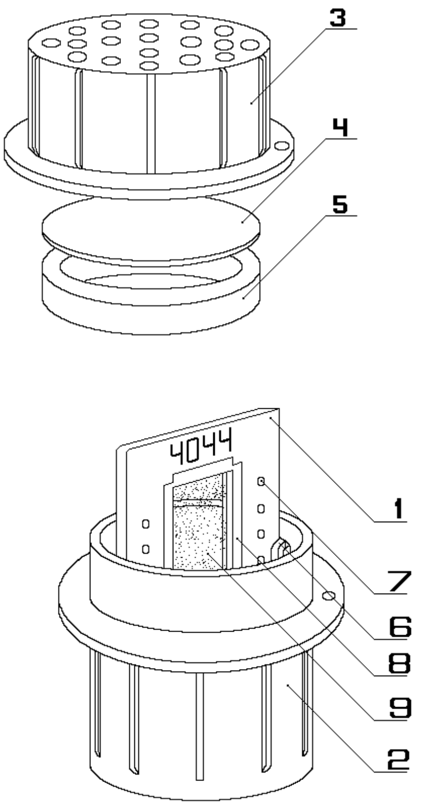

Figure 1. Passive diffusion chamber scheme. 1- film holder frame; 2- body of chamber; 3- cover of chamber; 4- aerosol filter; 5 - compression ring, 6-frame holder (way); 7- code; 8- film holder.

<u>*Continuous monitoring.*</u> We connect evaluation of the role of seasonal variations as well as some other factors of radon behavior to continuous (up to one year period) radon monitoring in different places. We used short integration period (4 hours, on the base of radon monitors AlphaGuard, RM-3, Eat Ease, Honey Well) as well as long period (exposure during one month, using passive track chamber). Peculiarities of seasonal variations were taken into account during data processing.

<u>*Screening.*</u> Charcoal based LSC method for radon determination was developed for screening purposes [2]. It allowed us to carry out integral radon measurements (during 2-7 days) with minimum detectable activity of 1 to 3 $Bq{\cdot}m^{-3}$.

<u>*Thoron.*</u> We conducted thoron gas measurements in cooperation with Japanese colleagues using passive diffusion track radonmeters [3]. Method allowed us provide simultaneous radon and thoron measurements. Film processing method we used was complicated. Investigations

of Masahiro Doi et all. [4] pointed to significant gradients for indoors thoron concentration around thoron sources. ICRP Publication 50 [5] gives us only approximate values (from 0.02 to 0.1) for thoron daughters equilibrium factor. All that shows us low precision of the estimations based on measurements of thoron gas concentrations and on using equilibrium factor range. Now we consider direct thoron daughters measurement methods.

Measurements of radon and thoron daughters. Methods for daughters measurement are more complicated. We measured radon and thoron daughters systematically only last year. We started with measurement methods. We used high volume air sampler TF1A-2 Staplex® together with aerosol filters Petrjanov fabric or paper filter (Whatman 41 or similar). For radon daughters we used modified Tsivoglou method [6, 7, 8] and ^{212}Pb measurements for thoron daughters. Basic method for filter measurements was LSC. We put air filter or its segment into LSC vial (See Fig. 2) and counted it using Quantulus 1220™, produced by Wallac, Finland. Solubility of Petrjanov fabric in solvents and moistening paper filter with solvents allows to obtain an absolute counting efficiency. Time scale for radon and thoron daughters decay for one environmental sample is shown on Fig. 3. LSC based radon daughters determination method - very precise and sensitive method - was used only for calibration purposes. It is seen that complete time scale separation between radon and thoron daughters is achieved 5 hours after sampling. That allowed us to determine thoron daughters (namely ^{212}Pb) during period from 5 to 40 hours after a sampling (during that time ^{212}Bi is in equilibrium with ^{212}Pb). We suppose that ^{212}Bi is in equilibrium while sampling as well, although its equilibrium does not matter because only 8% of working level for thoron (WLT) are defined by ^{212}Bi, rest 92% are defined by ^{212}Bi. Long time interval of 5 to 40 hours after a sampling we have for thoron daughters allowed us to monitor thoron daughters a great distance away have taken into account stationary low level LSC spectrometer we used.

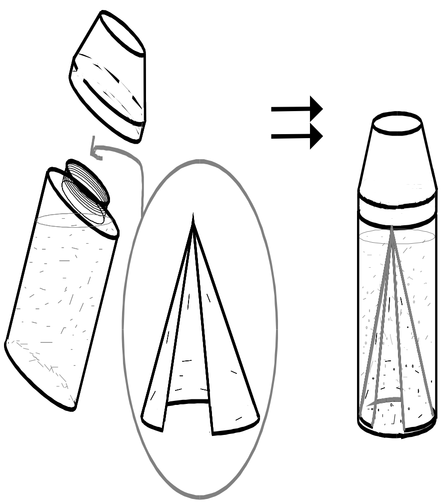

Figure 2. Manipulation with LSC vial and air filter.

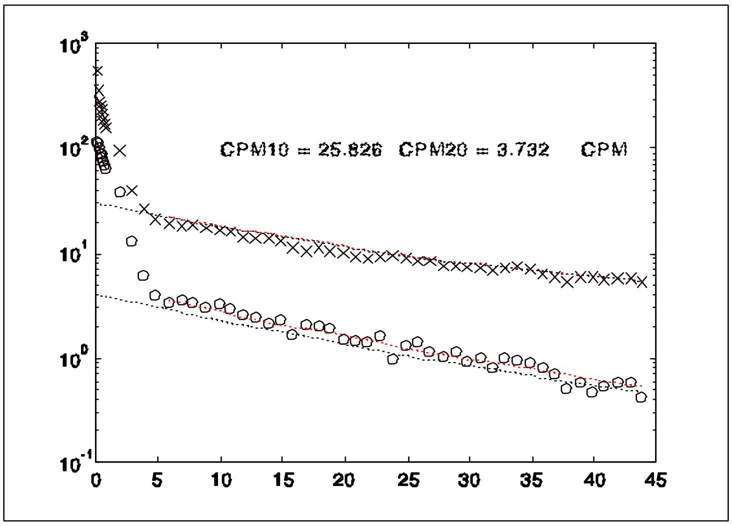

Figure 3. Time variation of alpha- (lower) and beta- count rate (upper) for air filter sample. Vertical scale - count rate (CPM), horisontal scale - time (hours).

RESULTS

Seasonal variations.

Two scale of radon integration are shown on Figure 4 and Figure 5. We used data of short time integration (Fig.4) for estimation of average and standard deviation for both year and month and also for modeling different radon measurement methods. Data presented on Figure 5 are seasonal variations of radon concentration that together with a number of other factors influencing radon concentration were taken into account during data processing.

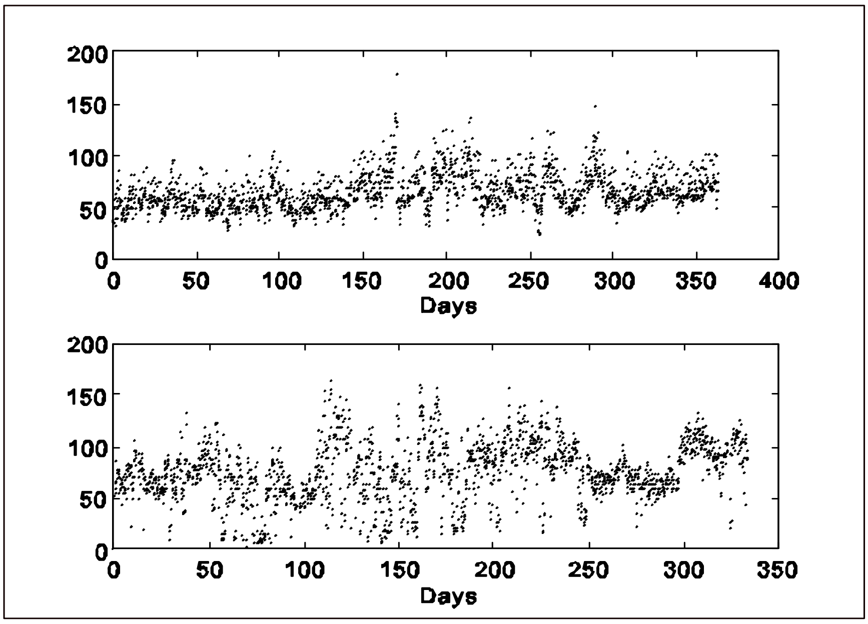

Figure 4. Seasonal variations of radon concentrations (Bq·m^{-3}) for two one-storeyed buildings (rural - upper and urban - lower chart).

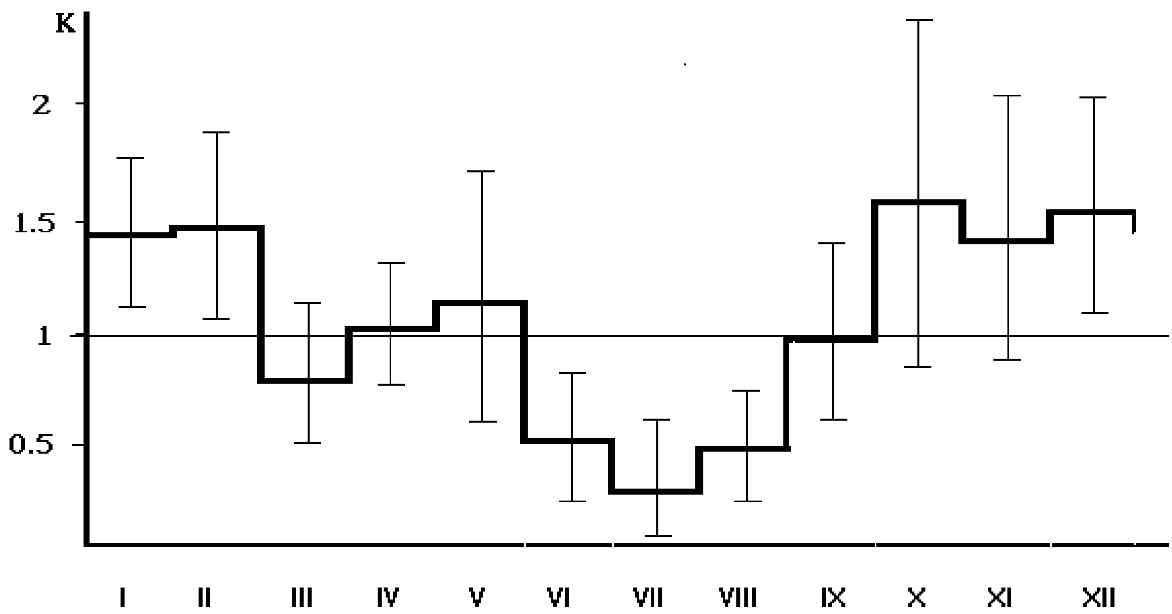

Figure 5. Seasonal variation for radon EEC averaged monthly for 13 one-storeyed buildings. Village Pogreby, Cherkassy region. Vertical scale - seasonal factor, horisontal scale - time (month).

Radon in water.

We studied water as one of possible ^{222}Rn in air contributors during April - May of 1990, in v. Mankovka, Cherkassy region [9].^{222}Rn in air variations in living rooms for two premises during several days are shown on Figure 6. The data gave us possibility to reconstruct ^{222}Rn water to air transfer factor. Figure 7 shows water bound ^{222}Rn contribution to indoor ^{222}Rn concentration for different floors and determined water to air transfer factor.

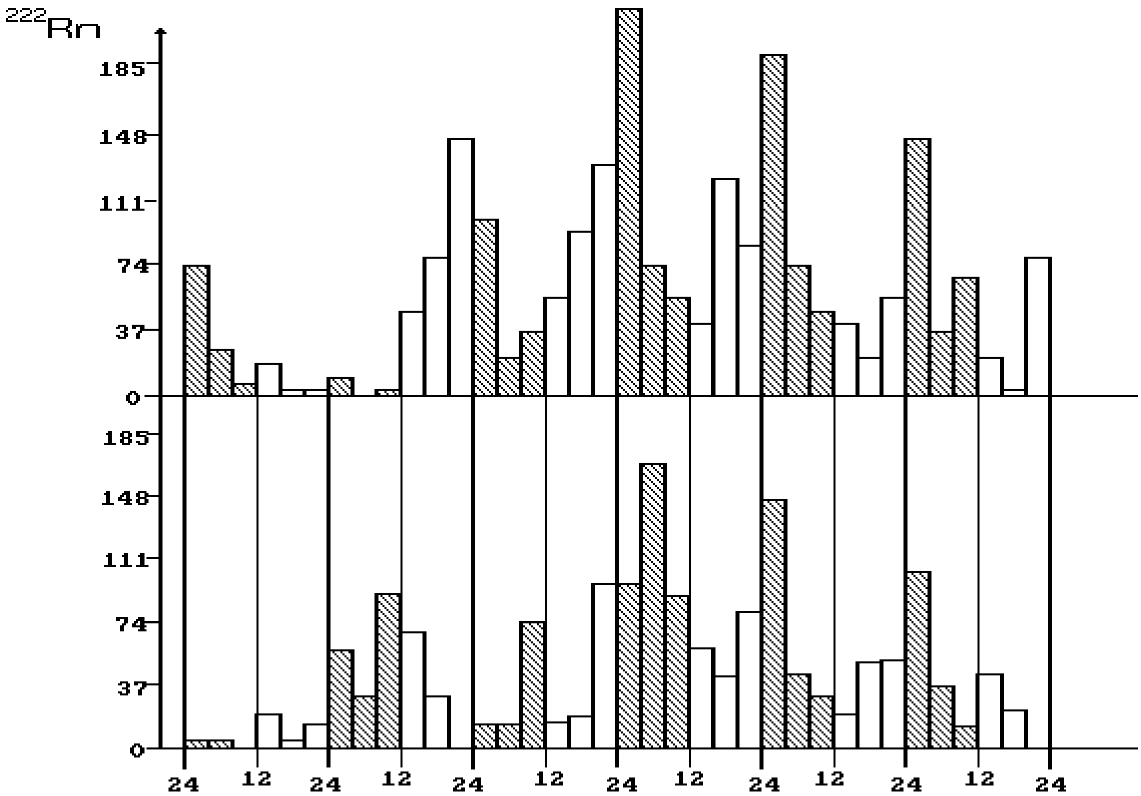

Figure 6. Indoor radon variations caused by daily water consumption regime [9]

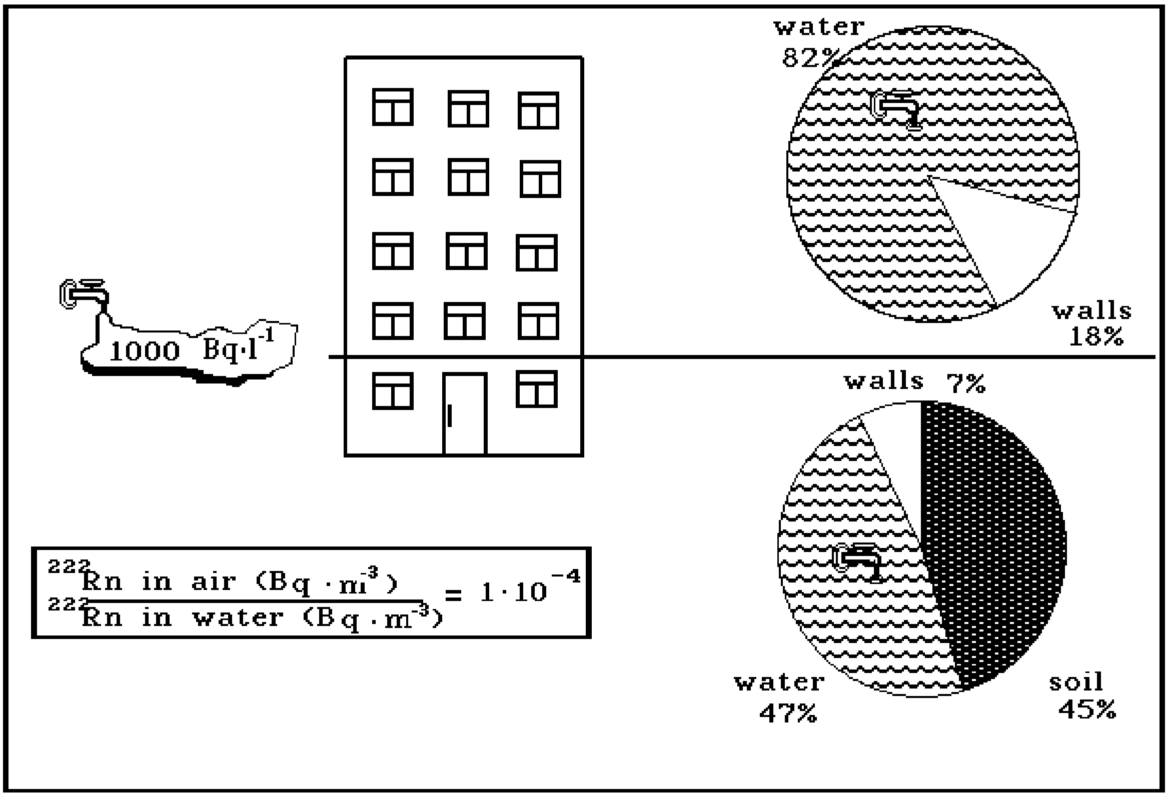

Figure 7. Contribution of water bound ^{222}Rn to indoor ^{222}Rn in air concentration (April-May 1990, v. Mankovka, Cherkassy region) [9].

Thoron

We analyzed more than 100 results of thoron gas measurements. Data distribution is good described as lognormal. Average levels recalculated for equilibrium factor f_t= 0.1 (maximum value) are presented in Table 1. It is seen significant difference for averaged values for different sampling sites. High variation for standard deviation (SD) of EEC level was observed for all of the sampling sites. Maximum level for ^{220}Rn EEC is 24.5 Bq$\cdot$m^{-3}. Average level for all the data was 5.4±4.5 Bq$\cdot$m^{-3}.

Table 1. Averaged values for thoron EEC in air for investigated living rooms in Kiev and Gitomir region (EEC and SD calculated for equilibrium factor of 0.1)

Sampling site	Average EEC ^{220}Rn, $Bq{\cdot}m^{-3}$.	SD, $Bq{\cdot}m^{-3}$
Kiev region Boguslav district, t. Boguslav	8.2	5.4
Rakitno district, v.Rakitno	2.8	3.1
v.Sinjava	1.2	2.6
Tarascha district, v. Kerdany	6.8	2.2
Gitomir region Olevsk district, v.Perga	2.0	7.5

Direct thoron daughters measurements.

^{212}Pb levels observed for two sampling sites (the rural houses in Kiev region, the same as in Table 1) are **3.5±1.6** (v.Rakitno) and **7.5±3.2** Bq·m^3 (v. Kerdany) for 20 houses in each site, that corresponds to WLT of 0.012 and 0.025 respectively. Compare with standard in force in Ukraine for ^{222}Rn EEC level in houses of 50 Bq·m^3 for new premises and 100 Bq·m^3 for existing ones (WLR=0.0135 and 0.027). We say about comparable figures for two different dose forming factors. Besides we can conclude that direct thoron EEC data are comparable with recalculated data obtained from ^{220}Rn when equilibrium factor of 0.1 was used. It showed us importance of study of thoron daughters in premises.

Population weighted average radon levels and doses.

More than 6000 radon measurements with exposure time of about 1 month were conducted. Radon EEC levels were calculated using equilibrium factor 0.45. Averaged radon EEC levels for different regions of Ukraine gave variations of 29 to 172 Bq·m^3. High levels were detected:

on the territory of Ukrainian crystalline shield;

in single-storey houses and at the ground floor in the multistory buildings;

in single-storey houses from adobe and clay without any basement;

in houses with poor ventilation of underfloor space or poor isolation;

in houses with high radon level in potable water from drilled wells.

Averaged values for all the data are present in Table 1. Dose rate and regime factors recommended by ICRP 50 were used for annual dose calculation. It is seen that main average figures (94 Bq·m^3 for single-storey houses and 28 Bq·m^3 for multistory houses) are in good accordance with our first estimation 87 Bq·m^3 and 31 Bq·m^3 respectively [10]. Average weighted effective dose from all natural sources in Ukraine was estimated to be about 4.2 mSv |a^{-1}, 79% of which is due to radon [11]. Dose pie (See Fig. 8) presented calculated population weighted radon doses as well as doses for different naturally occurred sources [9, 10, 12, 13]. BEIR IV data for thoron dose contribution relative factor of 1/3 were also taken into account for this estimation [14].

Table 2. Radon EEC distribution in dwelling houses for all Ukraine [11]

Description	**Number**	**Mean**	**Standard Deviation**
Single-storey houses (rural)	3450	94	86
Multistory houses, 1st floor	896	48	54
Multistory houses, 2nd and higher floors	511	28	45

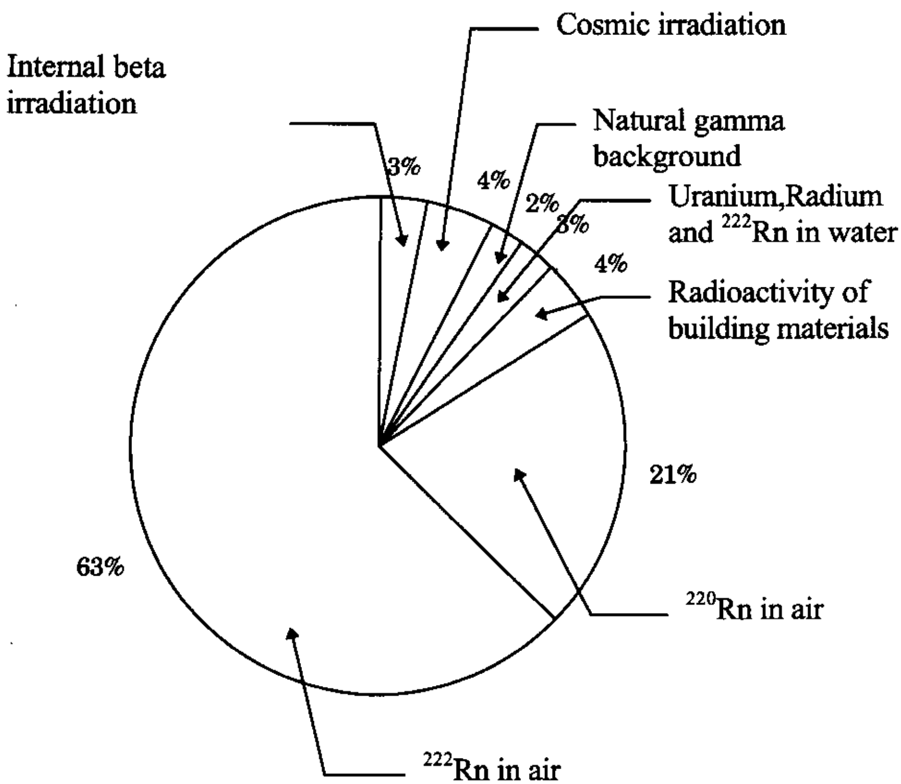

Figure 8. Natural irradiation dose pie for Ukrainian population.

CONCLUSION

Significant contribution of radon isotopes to population irradiation doses is clear. Different factors should be estimated influencing radon isotopes level in air and doses caused by radon progeny. Variations of average levels of radon effective equivalent concentration (EEC) obtained for all of the regions of Ukraine were found to be from 29 to 171 Bq.m^{-3}. First comparative measurements for ^{220}Rn and its progeny gave acceptable value of 0.1 or higher for equilibrium factor. High thoron daughter levels are expected for some regions of Ukraine. Future studies to be conducted should be related to determination of acceptable equilibrium factors fo radon and thoron daughters, determination of impact of different factors for radon and thoron daughter levels.

Future epidemiological studies with the participation of specialists of other countries should be carried in accordance with international scientific programs.

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APPENDIX

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RISK COMMUNICATION AND OUTREACH

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Abstract
Reducing the health risks posed by indoor air problems will require millions of self-initiated actions by the public, building owners and managers, and others. Effective government programs must emphasize communication and outreach to catalyze and influence actions by the millions of individuals who make decisions that affect their indoor environments. The experience of the United States of America (U.S.). Radon Program provides a compelling case study for understanding how a small staff created and leveraged a system for stimulating millions of voluntary individual behavior changes to address a major indoor air problem. This paper describes the U.S. initiative for communicating radon risks and summarizes the result achieved to date. The paper also outlines preliminary actions taken to integrate U.S. radon outreach into a broader national outreach strategy on indoor air quality.

KEYWORDS: Radon, Risk Communication, Outreach

THE RADON IN HOMES PROBLEM

Radon is invisible and ubiquitous. The U.S. Environmental Protection Agency (EPA) estimates that about 1 in 16 homes in the United States have average radon levels above 4 picocuries per liter of air (pCi/l), the recommended action level in the U.S. for deciding whether radon levels in a home need to be mitigated (U.S. EPA, Radon Division, 1992a). These levels of indoor radon have been found in all kinds of homes throughout the United States, even in areas with generally low potential for radon problems.

The U.S. EPA estimates that there will be more cancer deaths due to radon exposure than cancer deaths caused by any other source of environmental pollution. Radon is the second leading cause of lung cancer, after smoking, in the U.S.A. based on studies by the National Academy of Sciences, the National Cancer Institute, the U.S. Centers for Disease Control, and others. In 1990, the EPA Science Advisory Board (SAB), a group of distinguished scientists who provide independent scientific information and advice, examined the magnitude of many environmental problems and ranked indoor pollution, including indoor radon, as one of the four environmental problems posing the highest health risks to the American public (U.S. EPA, Science Advisory Board, 1990). Despite this scientific evidence,the public was not responding to this risk prior to the creation of EPA's Radon Action Program.

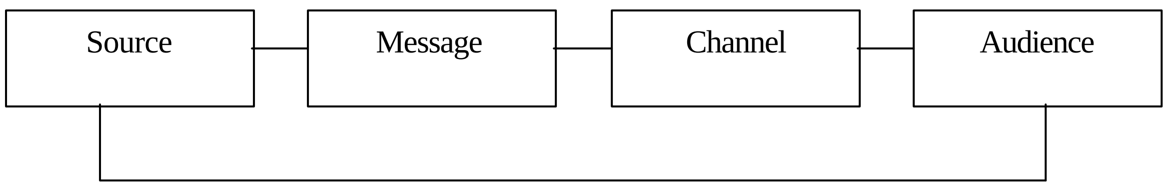
Established in 1985, the U.S. Radon Action Program's is to reduce the health risks of indoor radon (Page, l993).   With a small staff to accomplish this goal, EPA and its partners in States an other organizations work to increase public awareness of the problem and to stimulate risk reduction activity in key target audiences and members of the public.   The program encourages citizens to test their homes and mitigate high radon levels, but provides no government funding either for testing or mitigation.

EPA's PROGRAM TO ACHIEVE VOLUNTARY CITIZEN ACTION USING A DECENTRALIZED SYSTEM FOR REACHING DIVERSE PUBLICS

Consistent and accurate communication is critical to the success of a health protection program like the Radon Program that relies on millions of individuals' actions to achieve risk reduction.   A decentralized communications network is essential for reaching the diverse audiences potentially at risk from indoor radon.   This section first describes the traditional communications progress; it then outlines and highlights how EPA and others are cooperating to cost effectively achieve millions of voluntary actions to reduce radon health risks.

Basic Communications Model

The basic communications model has five major components (see Figure 1).   The model starts with a source (e.g. government agency) developing a message (e.g., "test for radon@).   The message is then delivered through selected channels (e.g., brochures, technical background documents, and press releases) to reach the intended audience (e.g., homeowners).   Feedback and evaluation from the audience (e.g., number of tests conducted) is used to refine the process until the desired effect (e.g. , actions to test homes) is achieved.



FEEDBACK EVALUATION

Fiigure 1: Basic Communication Model

The U.S. Radon program approached the design and implementation of its outreach efforts in a common sense fashion.   First, it determined what public actions were needed to reduce radon health risks.   Then it designed messages to encourage the desired actions.   The program carefully defined its target audiences and researched the sources of information likely to influence the target audiences. The program linked itself with those sources and obtained commitments from them to use their channels to obtain millions of individual actions by the public. Finally, the program has designed its efforts to provide measurable feedback and regularly adjusts its approach.

A. Designing Consistent Messages to Overcome Barriers to Action. Since its beginning, the Radon Program has worked to develop clear, user-friendly messages and to ensure consistency in radon messages. EPA, States, The Advertising Council, academic institutions, and others have conducted extensive risk communications research to learn how to overcome barriers to action on radon. This research has yielded valuable information on how to develop meaningful, actionable radon messages. These lessons have been directly incorporated into the national radon outreach program (U.S. EPA, Radon Division, 1992a).

The 1992 "Citizen's Guide to Radon" (U.S. EPA, Radon Division, 1992b) established common ground with the scientific community, the real estate industry, homebuilders, States, and other affected parties regarding the foremost radon-related messages. This consensus empowers each of these contributors to act in a coordinated manner to deliver a consistent message and secure commitments from the public to test for and mitigate radon. The basic radon message is summed up in the Surgeon GeneralFs 1988 Radon Health Advisory (see Figure 2). Each of the different organizations that cooperate with EPA on radon outreach uses variations of this basic radon message in conducting its specialized programs.

Figure 2: Surgeon General Health Advisory

"Indoor Radon is a national heath problem. Radon causes thousands of deaths each year. Millions of home.s have elevated radon levels. Homes should be tested for radon. When elevated levels are confirmed, the problem should be corrected."

B. The Audiences. Many target audiences are involved in reaching the millions of citizens, and building owners and managers who can reduce the radon risk by changing their behavior. Each audience has key Ainfluencers.@ The need is to identify *who* can be effective in reaching the public and stimulating action. *Who* says it is as important as *what* is said. These influencers include physicians, State and Local government health departments, lung health authorities, officials responsible for building codes and community safety, home inspectors, real estate agents, and others. The Radon Program targets these audiences to receive radon messages. In turn, each of these target audiences uses its own channels to deliver radon information to individual members of the public. These target audiences, like physicians and local government officials, become influential sources of information for their own target audiences such as their patients and local constituents respectively. This means that the public ends up receiving consistent messages on radon from a number of influential sources, such as doctors, builders, realtors, county and city governments, teachers, and the media. Consistent messages and accurate information delivered by multiple sources through multiple channels repeats and reinforces the need for Public action (see figure 3).

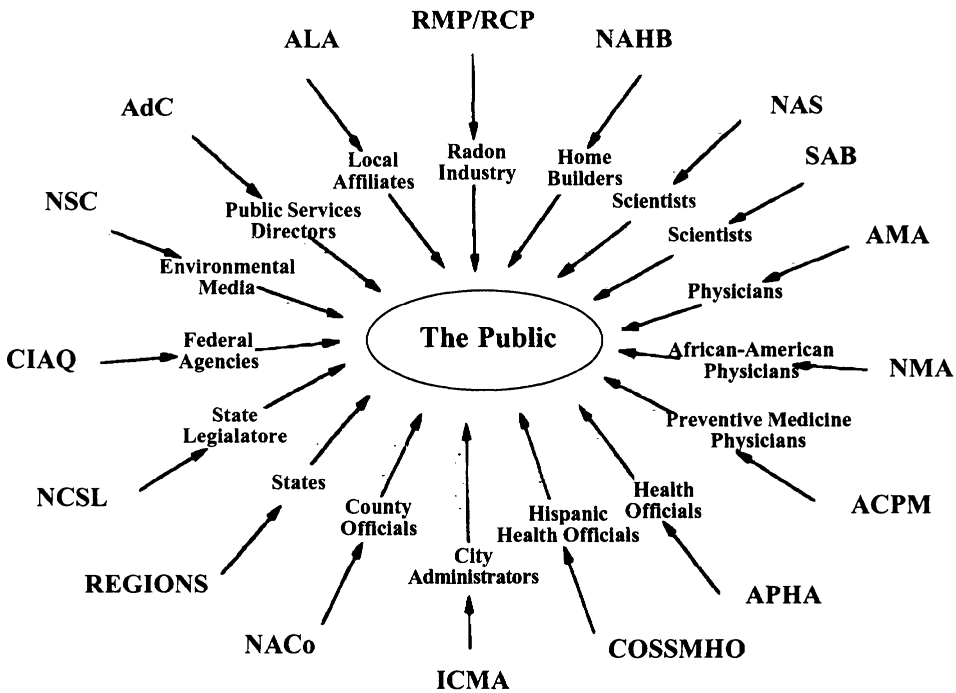


Figure 3: Radon Communications Network Repeats and Reinforces Need for Action

C. Multiple Respected Sources of Communication and Outreach. Once a target audience is identified, the next key step is to develop cooperative alliances with sources connected to these key target audiences. EPA recognizes, for a variety of reasons, that multiple, respected sources are needed to effectively communicate about radon risks. Multiple sources can better access many of the diverse audiences (e.g., African Americans, Hispanics, Asian Americans, Indians home owners, renters, the elderly) who must be reached with radon information. Sources similar to their target audiences have enhanced access and credibility. For example, EPA has teamed up with the National Medical Association and National Coalition of Hispanic Health and Human Services Organisations (COSSMHO) to address the relatively new finding that African Americans and Hispanics are not responding to radon messages at the same rate as the general population.

Enlisting numerous other sources multiplies the number of channels available for sending out radon information to the public.

EPA works with prominent leaders in each of the key ares of State government, local government, public health protection, media, and consumer protection. For example, EPA works with Radon Program contacts in all 50 States, the District of Columbia, Guam, and Puerto Rico. These contacts use their special affinity and geographic proximity to encourage radon action by their State constituents and other organizations.

Similarly, the American Medical Association, the National Medical Association, the American Lung Association, the National Association of Counties, the Consumer Federation of America, the National Association of Homebuilders, the National Safety Council, and others have joined with EPA in cooperative programs to reduce radon health risks. These cooperative partners use their expertise to reach their target audiences such as doctors, county health officials, public service directors, homebuilders, and others. These audiences become influential sources for other target audiences.

The resulting leveraged communications network, in which many respected organisations serve as sources of radon information, increases the likelihood that radon information will effectively reach different segments of the public and encourage public action to reduce risks. This leveraged approach makes it possible to clearly communicate the extensive scientific knowledge about radon to millions of citizens and empower them to make individual decisions to take actions to address the issue. Further,these decentralized sources are best positioned to quickly and easily evaluate the success of their communications efforts.

D. The Channels. A channel is a mechanism for delivering messages it is how the message gets from the source to the audience. Each State and influential national organization secures commitments for action from their target audiences through a wide variety of existing, innovative and diverse communication channels. These channels include: smoking cessation clinics; national consumer hotlines; continuing education courses for physicians, real estate agents, and home inspectors; radon education programs at national conventions; minority advertising campaigns; employer newsletters; and many others. The initiatives pursued by radon program partners through their channels can be arrayed along a continuum ranging from public information actions like distributing brochures, all the way to incentives such as discount coupons for radon detectors, and mandates to require radon resistant construction for new homes in high risk areas (see Figure 4). By leveraging source channels in these ways, radon messages cost-effectively reach millions of citizens. And, because cooperating sources already have these channels in place, the costs to society are much lower than if the government tried to create new channels of its own. Building delivery mechanisms is expensive and inefficient for government to do.

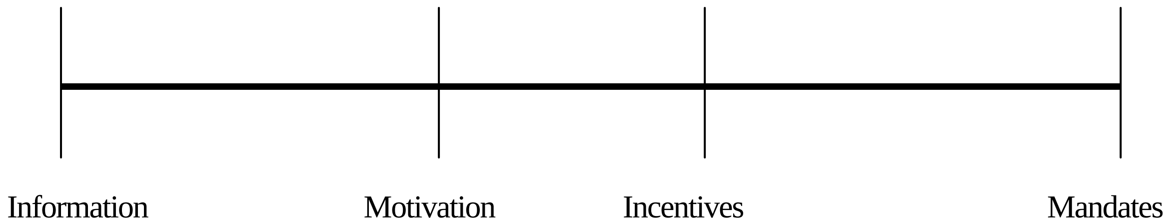


Figure 4: Continuum od Strategies

E. Feedback and Evaluation. The National Radon Program evaluates success in achieving its risk reduction mission primarily in terms of public action (e.g., homes tested, mitigated). The States, the scientific community, the radon industry, local governments, national health and consumer organizations, the federal government, and others contributing to the national Radon Program have accomplished a great deal since 1985. Surveys show that about 70 percent of the U.S. public is aware of the radon health problem (U.S. EPA, Office of Air and Radiation, and CRCPD, 1993). In addition, the Program has fostered the development of a well-trained and competent industry for radon testing and mitigation, as well as a large and diverse group of program partners that provide the public with necessary advice and assistance. Over ten million homes have been tested for radon, and three hundred thousand homes have been mitigated. Many builders now incorporate radon resistant features in new homes - about 500,000 have been built with such features --- and the first State and local radon building codes have been adopted. Regulations that require people to take action are being used by many States (Environmental Law Institute, 1992). Grassroots awareness and support have produced real estate radon disclosure laws and regulations in twenty-four States, and the real estate industry has voluntarily adopted disclosure policies in many other areas of the country. The relocation industry regularly requires a radon test and remediation, if necessary, as a condition of property transfer (Environmental Law Institute, 1992). About one-fifth of U.S. schools also have been tested for radon (U.S. EPA, Radon Division, l993). Statistics on overall U.S. radon results will be updated in the Winter of 1996.

The National Radon Program evaluates success also in terms of the number and scope of commitments by States and partner organizations to develop and carry out radon risk reduction initiatives. State, local, and professional organizations make specific commitments to take action on radon. These could include commitments to encourage radon testing (e.g., by developing or broadcasting public service announcements, through neighborhood awareness events, and so on), or to build new radon-resistant homes. By delivering on their commitments or securing desired commitments from others (e.g., homeowners, physicians, building inspectors), the National Radon Program goes beyond transferring information to accomplish the work that actually produces measurable bottom-line results. In short, the U.S. program defines success as not simply information dissemination, but as risk reduction.

INTEGRATING OTHER INDOOR AIR INITIATIVES INTO RADON OUTREACH

The U.S. EPA has already taken steps to integrate radon communications and outreach with its developing voluntary program for other indoor air contaminants. EPA's partners in radon outreach and communications have responded enthusiastically to leveraging their efforts to include other indoor air issues. Integration of radon and indoor air messages means our partners can now deal with closely related problems in a more holistic manner.

The Consumer Federation of America has developed and distributed a checklist guide for indoor Pollutants that covers biologicals, carbon monoxide, combustion products, environmental tobacco smoke, pesticides, and radon, as well as other common indoor pollutants. Similarly, the American Lung Association (ALA) is now incorporating a wide variety of these indoor air messages into their radon outreach activities; the U.S. EPA has brought indoor air issues into the scope of the regular training workshops it provides to ALA field and affiliate personnel. The Radon Program's existing partnership with ALA has also provided a platform for a joint EPA-ALA project on asthma afflicting African Americans due to indoor air contaminants. Another example: The U.S. Environmental Law Institute (ELI) has expanded its clearinghouse database beyond radon to include information about all indoor air legislation and litigation. The U.S. EPA Radon and Indoor Air programs are jointly working with the Extension Service of the U.S. Department of Agriculture to expand the communication network and conduct outreach on indoor air and radon on an integrated basis.

These new initiatives presage further collaboration between EPA's Radon and Indoor Air programs, Leading to organizational integration in the future. The placement of the Radon Program and the indoor Air Program into the same EPA office has already facilitated coordination. Greater integration can enable Radon Program partners to address the needs of the public through more holistic and cost-effective outreach approaches that more completely respond to the interests and concerns of their audiences.

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