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The 1991 International Symposium on Radon and Radon Reduction Technology

Volume I:
Government Programs and Policies Relating to Radon

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Opening Session Paper

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COMPARATIVE DOSIMETRY OF RADON IN MINES AND HOMES: AN OVERVIEW OF THE NAS REPORT

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ABSTRACT

The findings of the recent report by a National Academy of Sciences panel on radon dosimetry are reviewed. The committee was charged with comparing exposure-dose relations for the circumstances of exposures in mines and homes. The community first obtained data on the various parameters included in dosimetric lung models and then selected values that it judged to be best supported by the available evidence. Dosimetric modeling was used to calculate the ratio of exposure to radon progeny to dose of alpha energy delivered to target cells for various scenarios. The committee's modeling shows that exposure to radon progeny in homes delivers a somewhat lower dose to target cells than exposure in mines; this pattern was found for infants, children, men, and women.

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INTRODUCTION

Radon, an inert gas, is a naturally occurring decay product of radium-226, the fifth daughter of uranium-238. Radon decays with a half-life of 3.82 days into a series of solid, short-lived progeny; two of these progeny, polonium-218 and polonium-214, emit alpha particles. When radon progeny are inhaled and these alpha emissions occur within the lungs, the cells lining the airways may be injured and damage to the genetic material of the cells may lead to the development of cancer.

Radon has been linked to excess cases of lung cancer in underground miners since the early decades of the twentieth century. Epidemiologic evidence on radon and lung cancer, as well as other diseases is now available from about 20 different groups of underground miners (1,2). Many of these studies include information on the miners' exposure to radon progeny and provide estimates of the quantitative relation between exposure to progeny and lung cancer risk (2,3); the range of excess relative risk coefficients, describing the increment in risk per unit of exposure is remarkably narrow in view of the differing methodologies of these studies (2).

As information on air quality in indoor environments was collected during the last 20 years, it quickly became evident that radon is ubiquitous indoors and that concentrations vary widely and may be as high as levels in underground mines in some homes. The well-documented and causal association of radon with lung cancer in underground miners appropriately raised concern that radon exposure might also cause lung cancer in the general population. The risk of indoor radon has been primarily assessed by using risk assessment approaches that extend the risks found in the studies of miners to the general population. Risk models that can be used for this purpose have been developed by committees of the National Council on Radiation Protection and Measurements (NCRP) (4), the International Commission on Radiological Protection (5) (1987), and the National Academy of Sciences (Biological Effects of Ionizing Radiation (BEIR) IV Alpha Committee) (1).

Extrapolation of the lung cancer risks in underground miners to the general population is subject to uncertainties related to the differences between the physical environments of homes and mines, the circumstances and temporal patterns of exposure in the two environments, and potentially significant biological differences between miners and the general population (Table 1). A number of these factors may affect the relation between exposure to radon progeny and the dose of alpha-particle energy delivered to target cells in the tracheobronchial epithelium; these factors include the activity-aerosol size distribution of the progeny, the ventilation pattern of the exposed person, the morphometry of the lung, the pattern of deposition and the rate of clearance of deposited progeny, and the thickness of the mucous layer lining the airways.

The activity-aerosol size distribution refers to the physical size distribution of the particles containing the alpha activity. The term "unattached fraction" has historically been applied to progeny existing models that it judged to be best supported by the available evidence. The committee then utilized a dosimetric model, developed in part by the Task Group of the International Commission for Radiological Protection, to compare exposure-dose relations for exposure to radon progeny in homes and in mines. While the report provides the exposure-dose figures, the committee expressed its principal findings as a ratio, termed K in the BEIR IV report (1). K, a unitless measure, represents the quotient of the dose of alpha energy delivered per unit of exposure in a home to the dose per unit exposure for a male miner exposed in a mine. If the K factor exceeds unity, the delivered dose per unit exposure is greater indoors whereas if it is less than unity, the delivered dose per unit exposure is less indoors.

Factors other than lung dosimetry of radon progeny also introduce uncertainty in extrapolating risks from the studies of underground miners to the general population. The committee briefly reviewed the evidence on cigarette smoking, tissue damage, age at exposure, sex, and exposure pattern. These sources of uncertainty were considered in a qualitative rather than a quantitative fashion.

THE COMMITTEE'S FINDINGS

The committee selected several different sets of exposure conditions in homes and in mines (Table 2,3). The mining environment includes the areas of active mining, the haulage drifts, and less active and dusty areas such as lunch rooms. In some analyses, the values for active mining and haulage ways were averaged to represent typical conditions. Separate microenvironments considered in the home included the living room and the bedroom. Parameters for the living room and the bedroom were averaged to represent a typical scenario for the home. The effects of cooking and cigarette smoking on radon progeny aerosol characteristics were also considered. While the contrast between the home and mining environments was somewhat variable across the scenarios, homes were characterized as having greater unattached fractions and smaller particles. Higher average minute volumes were assumed for the mining environment (Table 2,3).

The committee also examined uncertainties associated with other assumptions in the dosimetric model. Doses to basal and secretory cells in the tracheobronchial epithelium were calculated separately, because all types of cells with the potential to divide were considered to be potential progenitor cells for lung cancer. The committee also compared the consequences of considering: lobar and segmental bronchi rather than all bronchi as the target; radon progeny as insoluble or partially soluble in the epithelium; of breathing through the oral or nasal route exclusively; of varying the thickness of the mucus lining the epithelium and the rate of mucociliary clearance; and cellular hyperplasia leading to thickening or injury causing thinning of the epithelium.

Across the wide range of exposure conditions and exposed persons considered by the committee, most values of K were below unity (Table 4). For both secretory and basal cells, K values indicated lesser doses of alpha energy per unit exposure, comparing exposures of infants, as ions, molecules, or small clusters; the "attached fraction" designates progeny attached to ambient particles (6). Using newer methods for characterizing activity-aerosol size distributions, the unattached fraction has been identified as ultrafine particles in the size range of 0.5 to 3.0 nm (6). Typically, mines have higher aerosol concentrations than homes and the unattached fraction would be expected to be higher in homes than in mines. Because of differing sources of particles in the two environments, aerosol size distributions could also plausibly differ between homes and mines.

The physical work involved in underground mining would be expected to increase the amount of air inhaled in comparison with the generally sedentary activities of time spent at home. The greater minute ventilation of miners would result in a higher proportion of the inhaled air passing through the oral route, in comparison with ventilation during typical activities in residences. The physical characteristics of the lungs of underground miners, almost all adult males, differ significantly from those of infants, children and thickness of the epithelial layer could also plausibly differ, comparing miners with the general population, because of the chronic irritation by dust and fumes in the mines.

Methods are available for characterizing the effects of these factors on the relation between exposure to radon progeny and the dose of alpha energy delivered to target cells in the respiratory tract. Using models of the respiratory tract, the dose to target cells in the respiratory epithelium can be estimated for the circumstances of exposure in the mining and indoor environments. One of the recommendations of the 1988 BEIR IV Report (1) was that "Further studies of dosimetric modeling in the indoor environment and in mines are necessary to determine the comparability of risks per WLM [working level month] in domestic environments and underground mines". The BEIR IV Report had included a qualitative assessment of the dosimetry of progeny in homes and in mines, but formal modeling was not carried out.

Consequently, the U.S. Environmental Protection Agency asked the National Research Council to conduct a study addressing the comparative dosimetry of radon progeny in homes and in mines. This paper reviews the findings of the recently published report of the committee (Panel on Dosimetric Assumptions Affecting the Application of Radon Risk Estimates). The panel was constituted with the broad expertise, covering radon measurement and aerosol physics, dosimetry, lung biology, epidemiology, pathology, and risk assessment, needed for this task.

THE COMMITTEE'S APPROACH

To address the charge of undertaking further dosimetric modeling, the committee obtained data on the various parameters included in dosimetric lung models that contributed to uncertainty in assessing the risk of indoor radon. The committee not only reviewed the literature, but obtained recent and unpublished information from several investigators involved in relevant research. After completing this review, the committee selected values for parameters in dosimetric

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children, men and women in homes with exposures of male miners underground. While the highest values of K were calculated for children, the values for children did not exceed unity, suggesting that children exposed to radon progeny are not at greater risk for lung cancer on a dosimetric basis.

The committee explored the sensitivity of the K factors to underlying assumptions in the dosimetric model. The general pattern of the findings was comparable for secretory and basal cells. The K factors remained below unity regardless of whether the radon progeny were assumed to be insoluble or partially soluble in the epithelium. The K factor was also not changed substantially with the assumption that lobar and segmental bronchi, rather than all bronchi, are the target. Assumptions regarding breathing route also had little impact. After the committee had completed its principal analysis, new data became available suggesting that recent higher values for nasal deposition reported by Cheng et al. (7) might be preferable to lower values from the 1969 report of George and Breslin (8); other new evidence suggested that a value of 0.15 um should be used for aerosol size in the haulage drifts. Inclusion of these two modifications of the committee's preferred parameter values in the dosimetric model reduced the values of K by about 20 percent.

The committee did not attempt to reach quantitative conclusions concerning sources of uncertainty not directly addressed by the dosimetric modeling. It noted the paucity of data on such factors as cigarette smoking, age at exposure and particularly the effect of exposure during childhood, and exposure pattern. The evidence on these factors received detailed review in the BEIR IV report (1) and the present committee did not reach any new conclusions on these sources of uncertainty. The committee also commented on the potential effects of the miners' exposures to dust and fumes while underground. Increased cell turnover associated with these exposures may have increased the risk of radon exposure for the miners.

SUMMARY

The Panel on Dosimetric Assumptions Affecting the Application of Radon Risk Estimates comprehensively reviewed the comparative dosimetry of radon progeny in homes and in mines. The committee's modeling shows that exposure to radon progeny in homes delivers a somewhat lower dose to target cells than exposure in mines; this pattern was found for infants, children, men, and women. This finding was not sensitive to specific underlying assumptions in the committee's modeling. Assuming that cancer risk is proportional to dose of alpha energy delivered by radon progeny, the committee's analyses suggests that direct extrapolation of risks from the mining to the home environment may overestimate the numbers of radon-caused cancers.

TABLE 1. POTENTIALLY IMPORTANT DIFFERENCES BETWEEN EXPOSURE TO RADON IN THE MINING AND HOME ENVIRONMENTS*

Physical Factors	
Aerosol characteristics	Greater concentrations in mines; differing size distributions
Attached/unattached fractions	Greater unattached fraction in homes
Equilibrium of radon/decay products	Highly variable in homes and mines
Activity Factors	
Amount of ventilation	Probably greater for working miners than for persons indoors
Pattern of ventilation	Patterns of oral/nasal breathing not characterized, but mining possibly associated with greater oral breathing
Biological Factors	
Age	Miners have been exposed during adulthood; entire spectrum of ages exposed indoors
Gender	Miners studied have been exclusively male; both sexes exposed indoors
Exposure pattern	Miners exposed for variable intervals during adulthood; exposure is lifelong for the population
Cigarette smoking	The majority of the miners studied have been smokers; only a minority of U.S. adults are currently smokers

*Taken from Table 1-2 in reference (6).

TABLE 2. ASSUMPTIONS FOR EXPOSURE SCENARIOS ASSUMED FOR MINES AND HOMES*

SUMMARY OF RADON PROGENY AEROSOL CHARACTERISTICS ASSUMED TO REPRESENT EXPOSURE CONDITIONS IN MINES AND HOMES

Exposure Scenario	f_p	AMD of Room Aerosol (μm)	AMD of Aerosol in respiratory tract (μm)
<u>Mine</u>			
Mining	0.005	0.25	0.5
Haulage drifts	0.03	0.25	0.5
Lunch room	0.08	0.25	0.5
<u>Living Room</u>			
Normal	0.08	0.15	0.3
Smoker - average	0.03	0.25	0.5
- during smoking	0.01	0.25	0.5
Cooking/vacuuming	0.05	0.02/0.15+ (15%/80%)	0.02/0.3 (15%/80%)
<u>Bedroom</u>			
Normal	0.08	0.15	0.3
High	0.16	0.15	0.3

*Based on Tables 3-1 and 3-2 in reference 6.

+The radon progeny aerosol produced by cooking/vacuuming has three size modes; 5% of potential alpha energy is unattached, 15% has an AMD of 0.02 m, and 80% has an AMD of 0.15 μm. The 0.02 μm AMD mode is hydrophobic and does not increase in size within the respiratory tract.

TABLE 3. ASSUMPTIONS FOR EXPOSURE SCENARIOS ASSUMED FOR MINES AND HOMES*

LEVELS OF PHYSICAL EXERTION AND AVERAGE MINUTE VOLUMES ASSUMED FOR UNDERGROUND MINERS AND FOR ADULTS IN THE HOME

Exposure Scenario	Level of Exertion	Average $\dot{V}_E$ (liters/min) Man	Woman
Underground Mine			
Mining	25% heavy work/75% light work	31	--
Haulage way	100% light work	25	--
Lunch room	50% light work/50% rest	17	--
Home-Living Room			
Normal and smoker	50% light work/50% rest	17	14
Cooking/vacuuming	75% light work/25% rest	21	17
Home-Bedroom			
Normal and high	100% sleep	7.5	5.3

*Based on Tables 3-1 and 3-2 in reference 6.

TABLE 4. SUMMARY OF K FACTORS FOR BRONCHIAL DOSE CALCULATED FOR NORMAL PEOPLE IN THE GENERAL ENVIRONMENT RELATIVE TO HEALTHY UNDERGROUND MINERS*

Subject Category	K Factor for Target Cells Secretory	Basal
Infant, age 1 month	0.74	0.64
Child, age 1 year	1.00	0.87
Child, age 5-10 years	0.83	0.72
Female	0.72	0.62
Male	0.76	0.66

*Taken from Table 5-1 in reference 6.

Session I:

Government Programs and Policies Relating to Radon

#5461

THE NEED FOR A COORDINATED INTERNATIONAL ASSESSMENT OF THE RADON PROBLEM

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INTERNATIONAL SYMPOSIUM ON
RADON AND RADON REDUCTION TECHNOLOGY
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The Need for a Coordinated International Assessment of the Radon Problem

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1. The radon problem - an issue of growing awareness

Radon is a natural pollutant which has been part of the human environment through all stages of evolution. However, the level of Rn-exposure has undergone various "technological enhancements" from the pre-historic days of taking up a habitat inside a cave dwelling, to the present day energy-efficient dwellings with ventilation rates below 0.3 air changes/hour.

As early as in the 1950's and 1960's individual scientists have emphasized the overriding dose contribution from radon (Rn) and its short-lived decay products (Rn-d) in comparison to those doses that the majority of their colleagues were dealing with at the time, i.e. resulting from the nuclear fuel cycle or nuclear weapon testing programmes (Hu 56, Po 65).

In the 1970's and the 1980's two series of scientific meetings stressed increasingly the importance of the radon issue, published in the form of proceedings of the US-DOE sponsored International Symposium Series "The Natural Radiation Environment", Houston (USA) and of the International Specialist Meetings held in Pocos de Caldas (Brazil), Bombay (India), Rome and Capri (Italy). During this period the first large scale national Rn surveys were conducted and regulatory guidelines issued in Scandanavia and Canada.

At the international level the Organization for Economic Cooperation and Development, Nuclear Energy Agency (OECD-NEA, Paris, France) and the Commission of the European Communities (CEC, Brussels, Belgium) reviewed all available Rn related information on metrology and dosimetry in the first half of the 1980's (OE 83, OE 85). Furthermore, CEC-NEA jointly initiated the International Intercomparison and Intercalibration Programme (IIIP), which has now been taken under the auspices of the IAEA. The CEC took a leading role in European research related to the Natural Radiation Environment (NRE) in general and in the Rn-issue in particular and supported several national programmes among its Member States (CE 80). In the second half of the 1980's the largest national Rn-research and survey programme so far has been undertaken in the USA (Co89) under the leadership of the Department of Energy (DOE) and the Environmental Protection Agency (EPA).

All internationally available information has been compiled regularly in the UNSCEAR reports. Over the past thirty years the previously seemingly invariable "constant" of 1 mSv for the average annual effective dose from all NRE sources was increased to 2.4 mSv (UN 88).

In view of the above 30+ years of evidence it is difficult to understand the statement made by the Health Physics Society in 1991, itself a most valuable source for radon-related data, ... "it was not until recently that it was realized that the largest radiation exposures received by most individuals come from the natural sources of radiation, primarily radon and its radioactive decay products " (HP91).

2. The global dimension of the radon problem

At all times everybody is exposed to radon (Rn) and its decay products (Rn-d) anywhere on earth. Therefore this topic warrants a global approach on the research and the regulatory level. In the following section some of the major international and national activities in response to the increasing significance of the Rn-problem are discussed.

2.1. IAEA-CEC coordinated research

In response to the requests from Member States of the International Atomic Energy Agency (IAEA, Vienna, Austria) and in recognition of the global concern over the Rn issue the IAEA, jointly with the CEC, initiated the Coordinated Research Programme (CRP) on "Radon in the Human Environment". The World Health Organization (WHO, Geneva, Switzerland) and the International Cancer Research Agency (IARC, Lyon, France) agreed to provide logistic support in all areas related to the assessment of potential health effects. The potential for US-EPA and US-DOE involvement in Quality Assurance Programmes and risk assessment studies of this CRP is currently being explored.

Altogether 111 projects from five continents have been recommended for a phase-wise inclusion in the CRP. In addition, 25 CEC-approved projects are part of the CRP.

The objective of the CRP is to coordinate international research efforts aimed at the quantification of the impact of environmental Rn on man. Four areas are emphasized:

a) international intercalibration and intercomparison of Rn-measurement technology;

b) standardization of large scale Rn-survey techniques;

c) institutionalised exchange of information on Rn-levels, dosimetric methods and associated risk assessment, and mitigation techniques through Research Coordination Meetings under the auspices of the IAEA;

d) establishment of an international databank on Rn. This databank would enable members of the international scientific community and national regulatory agencies to obtain structured access to the results obtained from the multiple large scale Rn-surveys, which will be performed over the next five years mainly in the USA, Canada, Africa, Europe and Asia, Provided that the input data have fulfilled certain criteria, these data sets can be used for follow-up research, ranging from optimisation of technical remedial measures to improved lung cancer risk assessment. Finally such a database facilitates the exchange of scientific and technical know-how from developed to developing countries.

The implementation of the first phase of the CRP started in 1990 by awarding 12 Research Contracts and 37 Research Agreements (Fig. 1). The second phase, concerning the acceptance of the remaining projects, is scheduled for 1992.

The CRP-Quality Assurance Programme (QAP) is an essential element of the CRP (Fig. 2). For this purpose it is intended to invite the participants in the former OECD-NEA/CEC International Intercalibration and Intercomparison Programme (IIIP), as they are: ARL (Melbourne, Australia), NRPB (Didcot, UK), EML (New York, USA) and US-BM (Denver, USA). These laboratories, well-renowned in Rn metrology, are able to act as "Reference Centres" for designated "Regional Coordinated Centres": Ministry of Public Health (Beijing, China P.R.) for the Asian-Pacific region; Institute of Radiation Protection and Dosimetry (Rio de Janerio, Brazil) for the South American region; Ghana Atomic Energy Commission (Legon, Ghana) for the African region; Institute of Atomic Physics (Sofia, Bulgaria) for the Eastern European region and Middle East; Centre of Radiation Hygiene (Prague, CSFR) for the remaining European regions.

Quality control is maintained by the interchange of Rn-detectors between Regional Coordination Centres and Reference Centres. This will involve an initial calibration and subsequent qualifying tests. The aim of the initial calibration is the establishment of calibration factors, lower limit of detection, reproducibility, accurance and linearity of the detectors used in the CRP. An exposure test regime in a Rn-chamber will include blanks, low-, medium- and high level Rn-exposure of the detectors, taking into account different climatic exposure conditions. The analysing laboratory will be informed of the actual exposure values. For the qualifying tests CRP-participants provide detectors to a Reference Centre as above, but the analysing laboratory is not informed of the exposure levels prior to the reporting of their results. This test will be repeated annually. Pre-defined criteria for passing the test will be used, e.g. the mean value for each group of exposure category would be within ± 25% of the calibration exposure (except blanks).

Surveys will be carried out in two stages. In a pilot Rn-survey all logistic and technical components for the follow-up large scale Rn-survey are tested. Secondary aims are the training of survey personnel and the establishment of the necessary national and regional programme infrastuctures. A follow-up large scale Rn-survey is aimed at determining yearly averaged indoor Rn-values using a standardized survey protocol. Since these surveys are carried out in areas with largely different climatic and socio-economic characteristics, it is necessary for the standardized format to be adopted to the local needs.

Each participant who does not already have an established integrating Rn-detection system, is provided with:

- passive open-faced track-etch detectors (material: LR 115) for short-term integrating screening measurements (exposure period: 1 week);

- passive electric-based ion chambers (material: permanently charged Teflon material) and/or passive track-etch detectors (material: CR-39) for repeated long-term integrating measurements (exposure period: 6 months).

In the pilot-type surveys, sites are selected on a pseudo-random method, based on population distributions, in one urban and one rural community each. Detectors are distributed and collected after exposure either by mail or survey teams, following the guidelines of a standardized experimental protocol. The large scale-type surveys are population-based, with statistically chosen sampling of dwellings within each

Member State. The detailed sampling method is country-specific and takes into consideration different approaches to approximate optimal randomization. The preferred method consists of a questionnaire being mailed to randomly selected individuals, together with a pre-paid, pre-addressed envelope. Upon return of the completed questionnaires, detectors are sent to those interested parties. This approach should improve the rate of active participation and maximize detector return. Optionally, the questionnaire can be completed individually by the survey team at the time of distribution of the detector in the randomly selected dwelling.

The results of the CRP are planned to be summarized in 1995 in the form of joint IAEA/CEC publications in the IAEA Safety Series and will include a summary of: a) the practical implications of the findings of the CRP, with the emphasis on international guidance on Rn control; and, b) the results of the IIIP on Quality Control organized prior to and under this CRP.

2.2. International research activities

The international research community is currently carrying out intensive Rn-ralated research. The main activities involve about 30 European research teams collaborating within the framework of the CEC Rn-programme (Si 91), approximately 50 US-institutions engaged in Federal Rn activities in the USA and worldwide additionally approximately 100 laboratories among the other IAEA-Member States. In this section some of the main Rn-related research activities outside the USA are described (the corresponding contact persons are listed in the Appendix).

a) Research in detection and analytical methods

Development of a device for continuous Rn-measurements in water, based on an integrated Rn-deemanation device and scintillation counter (A-Pi); the use of Po 210-activity on glass surfaces as an estimator for past Rn indoor exposure (A-Sa); optimisation of passive/open alpha track etch detectors for the short and long term estimation of the Potential Alpha Energy Concentration (PAEC), including thoron (Rn 220) daughters (A-An[1]); development of a low-level continuous Rn- and thoron- PAEC monitor, using α-spectroscopic analysis of Po 218, Po 214 and Po 212 (A-Ku); optimisation of a low level environmental thoron monitor, using Po 210-deposition on a surface barrier detector in a high tension field (A-Ke); thoron detection based on flow-through scintillation cells and multiple time analysis of recorded pulse events (A-Fa); simulation of rapidly changing environmental Rn/Rn-d levels with a walk-in type test facility (A-Sc); optimisation of quality assurance programmes for national indoor Rn-surveys (A-Bo); accuracy tests of integrating Rn-detectors (A-Me).

b) radon dynamics and aerosol science

behaviour of the unattached fraction in underground environments with variable aerosol concentration (A-Bu); the effect of mechanical air filtration and electrostatic precipitators on the unattached fraction and the equilibrium fraction of Rn-d indoors (A-Ko); sub-micron sized Rn-d particle size distributions in mines (A-Bol); modelling of atmospheric diffusion of Rn and thoron, describing the relationship between atmospheric concentration and the vertical diffusion coefficient (A-Cu); indoor behaviour of Rn-d in dependence of aerosol attachment, nuclide desorption from the aerosol and Rn-d plate-out on surfaces (A-Po); the effects of seasonal differences on indoor Rn (A-Pa); determination of the Rn and thoron exhalation rate and its dependence on surface cover and material temperature (A-Le, A-Al); development of rapid diagnostic techniques for determining Rn entry rates into dwellings (A-Ra); in situ-determination of Rn exhalation, combining time-dependent Rn and Rn-d measurements (A-Al); in situ-determination of gas permeability in soil with miniature probes (A-Da); temporal RaA-variability indoors, using continuous measurements (A-Ni); measurement of Rn-d equilibrium activity deposited on surfaces by analysis of the spatial distribution of alpha tracks on CR-39 (A-La); Rn diffusion characteristics through hydrocarbons for application in oil exploration (A-Ra[1]);

c) outdoor studies

airborne surveys in order to correlate outdoor-, indoor Rn levels and geology (A-Gr); ship-based atmospheric studies on the Rn- and Rn-d distribution trend over the equatorial Pacific Ocean (A-Mo); model validation describing the temporal variation and horizontal distribution of Rn in the atmosphere (A-Ik); wash-out effects on atmospheric Rn-d (A-Fu); temporal variation of the specific activity of Rn-d in rainwater (A-Yo); multi-parameter correlation of the Rn concentration with the variation of the atmospheric boundary layer (A-Ka); enhancement of outdoor Rn-levels due to uranium mining (A-Kr); optimisation of radon potential mapping, using airborne-, ground surveys and borehole radiometric procedures (A-Ba);

d) indoor studies

influence of fly-ash containing construction materials on indoor Rn levels (A-St); thoron and thoron decay products indoors due to building materials (A-Cl); survey of workplaces with elevated Rn levels (A-Di); Rn-levels in dwellings built on uranium deposits and phosphate rocks (A-Si); identification of dwellings with high Rn-levels due to wall constructions using soil (A-Do); atmospheric Rn concentration in underground subway transport systems (A-An); identification of sources in dwellings with extremely high Rn-levels situated in former uranium mining communities (A-Th); thoron decay product exposure assessment for inhabitants of volcanic tuff-made dwellings (A-Sc[1]); correlation of Rn-d levels with the unattached fraction in houses with anomalous Rn-levels (A-Ro); Rn-levels in tourist caves, show mines and historical monuments (A-Ro, A-Hu).

e) dosimetry and risk assessment

microdosimetry of inhaled Rn-d by simulating randomized energy deposition at different cells (A-Ho); low dose extrapolation of Rn-related dose-effect curves with a hypothetical threshold (A-Ci); lung cancer risk assessment based on case-control studies in normal and coal brick-dwellings (A-De, A-Wa).

3. International regulatory approaches to radon control - a mosaic of options

Over the past 25 years the International Commission on Radiological Protection (ICRP) has drastically changed its approach to Rn control. In 1966 the ICRP categorically declared that its dose limitations referred only to exposures from technical practices that added to the natural background radiation (IC 66). In 1991, however, the proposed revised recommendations acknowledge that "....radon in dwellings needs special attention" (IC 91). For existing dwellings the ICRP discriminates between the recommendation of a vague "guidance" for owner-occupied dwellings and an "action level" for rented properties, without specifying any numerical values. Also the advice provided on the choice of action level is rather philosophical, i.e. it should be such that the number of houses in need of remedial work should not be "unmanagable". From the view point of the ICRP a recommendation for a "new building" is not really warranted because the concentration of radon cannot be determined with confidence until its completion and having been occupied for about a year. By then it is an existing dwelling . Finally the ICRP admits it is proceeding "cautiously" and recommends to continue using its Recommendation no. 39, i.e. an equilibrium equivalent concentration (EEC) of 200 Bq/m3 as a "reference level" for new dwellings. This would result in an effective dose of 12 mSv/yr with the present lung model. However, "revised recommendations in due course" are already announced.

The World Health Organization (WHO) recognizes in 1989 that "...radon and its daughter products remain a matter of concern due to widespread occurrences and the total delivered dose" (WH 89). Using a different approach, it accounts for the extent of mitigation required in the case of existing buildings (Ah 90): if the annual average EEC exceeds 100 Bq/m^3, remedial actions should only be taken, provided they are simple to implement. This caveat does not apply if an annual average of EEC > 400 Bq/m3 is prevailant and then prompt actions should be taken. WHO recognizes "new buildings" as being a different situation than already existing dwellings and recommends that an annual average EEC of 100 Bq/m3 should not be exceeded.

The Commission of the European Communities (CEC) recommends to use a dose-related "reference level". If an effective dose of 20 mSv/y is exceeded, this should be "cause for consideration" of "simple, but effective" countermeasures (CE 90). Applying presently available dosimetry this corresponds to an annual average EEC of 200 Bq/m^3 ($F = 0.5$). Also the CEC recognizes the difference between existing and new buildings and recommends in the latter case a "design level" of 10 mSv/yr (= EEC: 100 Bq/m^3; $F = 0.5$). It is emphasized by the CEC that a) all decisions should be based on annual averages of Rn or Rn-d, using integrating techniques;
b) adequate Quality Assurance Programmes should be in effect.

In the following two examples for national regulatory actions are discussed. In Austria the total radiation exposure indoors resulting from building materials is regulated, i.e. the sum resulting from external gamma radiation and exhalation of Rn (ON 88). Different equations apply for single component- or multiple-compound building materials. The materials are considered suitable if the resulting effective dose from the total indoor exposure does not exceed the average national value of 2 mSv/yr. Contributions from cosmic rays, Rn from drinking water, etc. are excluded in this recommendation on building materials.

In 1980 the Swedish government took the lead worldwide to introduce a system of comprehensive limits and recommendations for decreasing Rn concentrations in all dwellings (NB 80). At present a Rn- "action level" of 200 Bq/m^3 is used for existing dwellings, provided simple measures can be taken; otherwise 800 Bq/m3 are recommended. For new dwellings a Rn- "design level" of 140 Bq/m3 is in effect. In 1985 Rn has been recognized officially as an urgent health problem requiring action (SG 85). Therefore, the government recommended each municipality to take appropriate measures to ensure via building permit that in new buildings the average collective exposure to Rn-d and to gamma radiation is decreased as far as it is practical and economically reasonable (Fa 90).

4. Recommendations for a unified approach

Radon represents a multidisciplinary issue on an international scale. Therefore it appears advantageous to use a unified approach to its solution. Such an internationally coordinated approach should address the following areas:

4.1 Research needs

In the following areas further research is needed in order either to overcome actual lack of data or to improve existing databases.

a) Source Term Characterisation:

Radon 220 (Thoron, Tn) and its decay products (particularly ThB) may represent a non-negligible component of the indoor environment in some areas; more measurements are needed to characterize occurrence and dynamics of these nuclides; Rn-related convective/advective/diffusive/ transport phenomena need quantification for a variety of environmental boundary conditions, such as under the influence of meteorological parameters; interaction of pressure-driven flow with subsoil; multizone transport and interzone flow; quantification of Rn-entry into spaces; Rn/Tn generation and mobility in soil and rocks as a function of: soil moisture, -porosity, -type, -depth, weathering; emanation process into gas and vapour phases dependent on pore space, grain size, permeability; microdistribution of radium 226 within grains.

b) Aerosol Sciences:

Chemical and physical characteristics of Rn/Tn and their decay products, e.g.: formation of cluster ions and their reaction products; dynamics of Rn-d/Tn-d interactions with indoor aerosol (size distribution, diffusion coefficient, recoil phenomena, plateout rate); Rn-d/Tn-d interaction with other indoor pollutants: generation rate of free radicals, ions, neutral products; long-term measurements of unattached fraction in a variety of environments, including size distribution studies and humidity effects.

c) Dosimetry:

Microdosimetric calculations to obtain values for the quality factor and RBE for Rn-d; biological dosimetry for evaluating prior Rn-d/Tn-d-exposure, using samples of bone, teeth, blood, hair, etc; refined dosimetric modelling for infants, children, sick and older people using actual morphological and physiological data rather than scaling factors only; development of species-specific physical models of different regions in the respiratory tract.

d) Radiobiology

Molecular approach to mechanisms of Rn/Tn-induced injury:
Rn/Tn-in vitro exposure of human cell cultures; biophysical and biochemical modelling for the identification of cellular markers for pre-malignant or malignant cells; use of molecular probes of genes cloned as recombinant DMA molecules to study Rn/Tn-induced DNA changes; activation of oncogenes;

Cellular approach:

quantification of the changes of parameters indicative for transformation processes, such as:
anchorage-independent growth, immortalization, growth enhancement; abnormal expression of growth factors; adaption studies to ultra-low levels of Rn-d exposure (hormesis); Tn-d distribution in different organs after inhalation; interaction of Rn-d/Tn-d smoke and other irritants known to occur indoors and underground;

4.2 Logistic requirements and aspects of programme design

Over the next few years a large number of Rn-programmes will be carried out worldwide. In order to achieve optimal cost-effectiveness and comparability of results international coordination is desirable also in the implementation of these programmes, addressing logistic requirements and programme design:

a) standardisation of the data collection-methods for describing the Rn exposure indoors and outdoors in different types of exposure situations (homes, schools, offices, factories, public buildings, recreational areas, health spas, mines) and reflecting the subsequent use of the data (real estate transaction, design of mitigation procedures, epidemiological research);

b) definition of minimum criteria to be fulfilled by quality assurance programmes concerning different measurement programmes (short-term integration, long-term integration; measurements of Rn-, Rn-d, thoron daughters and unattached fraction; Rn determination methods for soil gas, water, exhalation rates);

c) establishment of an international Rn-databank

d) harmonization of the international <u>regulatory approach</u> to risk limitation from Rn-exposure, differentiating between the residential-use of owner occupied buildings, rented accomodations, public buildings and work places;

e) provision of <u>information material</u> (graphical, audio-visual) for specific target groups, such as public health services, scientific-technical community, real estate agents, Rn-testing companies and contractors, and the media. This material should be scientifically sound, presented but also sufficiently interesting to reach the target audience. It should assist in obtaining a positive response from the public, thereby adding to improved control of the exposure situation.

f) development of durable <u>Rn-mitigation techniques</u> for different architectural styles and geo-climatic regions, taking into account the cost-effectiveness of achievable dose-reductions;

Summarizing it appears advantageous to find an international agreement on a unified approach to view the issues of "Radon in indoor air" and related public health risks from individual and collective exposures in a consistent manner with risks from other radiation sources but also from all other contaminants occurring indoors, such as microorganisms, organics, combustion products and passive cigarette smoke.

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Fig. 1: Participants in the IAEA Co-ordinated Research Programme "Radon in the Human Environment" (Status: February 1991)

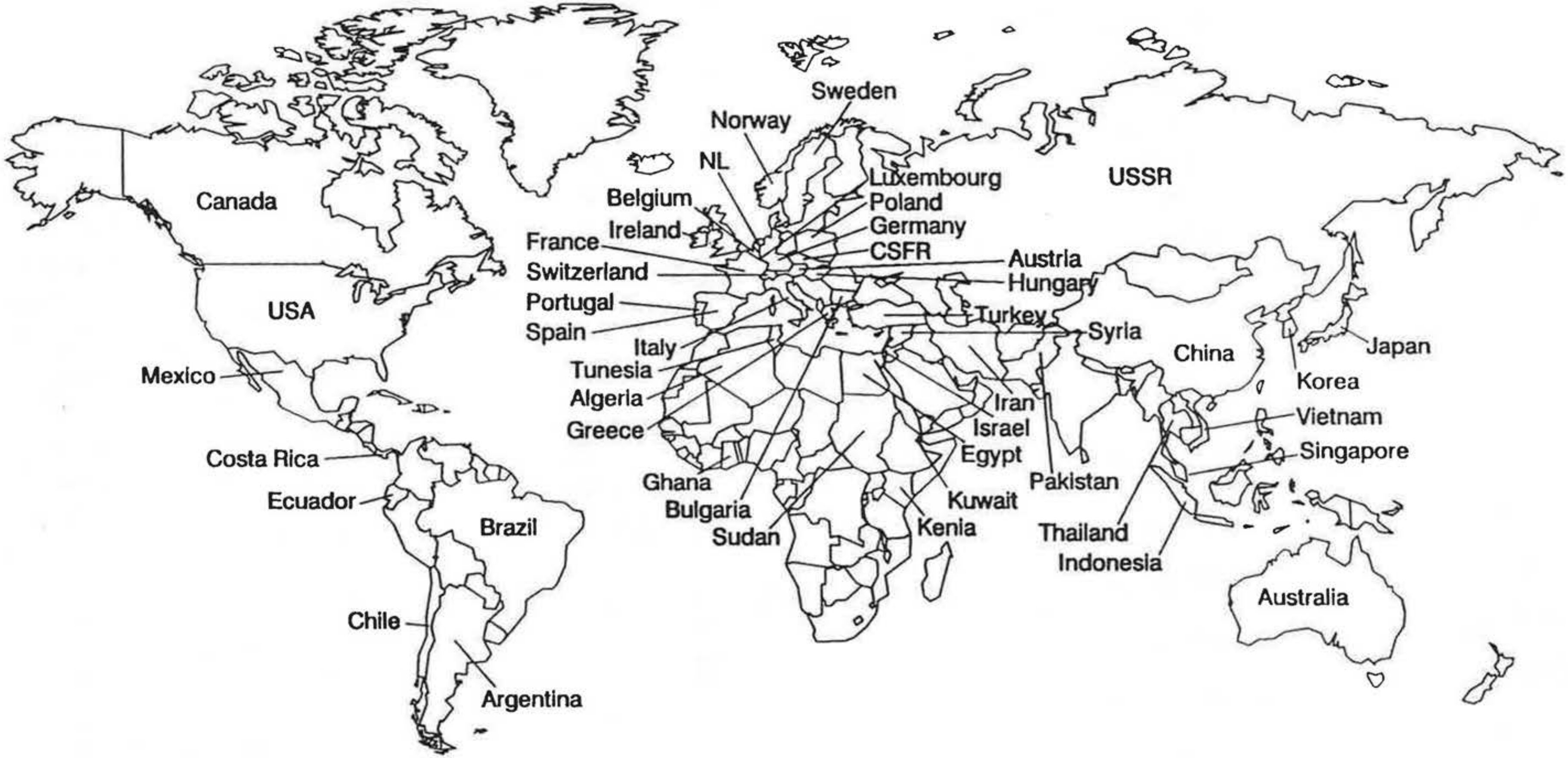

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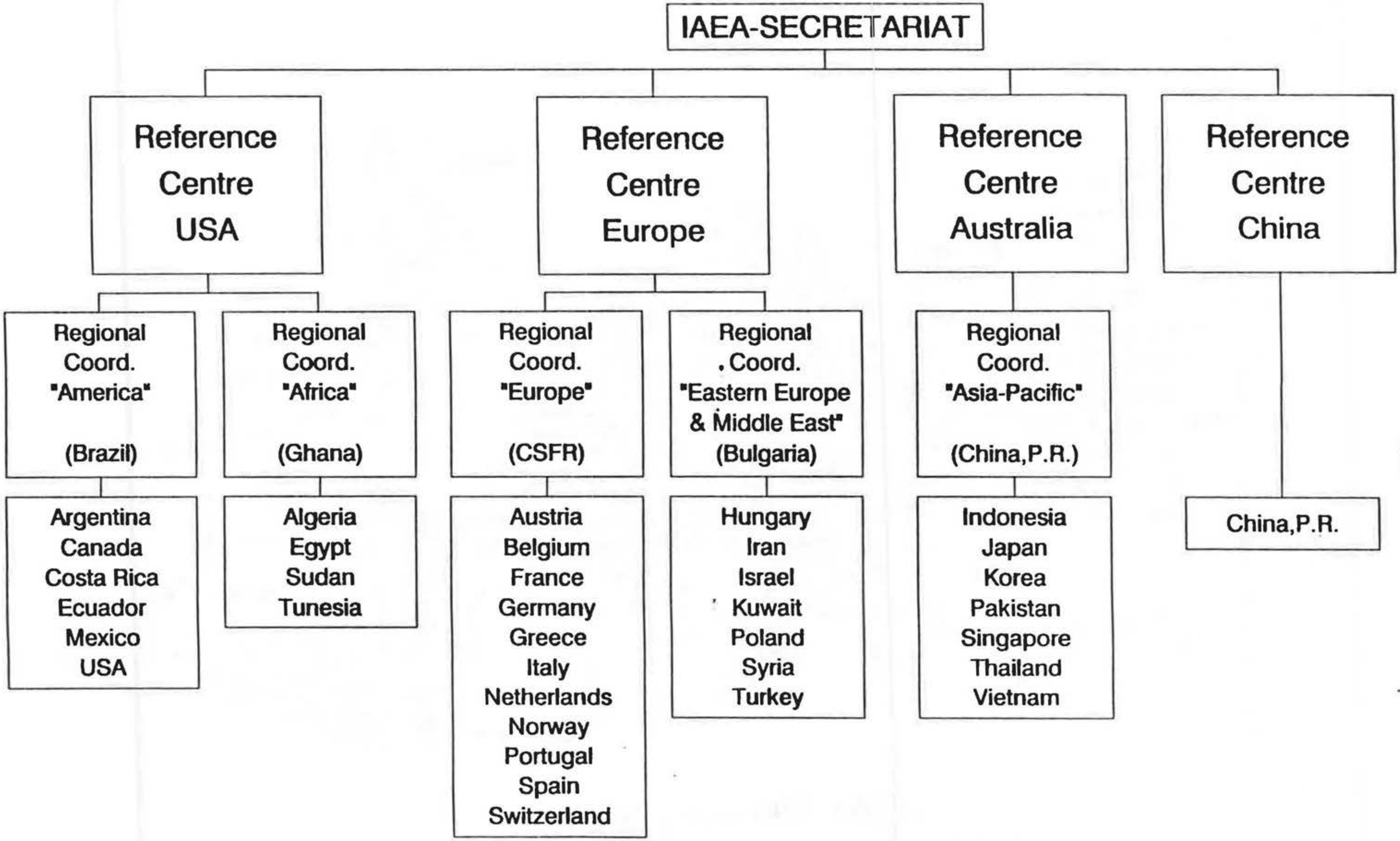
Fig. 2: Implementation of Quality Assurance Programme within the Framework of the IAEA-CRP "Radon in the Human Environment"



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THE US DOE RADON RESEARCH PROGRAM:

A DIFFERENT VIEWPOINT

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ABSTRACT

The United States Department of Energy, Office of Health and Environmental Research (DOE/OHER) is the principal federal agency conducting basic research related to indoor radon. The OHER has supported research on the biological effects of ionizing radiation for many decades and is responsible for the scientific knowledge upon which occupational exposure standards are based. Legislative mandates, including the Atomic Energy Acts of 1946 and 1954, The Energy Reorganization Act of 1974, and The Federal Nonnuclear Energy Research and Development Act of 1974, provide the broad authority under which the radon research program is funded.

In 1987, the OHER targeted several million dollars of support for basic research targeted toward evaluating the health risk of environmental levels of radon. In 1989, this program expanded again to an annual level of approximately $11-13 million. The scientific information being sought in this program encompasses research designed to determine radon availability and transport outdoors, modeling transport into and within building, physics and chemistry of radon and radon progeny, dose response relationships, lung cancer risk, and mechanisms of radon carcinogenesis. The main goal of the DOE/OHER Radon Research Program is to develop information to enable an improved health risk estimate for radon exposure and thereby facilitate sound public policy decisions.

Introduction

The Department of Energy (and its predecessor agencies) is an historic participant in radiation issues currently facing the U.S. government and U.S. population, as both a generator of radioactive materials and as the leading radiation research organization. Indeed much of the basic knowledge of radiation effects which underlie occupational radiation standards comes from DOE research efforts. This paper is directed toward a discussion of the radon research program, the major radiation research program currently supported by the Office of Health and Environmental Research.

This program, basic in nature and mandate, has not been able to keep abreast of the radon policies rapidly being developed by the US EPA, nor adequately provide for the immediate scientific needs of a burgeoning radon industry that is often driven by economic factors. Scientific uncertainty on radon risk, the key factor driving the DOE radon research program, often differs in perspective from radon action and risk communication interests. The inherent "give and take" between science and action contribute to more balanced and reasonable policy choices.

THE DOE RADON PROGRAM: UNCERTAINTY REDUCTION (Figure 1)

Addressing areas of uncertainty is the focus of the DOE Radon Research Program. Six specific areas of research have been developed to describe the areas in which information is needed. These six areas are discussed below.

In most cases, radon found in homes originates from the soil around and beneath the house. However, the exact relationship between the occurrence of radon in the soil and the amount of radon available for transport into the home remains unknown. To address questions regarding the levels of radon progeny likely to be found in homes and other buildings, OHER has established the following two program areas: Availability and Transport of Radon in Soil and Transport of Radon into and within Buildings.

The dose of radon progeny and thus radiation received is dependent on a number of variables in addition to the overall level of radon in the building. These variables include the fraction of the radon progeny attached to particles and the size distribution of the particles, among others. To investigate how these parameters affect the dose of radiation received by an individual, OHER has established the following program areas: Physical/Chemical Interactions of Radon Progeny in Air and Relationship Between Exposure and Dose.

Although underground miners exposed to elevated concentrations of radon have been shown to contract lung cancer, the exact biological effect of radon on the lungs and the reason this effect causes lung cancer remain unknown. Two areas of the research program are directed at examining the types of damage caused to cells by radiation from alpha progeny and how this damage ultimately results in lung cancer. These two program areas are the following: Mechanisms of Lung Cancer Induction and Quantification of Cancer Risk from Radon Exposure.

MANAGEMENT OF THE RADON RESEARCH PROGRAM (Figure 2)

The DOE technical staff developed the original research program goals and continue to guide the program tasks in support of the attainment of these goals and the reduction of critical uncertainties. These tasks include the evaluation and selection of research projects relevant to the reduction of uncertainties; the continual coordination, maintenance, and review of the projects; and the promotion of exchange of research findings among members within the national and international radon research communities. In these tasks, management is assisted by a panel of principal scientists selected from among the researchers participating in the program. These scientists, chosen to represent different disciplines, work together to ensure that levels of technical quality and relevance of program activities meet high standards.

Development of Relevant and Coordinated Program Goals

The Radon Research Program coordinates research goals and share information with other national and international programs. While OHER has for some time coordinated its efforts with other DOE offices, such as the Office of Conservation and Renewable Energy, the Office of Nuclear Energy, the Office of Environment, Safety and Health, and the Bonneville Power Administration, recent efforts have broadened the scope of the coordination to include other agencies, both Federal and International.

DOE signed a Memorandum of Understanding to coordinate its research efforts with those of the Environmental Protection Agency (EPA). As a result, DOE has taken responsibility for conducting basic research related to radon, particularly as it relates to public health. EPA has taken responsibility for conducting applied research, public outreach, and operational programs involving the states and the private sector.

The DOE Radon Research Program, now over four years old, is mature enough for a reevaluation of the research vs. uncertainties and risk. An effort to identify contributions to risk assessment approaches with this newly available data will commence in 1991 with an initial planning meeting of key scientists.

DOE also signed a Memorandum of Understanding with the Commission of European Communities (CEC) and meets annually with the managers of the CEC Radon Program to coordinate activities. The program managers have agreed to hold annual meetings, review each other's programs, and cooperate in the funding of international workshops on radon research findings. Emphasis is being placed on conducting complementary research programs across national boundaries.

A major scientific accomplishment occurred in July 1989, when over 50 participants representing many different countries attended an International Workshop on Residential Radon Epidemiology sponsored by DOE and CEC. Discussions focused on assessment of lifetime radon exposure, design considerations for residential radon epidemiological studies, and statistical power and data analysis. Participants concluded that pooling data from different studies was essential to obtain quantitatively useful information. Participants also emphasized the relationship (or lack of) between the needs of policy makers and the capacity of epidemiological investigations to satisfy these needs. Plans now call for a repeat workshop of the epidemiology investigators in the summer of 1991 to plan a meta-analysis of their combined data when it is available.

The DOE Radon Research Program manager co-chairs with EPA, the Federal Interagency Committee on Indoor Air Quality (CIAQ) Radon Work Group. This work group coordinates activities among all Federal agencies involved in radon research. Members meet regularly to exchange information and review and comment on technical documents. In addition, special activities, such as the development of a Federal Radon Activities Inventory, have been undertaken.

DOE is also a participant of the Committee on Interagency Radiation Research and Policy Coordination (CIRPPC). This committee is comprised of members of all the Federal agencies conducting radiation research.

Funding of Selected Projects

Radon Research Program management supports the attainment of the research goals by selecting and funding projects likely to produce information needed for reducing uncertainties. The Radon Research Program management sets priorities for research activities through an evaluation and ranking of proposals. In FY 1987, OHER solicited applications for funding and received 128 research proposals. The proposals were reviewed and projects were selected to receive funding based on scientific merit and relevance to program initiatives.

Funded projects are reviewed continually on an informal basis. A formal scientific peer review process was undertaken in FY 1990 and evaluated the entire radon program. A significant number of projects were terminated and recommendations were made for program redirection, adding risk assessment and modelling components. Management staff will use significant research developments revealed in the formal review process to target the next three-year phase of the program, incorporating the change in emphasis in their selection of the next round of projects for funding.

Information Flow

DOE hastens the progress toward program goals by facilitating the flow of information among research laboratories, other agencies, national and international committees. The ready exchange of information serves to maximize technical input on research projects and helps to prevent duplication of activities.

The panel of seven principal scientists from various research disciplines serves to facilitate communications between the managers and radon scientists. The group meets to evaluate the status of the program with regard to the quality, relevance, and cohesiveness of the research being conducted and to exchange information.

Meetings

The Radon Research Program conducts an annual contractor meeting of all OHER radon researchers, radon technical staff, and guests from other Federal programs. The scientists highlight accomplishments, resolve problems, share collaborative results, and address changes in program emphasis.

OHER also plans small workshops for the various research areas. Specific goals for each meeting are identified, and other scientists are invited as the needs for specific expertise are identified.

Publications

Each year, the Radon Research Program publishes a research program update with project summaries and accomplishments. In 1990 it began the publication of a newsletter which highlights radon research activities in DOE and elsewhere. This can be obtained at no cost by writing Gloria Caton, Oak Ridge National

Laboratory, Oak Ridge, Tennessee 37831.

A series of technical radon documents continues each year as topics are identified and manuscripts are completed. Several documents on epidemiology and animal studies have been completed in the last several years.

The Radon Research Program oversees and funds the research activities of a national network of over 60 projects in university, private, national, and contractor-operated laboratories. In addition, the program manages various activities which promote the exchanges of information among all radon research programs, both nationally and internationally, in order to promote the reduction of uncertainties surrounding human exposure to radon.

UNCERTAINTIES: AN OVERVIEW [FIGURE 3]

Reducing radon uncertainties is the goal of the DOE Scientific Research Program. This program has evaluated these uncertainties, determined those which are amenable to scientific methods, and is attempting to address many of the most outstanding questions. The major uncertainties in Radon Risk are listed here as a broad overview of the research issues.

Miners vs. Public

Using observations in underground miners as a basis for estimating the risks of radon to public health yields a risk estimate containing major uncertainties. Some of the uncertainties exist within the *miner* data and make the *risk* estimate calculated for miners uncertain. Other uncertainties are added when the miner estimate is used as a basis for predicting health risks to the public because of differences that exist between mining and residential exposures and between miners and other members of the population. An EPA sponsored National Academy of Science Panel on dosimetry has explored this issue and will be publishing its findings this year. Although there is general scientific agreement that exposure to radon progeny is associated with an increased occurrence of lung cancer in miners, there remains some uncertainty as to the relationship between the extent of exposure and risk, even in miners.

Potential Errors in Measurement

A major source of uncertainty in most scientific radon studies is the validity and accuracy of the radon measurements used to determine exposure. Using currently available techniques, radon measurements may vary from some "actual" or calibrated level by more than twenty-five percent. Also, differences in readings may arise as a result of variations in monitoring, calibration, and quality control procedures. This issue is further complicated in radon studies because technical limitations discourage the direct measurement of radon progeny, the factor causing the lung cancer.

Potential Errors in Exposure

Radon levels fluctuate throughout the work day and from place to place within a mine. Consequently, the exposure level for a given individual may differ from the level at the time and place the measurement was taken. In fact, in many miner studies, the levels were not measured during the period of exposure but were estimated based on measurements acquired more recently or "guestimated" from other sources.

Potential Errors in Diagnosis

In addition to errors in the exposure estimates, there may be errors in the number and kind of lung cancer cases diagnosed for the members of the studies.

Potential Errors in Model Selection

Selecting an appropriate model for relating the history of exposure for the study subjects to the observed lung cancer rate is a complicated task. For example, how do you quantitate the exposure of an individual who spent five years in a mine over twenty years ago? How does this compare with a person exposed for five years just five years ago? In the case of radon, model selection is particularly difficult because two of the variables, radon and cigarette smoke, are believed to interact.

ENVIRONMENTAL CONDITIONS

Another category of uncertainty is a result of the inadequate understanding of how the environmental conditions that predominate in a mine contribute to the health effects seen in miners, and how these environmental conditions compare to those found in a home.

Factors, such as the distance to the source of the radon and the amount of ventilation, influence the concentration of radon progeny present in the air. If everything else is equal, the higher the concentration, the more radiation that may be available to be inhaled. But generally everything else is not equal, and the relationship between exposure level and dose is not straightforward. At least two other environmental parameters affect the dose-the number and size of particles in the air.

Differences in Environmental Sources

Environmental conditions and radon sources within mines are relatively constant compared to conditions and inputs to homes. Radon levels within homes can vary more than an order of magnitude, depending on environmental factors such as climate, season, wind speeds, pressure differences, humidity, and radon emanation potentials from heterogeneous soils and rocks.

Differences in Levels of Radon Progeny in Mines and in Homes

Although some homes have been found with extremely high levels of radon, the majority of homes have levels much lower than those generally found in underground mines. Currently there is very limited information about the health effects associated with radon at the levels commonly encountered by the public. As a result, some of the uncertainty in the risk estimates stems from having to extrapolate risks that are likely to occur at the low concentrations of radon commonly found in homes from data about the higher concentrations found in mines.

Differences in Particle Sizes and the Unattached Fraction

Investigators of homes in New York and New Jersey and mines in Colorado and Canada have shown the sizes of particles differ in the two environments. Poor ventilation in mines and the preponderance of dust-generating activities keeps the concentration of airborne dust high and perhaps the fraction of unattached particles low. Although recent improvements in ventilation in mines have reduced the concentrations of dust, this has been counteracted by an increased use of diesel driven equipment. Unattached fractions in mines have been found to range from less than 1% to as high as 16%.

Various activities within the home such as cooking and smoking contribute to the prevalence of particulate matter in indoor air and affect the fraction of attached progeny found in homes. However, many of the aerosol creating activities are reduced at night when residential exposures predominate and consequently the particulate concentration is also reduced. Unattached fractions in homes have been measured to range from below 5% in the presence of specific aerosol sources to between 6% and 15% in the absence of the sources. This value indicates that the unattached fraction in homes may be twice as high as that found in mines although more adequate information is needed for mines.

Other Toxicants

Toxic air pollutants, such as those found in diesel exhaust, can accumulate in the air of mines due to confined conditions and inadequate ventilation. The contributions of these pollutants to the effects observed in miners is unknown.

Additionally, most of the miners that have been studied were cigarette-smokers. Not only does cigarette smoking itself lead to lung cancer, the presence of naturally occurring radionuclides in tobacco contributes to the overall radiation exposure. It is believed that the combined effect of radon progeny exposure and cigarette smoking is multiplicative. As a substantial portion of the general population is nonsmoking, the extrapolation of effects from a predominantly smoking miner population to other members of the public may result in an overestimated risk.

UNCERTAINTIES IN CHARACTERISTICS OF THE EXPOSED POPULATION

A final category of uncertainty results from a poor understanding of the actual differences in the physical characteristics of miners and members of the general public and how these factors affect risk. Even if the same environmental conditions prevailed in mines and in homes, uncertainties would remain because differences in sex, age, smoking status, and activity level affect an individual's response to radon exposure.

Amount of Air Inhaled per Unit Time

During the period of exposure, miners are expected to be participating in relatively strenuous activities. As a result they are likely to be breathing deeply and frequently. In contrast, residential exposures generally take place when individuals are involved in light activity or are sleeping. Under these conditions, breathing is likely to be shallow and slow.

The increased volume of air brought into the lungs brings in a greater amount of radon progeny; however, the increased frequency of breathing decreases the mean residence time of aerosols in the lung and consequently, reduces the time available for diffusion to deposit particles on the bronchial airways.

Oral vs. Nasal Breathing

The dose of radon progeny delivered to the lungs can be influenced by the proportion of oral and nasal breathing because larger portions of some sizes of particles are deposited in the nose during nasal breathing than in the mouth during oral breathing, though the significance of this difference is not known.

Differences in the Lung Characteristics

The dose of radon progeny is dependent on the amount of material deposited in the lungs which in turn is dependent not only on the factors mentioned above, but also on the sizes and branching patterns of the airways. Size and branching factors can vary with the sex and age of the exposed individual. The geometry of the female airway is similar enough to that of the male that the use of scaling factors can probably account for differences. The same is not true for children, however. The extent to which the adult miner data need to be adjusted to account for different lung characteristics is uncertain, particularly for children. This is further complicated by reports of a National Cancer Institute epidemiological study of miners exposed as children to radon while working in tin mines in China in which it was reported that there was no evidence of an increased incidence of lung cancer from these early exposures.

The dose is also dependent on the rate at which deposited materials are cleared from the lungs. Clearance rates are affected by smoking status and age, and it is important to consider differences in these parameters when comparing miners and the general public. There are no data on clearance rates for children.

UNCERTAINTIES IN EXTENT AND DURATION OF EXPOSURE

In addition to differences in environmental and physical factors, significant differences in the timing of exposure exist between miners and the general population. For the general population, exposure may begin at birth and continue throughout the lifetime or until the radon is detected and remedial action is taken. The effects of the differences in the timing of exposure between miners and the general population are difficult to judge and add uncertainty when miner risk estimates are used to predict risks to the public.

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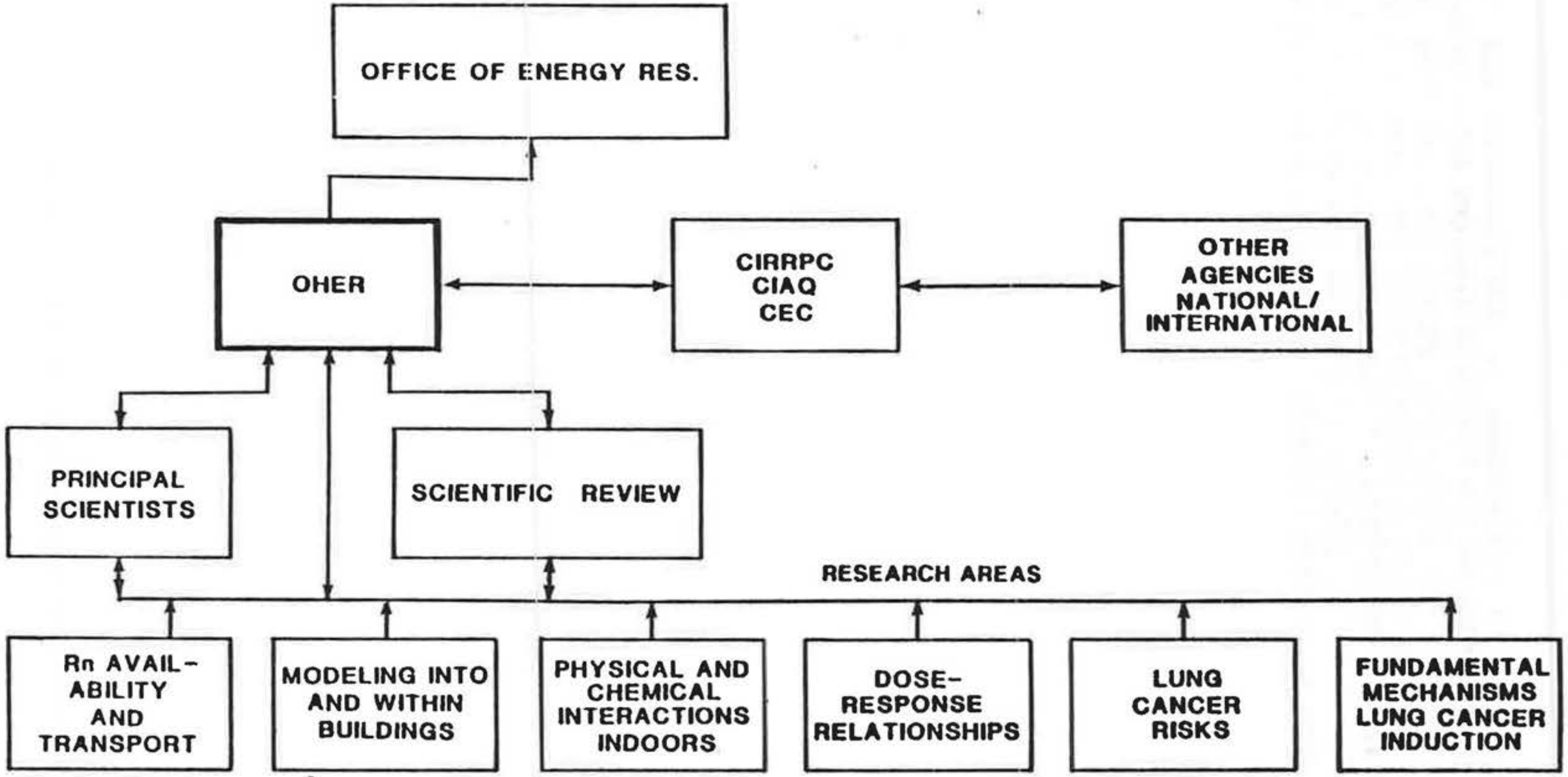

Figure 1. **Principal Elements of the DOE/OHER Radon Research Program.**

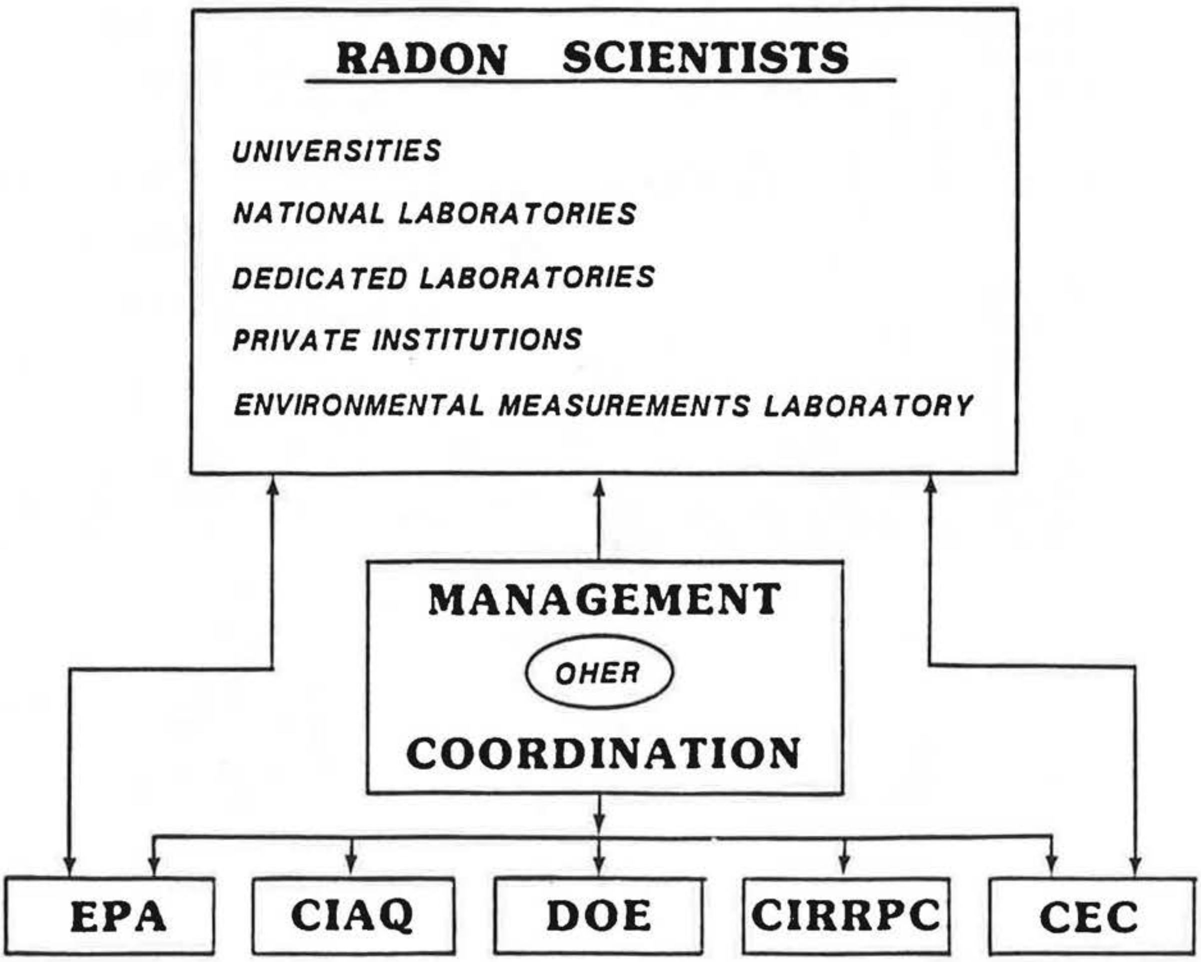

Figure 2. Mechanisms for Radon Program Coordination. Abbreviations used are: CIAQ = Committee on Indoor Air Quality, CIRRPC = Committee on Interagency Radiation Research and Policy Coordination, and CEC = Commission of the European Community.

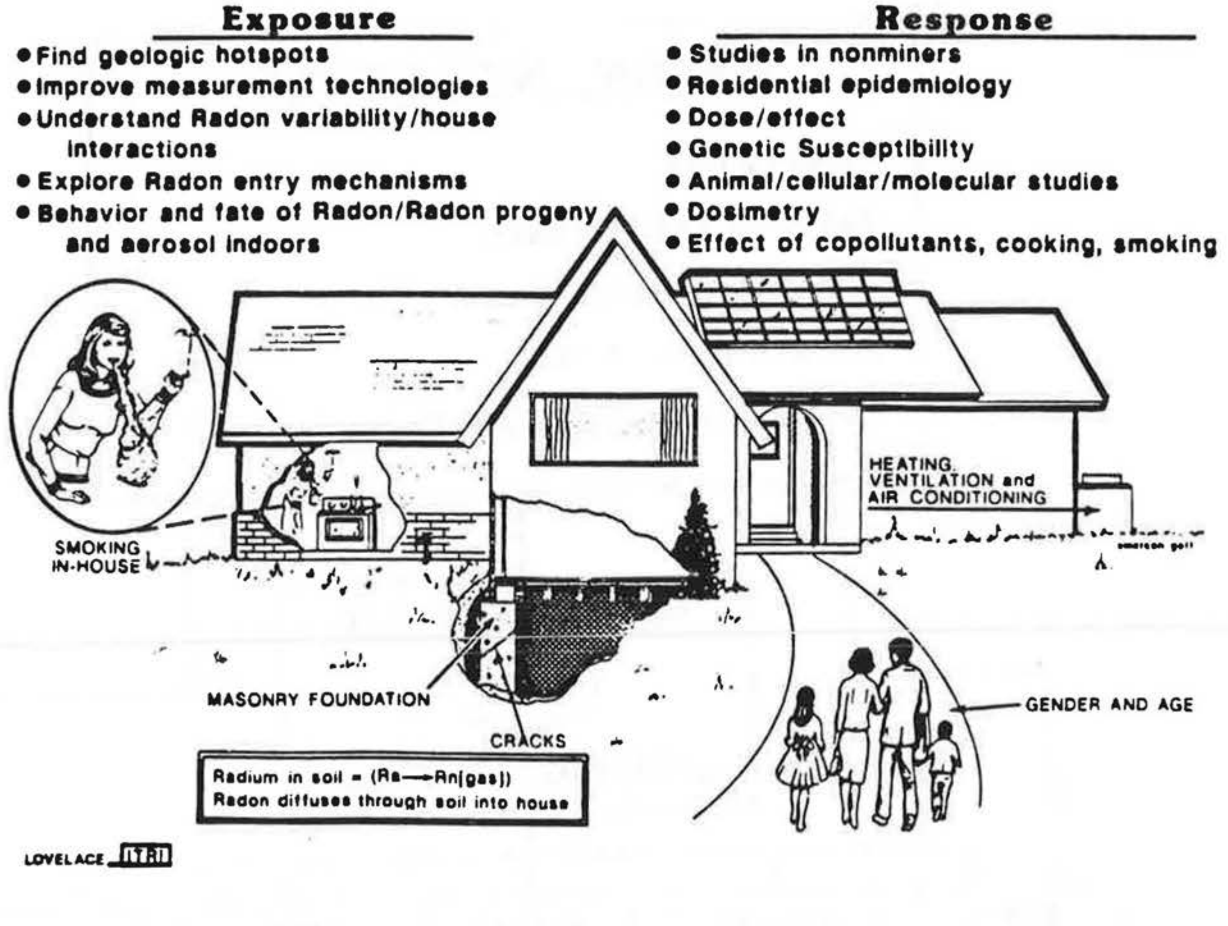

Figure 3. Sketch Illustrating Some of the Uncertainties in Estimating Lung Cancer Risk from Indoor Radon Progeny.

Session I:

Government Programs and Policies Relating to Radon -- POSTERS

TITLE: State Indoor Radon Grant Program: Analysis of Results After First Year of Funding

AUTHOR: Sharon Saile, EPA - Office of Radiation Programs

This paper was not received in time to be included in the preprints so only the abstract has been included. Please check your registration packet for a complete copy of the paper.

The State Indoor Radon Grant (SIRG) program was authorized by the Indoor Radon Abatement Act (IRAA) of 1988 in order to provide seed money to assist States in developing and implementing State radon programs. The first SIRG grants were awarded in 1990 to 48 States, the District of Columbia, and Guam, with an average grant award of $150,000 in Federal funding per State. EPA established the following four goals for the SIRG program:

- To achieve widespread participation in the program
- To establish basic, core capabilities in States for radon response, and to stimulate innovation and expansion in State radon programs
- To foster radon program development that appropriately reflects the differences in the scope and severity of radon problems
- To help States develop programs that will continue to reduce radon risk beyond the life of the SIRG Program.

This paper will examine the State's progress toward fulfilling these goals, based on the completion of their first year of activities under the SIRG program. In addition, this paper will present a preliminary analysis of the success of this type of "seed money" program for State capability development.

#5463

IP-2

EPA RADON POLICY AND ITS EFFECTS ON THE RADON INDUSTRY

by: David Saum
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Although the EPA has always stated a goal of solving the indoor radon problem through private sector testing and mitigation, EPA programs may be impeding the development of a viable private radon industry. Several possibilities for modification of the EPA programs are discussed: 1) "sunset" provisions for EPA programs that would schedule their termination so that the private sector could plan for privatization, 2) increased utilization of voluntary consensus standards organizations such as ASTM and ASHRAE to replace EPA protocols and guidelines, 3) cost/benefit analyses of impact of past and future EPA programs on the radon industry, 4) an EPA ombudsman to serve as a contact point for radon industry comments to the EPA, 5) increased radon industry participation in future development of EPA programs and guidelines to prevent surprises and allow for longer term planning, 6) a revision of the EPA authority to issue guidelines, protocols, examinations, etc. so that this de facto rulemaking would be subject to the same review as formal EPA rule making.

INTRODUCTION

What is the proper response of the federal government to the indoor radon problem? This paper will briefly consider policy approaches, outline the problems with the current EPA indoor radon programs, and offer suggestions for a change in direction current federal policy that should offer better services to the public by allowing market forces to operate more efficiently.

Under our constitutional republic, all governmental authority must be authorized by the constitution which makes no mention of indoor radon. We must assume that the current activities are authorized under the "general welfare" clause in the preamble. This phrase allows for broad interpretation which varies with the vision of the current executive, legislative and judicial branches. The EPA, as a member of the executive branch, appears to be following President Bush's vision (last stated in The State-of-The-Union address) of relying on the private sector whenever possible and returning power to the states and localities. Congress appears to have agreed by authorizing the EPA to assist the states in developing and regulating radon activities, and the most recent legislation is the Indoor Radon Abatement Act (IRAA) of 1988. All of this activity has been characterized the EPA and Congress as "non regulatory" since radon is naturally occurring and its primary exposure has been in private residences where the government does not want to intrude. The EPA has issued radon guidelines and has provided "voluntary" proficiency demonstration programs to assist the states in determining who is capable of measuring and mitigating radon problems. The EPA has also provided extensive public information, and it has often stated that it wants private industry to provide a solution to the indoor radon problem through a non regulatory program.

Unfortunately, this non regulatory approach has resulted in a highly regulated marketplace from the point of view of private industry participants. More and more states have enacted regulation to make it impossible to perform radon related work without full compliance with all the latest EPA "voluntary" programs. Mandatory state regulation through the use of voluntary EPA programs appears to be an ideal situation to state regulators since they can rely on the authority of the EPA to legitimize the state programs at little or no expense. But it presents an increasing burden to those in the industry who face increased competition from competitors trained by EPA developed courses and certified by EPA developed examinations, increased costs to private industry from fees mandated to support these programs, and an increased paperwork burden from an ever increasing "voluntary" protocols and revisions to these programs. The EPA has no attempted to justify these programs by offering proof that these programs offer the public a higher quality and more cost effective service.

These programs each appear to be well intentioned, but in their sum they are creating an industry that is focussed around the lowest common denominator. The only standard of quality is whether a firm has the required EPA "certification". These programs were created without significant industry input, they are completely controlled and managed by the EPA without continuing industry input, there is no plan for eventual privatization of these programs, an increasing bureaucracy is being created to support these programs, and Congress has directed the EPA to support these programs through the imposition of user fees on the industry but not the States who are the prime beneficiaries. Many persons who have remained in the industry despite the current severe recession are discussing whether to hold on a little while longer in the hope that the competition will succumb before they do, or whether to begin a strike against the increasing governmental regulations on the industry.

POSSIBLE EPA APPROACHES

What approaches could the federal government have used in dealing with the indoor radon problem? Within the current federal economic and political constraints at least three approaches can be imagined:

Laissez-faire Approach

Although true laissez-faire would involve no governmental programs, we can imagine approaching laissez-faire by limiting the federal government to the conduct of limited research to identify the problem, issuing recommendations, and leaving the market place to develop solutions. This approach assumes the indoor radon problem is not an immediate emergency of such complexity that emergency measures are called for, and that the complexity of society requires the variety of solutions that can best be offered by relying on individual initiative rather than a bureaucracy. The primary disadvantage of this approach is that it might have taken longer for a significant market solution to have developed, given what we now know about the public apathy and the extraordinary amount of education that it has taken to generated even today's marginal response. Possible advantages of this approach include low cost to the federal government, and the potential for the development of a "Sears or McDonalds" approach to radon where some large, well financed company would have the incentive to devote the resources necessary to develop a high quality radon service firm. In today's market where anyone can get EPA "certification" there is little advantage to offering a well established, brand-name, quality service. One disadvantage is that the states would have to develop their own programs for certifying competent firms, such as they currently do for home improvement contractors.

Bootstrap-Sunset Approach

Under a bootstrap-sunset approach, the federal government assumes that the problem is serious enough to justify the development of programs for training and proficiency demonstration to get the industry started, but the government realizes that this bureaucracy can never be able to deal with the evolving complexities of the situation and so each program would have a sunset provision so that they could be taken over by industry groups or private firms. In this way, the EPA could prevent the heavy hand of bureaucracy from becoming a permanent burden on the industry and determining every aspect of its future. One disadvantage is that the states would eventually have to develop their own programs to identify the competent members of the profession. This approach would not require continuing expenditures by the federal government and the imposition of user fees to pay for them.

Bureaucratic Approach

Under the bureaucratic approach, the federal government assumes that the problem is so complex that a permanent federal bureaucracy should be developed to control all aspects of the radon industry through "voluntary" guidelines and programs that are offered to the states as the basis for their non-voluntary regulation. One disadvantage of this plan is that it is expensive, even if it is financed by mandatory user fees, because in any case the funding will come from the public. Another hidden cost of the program is that it stifles new market solutions to the problems because the heavy hand of bureaucracy drives out the best services, reducing everything to a common denominator. The primary advantages are that the states will have a simple solution to the problems of providing lists of competent "EPA certified" firms. This appears to be the approach that the EPA has selected.

EVALUATION OF CURRENT EPA PROGRAMS

When the indoor radon problem was first identified in the mid 1980s, EPA researchers provided contractors with vital information on radon mitigation and testing, and the EPA policy office provided much needed public information material. This activity seemed to be an excellent marriage between public and private interests that served to bootstrap a market solution to the problem. However, now that the radon industry is maturing, it is time to consider the potential benefits of returning as much of the EPA radon program as possible to the private sector. Many of the services now being provided by the EPA are in areas such as training, certification, and calibration are not special types of services (such as law enforcement and court systems) that can only be provided by the government. Privately provided services are generally acknowledged to be more efficient , and this privatization of indoor radon will certainly provide a welcome reduction of government expenditures in this time of budget deficits. An orderly transition to private services should provide services that are more responsive to the marketplace, and the alternative to privatization is a permanent government bureaucracy which has never been the stated intention of the EPA or Congress.

RMP Program

Consider, for example, the EPA's Radon Measurement Proficiency (RMP) Program. Certainly everyone wants to have accurate measurements, and RMP initially provided a valuable service when no private sector services were available. Unfortunately, the current program may actually be impeding the development of private sector efforts to provide calibration and quality assurance services. Wouldn't it be preferable to have many private calibration facilities, conveniently located, offering competitive services; rather than a few of EPA laboratories in distant locations offering very limited services? The presence of the "implied EPA certification" provided by RMP makes it difficult for anyone to take the private labs seriously. The private sector can not compete with the authority of EPA pronouncements, even if the private service is demonstrably better.

A second problem with RMP is that it is a proficiency demonstration program that does not certify contractors, but everyone who uses the program (contractors, states, and local governments, etc.) treats it as a certification of calibration. Private labs find it impossible to sell real calibration services since they do not have the EPA authority, and why should anyone go to the extra expense of going through two programs (RMP and private) when all anyone asks for is the RMP seal of authority). The net result is that RMP has resulted in a low level of calibration in the industry because it has monopolized the calibration business and then offered very infrequent services (approximately every 2 years).

A simple privatization plan for the EPA RMP program would begin with an announcement by EPA of a date (e.g. June 1, 1992) after which the EPA would no longer provide laboratory services for the RMP program. The EPA would also announce conditions under which private laboratories could provide the equivalent laboratory service in lieu of the EPA labs. This would allow the private laboratories to make plans to take over this service. The EPA might initially provide an intercalibration service to certify these new labs, and it might even work with the National Institute of Standards and Technology (NIST) to develop improved radon calibration standards. Currently there does not appear to be any EPA effort to assist private labs in taking over the RMP role. In addition, EPA literature would be modified to indicate that the public should look for testing firms that can "demonstrate fulfillment of a plan to provide accurate measurements either through private calibration facilities or though the temporary EPA RMP". Ultimately the EPA could turn the remainder of the RMP program (record keeping, publishing lists, etc.) over to the highest bidder or an industry trade group.

RCP Programs

In contrast to RMP, the EPA Radon Contractor Proficiency (RCP) Program is an example of an EPA program where some consideration has been given to privatization. In order to stimulate and guide the radon mitigation industry, the EPA developed training courses and exams on radon mitigation, and these courses were originally given by the EPA. To protect its investments in this program, and guarantee geographic distribution of these services, the EPA competitively selected regional training centers where the courses and exams are given from the EPA prepared materials. In addition to these centers, private firms can apply to give the courses if they met specified criteria.

Ideally, the entire RCP program would be turned over to the private sector. This includes updates to the courses and exams, and will require a number of changes since the program was developed without significant industry input or control. Today the radon industry does not have a formal role in revising the examinations or courses, there is no formal plan to phase out EPA control, there is no appeals process for RCP examination results, no grading criteria have been published, and there is no EPA response to comments submitted after completion of the examination or course. The RCP exam also diminishes the possibility of competition among radon mitigation companies. Home owners do not want to hear about a contractor's years of high quality work and innovative solutions, they just want to know "Are you EPA certified?".

De Facto Rulemaking

All the EPA guidelines, recommendations, and proficiency demonstrations quickly become de facto rules because the states are quick to incorporate them into law or local regulations. But the EPA is not required to subject these de facto rules to the same level of public scrutiny as their other formal rule making activity. All of these activities should be open to public scrutiny, and anyone who submits written comments should have a response in writing as to the disposition of the comments. An EPA indoor radon ombudsman is recommended as a contact point for comments on current EPA programs. The industry has lost confidence that any of its comments are taken seriously unless they are made though congress.

User Fees for EPA Programs

The EPA was authorized by the IRAA to implement user fees with the goal of recovering costs in programs like RMP and RCP. Again this appears to be an excellent idea in these days of budget deficits and "pay as you go". Since RCP and RMP are voluntary and provide valuable services, why shouldn't the users pay for them.

The case for user fees would be stronger if the programs were truly voluntary and the programs had not made it impossible for the private sector to provide equivalent services. Much of the industry does not have any choice, they must participate in RCP and RMP or the State will not allow them to stay in business. For this reason, the EPA should consider privatization of these services as an alternative to user fees for cost recovery.

It is well known that the demand for free or underpriced services/items of value is very large, and I think that the EPA has proven this again at great expense, especially in the RMP program. Some sort of price (not necessarily money) must be imposed in order to avoid wasting money on applications that come from companies that are not serious about providing radon services. But this does not mean that the proposed fees must be related to cost recovery.

Let's take cost recovery to its logical extreme. There is only one ultimate "payer" in business and that is the customer. If there are increased costs to the industry, then the customer is ultimately going to have to pay for it. In todays radon mature market, the consumer has largely decided to ignore the problem, and the radon business is primarily related to a small percentage house sales. I estimate that in this market approximately 10,000 mitigation jobs and about 100,000 testing jobs are done every year, and a mitigation job costs about ten times more than a test. I also estimate that the EPA is spending about $10 million per year on indoor radon, and if this was allocated to each test and mitigation and test proportional to their present cost, then simple algebra shows that we would have to add $500 to the cost of each mitigation and $50 to each test in order to provide full cost recovery for the EPA radon program. Would the public put up with this surcharge or even a fraction of it?

Quality Assurance Programs

A Quality Assurance (QA) Program has been suggested as part of RMP for all radon test companies. This could be considered as a response to the realization that RMP has become the primary radon industry calibration program, even though it was never meant to provide that service, and it is a very poor substitute. Privatization of this aspect of RMP is somewhat confusing because the marketplace would probably not recognize the artificial distinction that is being made between "demonstrating proficiency" and running a measurement QA program. Again we see an apparently good idea that could result in all companies offering "EPA certified QA Plans", making it impossible for the consumer to determine which companies have a serious commitment to QA. A more effective approach to accurate measurements might be to encourage "double blind" evaluations of testing companies where testers would be evaluated without their knowledge, and the results would be published for all to see. Then there would be a real premium on QA - not just a paper requirement

RMP Examinations

A "voluntary" examination for radon testers is under development that would require that all test personnel attend EPA approved training courses. Again, no cost/benefit or industry impact studies have been offered by the EPA to justify this program to the industry, but it will certainly give the states an easy way to recommend test companies. Again, the radon industry has had no part in this development, and no plan for its ultimate privatization has been suggested.

RCP Mitigation Protocols

The next step in the RCP program appears to be the promulgation of EPA protocols for radon mitigation. It seems that when radon mitigators signed up for the voluntary RCP exam, they agreed to adhere to EPA mitigation guidelines. The draft protocols contain valuable material, and they would make a useful technical resource document that might replace or supplement the aging 1987 EPA Technical Guidance document on radon mitigation. Unfortunately, the new document was produced without formal industry input, without a cost/benefit analysis, and without plans for consensus approval and periodic updates. The IRAA directed the EPA to work with consensus standards groups such as ASTM, an this should be expedited by EPA. During the extensive open review necessary to arrive at a consensus document, all substantive comments must be dealt with in writing, and there is an automatic provision for periodic updates. The EPA is currently under no such restrictions for developing its current "voluntary" guidance and recommendations. Under current EPA policy, we can expect a cursory review period for the EPA mitigation protocols, after which the states will pick them up, as gospel, and create an increased level of regulation for the radon industry.

Redraft of "Citizen's Guide to Radon"

The EPA recently asked for comment on a new draft of the "Citizens Guide to Radon" which contained major shocks for the radon industry. Since this draft was prepared in response to the IRAA which directed EPA to recommend that home owners reduce their indoor radon levels as close to ambient as possible, few in the radon industry expected new EPA guidance that would effectively raise the radon action level that the radon industry is currently implementing. The technical arguments in this debate are outside the scope of this paper, but I think it is safe to say that if the industry had understood that the EPA was heading in this direction, then many in the industry would have reconsidered their commitment to the radon business. As you can understand, business people have to make long range plans, and it would be very helpful if they knew as early as possible about major policy shifts that might radically alter the economics of their business. Preliminary EPA response to industry comments suggests that the EPA did not anticipate the negative industry response to the draft Guide. This misunderstanding might have been avoided if the EPA had performed a cost/benefit analysis on the radon industry in addition to their study of the impact on the U.S. population. The radon industry could provide valuable input in these matters if there was a partnership between EPA and industry that allowed for continuing communication during the development of these guidelines, protocols, examinations, etc. Although the Citizens Guide contains only recommendations and guidance, it has an impact on the U.S. population and the radon industry that is comparable to any EPA rule making. Therefore, this guidance should be subject to the same full public review as formal EPA rule making.

RECOMMENDATIONS

It appears that Congress did not direct the EPA to work as a partner in assisting the private sector to create a high quality radon industry with a planned rapid transition to a fully private sector effort. Rather, it has effectively directed the EPA to create programs that have taken over the management of the industry with no plans for future privatization. It is no wonder that there are few signs from the industry of increasing self management, since the burden of EPA regulation increases daily.

It's ironic that these problems are taking place as Eastern Europe throws off the shackles of central planning and acknowledges that most problems are more efficiently solved by the free market. Well meaning controls that stifle innovative market solutions must be guarded against with constant vigilance. Sometimes we forget that the radon industry is a trade that is closer to home improvement contracting than it is to brain surgery, and radon industry regulation should be consistent with that fact.

DISCLAIMER

The work described in this paper was not funded by the U.S. Environmental Protection Agency and therefore the contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

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Radon Control - Towards a Systems Approach
R.M. Nuess and R.J. Prill, Washington State Energy Office

Mini Fan for SSD Radon Mitigation in New Construction
David Saum, Infiltec

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Paleozoic Granites in the Southeastern United States as Sources of Indoor Radon — Posters
Stephen T. Hall, Radon Control Professionals, Inc.

Comparison of Long-Term Radon Detectors and Their Correlations with Bedrock Sources and Fracturing — Posters
Darioush T. Ghahremani, Radon Survey Systems, Inc.

Geologic Assessment of Radon-222 in McLennan County, Texas — Posters
Mary L. Podsednik, Law Engineering, Inc.

Radon Emanation from Fractal Surfaces — Posters
Thomas M. Semkow, Pravin P. Parekh, and Charles O. Kunz, New York State Department of Health and State University of New York at Albany; and Charles D. Schwenker, New York State Department of Health

Session X: Radon in Schools and Large Buildings

Extended Heating, Ventilating and Air Conditioning Diagnostics in Schools in Maine
Terry Brennan, Camroden Associates; Gene Fisher, U.S. EPA, Office of Radiation Programs; and William Turner, H. L. Turner Group

Mitigation Diagnostics: The Need for Understanding Both HVAC and Geologic Effects in Schools
Stephen T. Hall, Radon Control Professionals, Inc.

A Comparison of Radon Mitigation Options for Crawl Space School Buildings
Bobby E. Pyle, Southern Research Institute; Kelly W. Leovic, AEERL

HVAC System Complications and Controls for Radon Reduction in School Buildings
Kelly W. Leovic, D. Bruce Harris, and Timothy M. Dyess, AEERL; Bobby E. Pyle, Southern Research Institute; Tom Borak, Western Radon Regional Training Center; David W. Saum, Infiltec

Radon Diagnosis in a Large Commercial Office Building
David Saum, Infiltec

Design of Radon-Resistant and Easy-to-Mitigate New School Buildings
Alfred B. Craig, Kelly W. Leovic, and D. Bruce Harris, AEERL

Design and Application of Active Soil Depressurization (ASD) Systems in School Buildings — Posters
Kelly W. Leovic, A.B. Craig, and D. Bruce Harris, AEERL; Bobby E. Pyle, Southern Research Institute; Kenneth Webb, Bowling Green (KY) Public Schools

Radon in Large Buildings: Pre-Construction Soil Radon Surveys — Posters
Ralph A. Llewellyn, University of Central Florida

Radon Measurements in North Dakota Schools — Posters
Thomas H. Morth, Arlen L. Jacobson, James E. Killingbeck, Terry D. Lindsey, and Allen L. Johnson, North Dakota State Department of Health and Consolidated Laboratories

Major Renovation of Public Schools that Includes Radon Prevention: A Case Study of Approach, System Design, and Installation; and Problems Encountered — Posters
Thomas Meehan

The State of Maine School Radon Project: The Design Study — Posters
Henry E. Warren, Maine Bureau of Public Improvement and Ethel G. Romm, NITON Corporation

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