Radon in the human environment: Assessing the picture

More than 50 countries are involved in an IAEA/CEC research programme on radon which is set to conclude later this year

by Jasimuddin U. Ahmed

Until the late 1970s, radon and its daughter products were regarded as radiation health hazards only encountered in the mining and milling of uranium. This notion has dramatically changed as a result of widespread indoor measurements of radon in many parts of the world. Increased radon concentrations in dwellings, for example, have been noted in countries in the temperate regions, where stringent energy conservation measures caused people to tightly seal doors and windows, particularly during the cold months. Radon problems also have been increasingly recognized in many non-uranium underground mines or in underground workplaces where ventilation is insufficient.

Attention to the problem of radon exposure and the associated health risks has thus been growing around the world. According to the assessments made by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), radon in the natural environment constitutes about 53% of the human exposure to natural radiation.

In underground mining, mainly uranium mining, incidence of excess lung cancer has been observed in the United States (Colorado) the Czech Republic, and Canada (Ontario). This also has been the case among underground fluorspar miners and in iron ore miners in Sweden. Today, the scientific community agrees on the link between the incidence of excess lung cancer among underground miners and exposure to radon and its daughters.

Current knowledge of potential health effects from radon exposure in dwellings, on the other hand, is rather limited. The relationship between the incidence of excess lung cancer among underground miners and exposure to radon cannot be sensibly used to understand potential health risks to the public. This is because the level of exposure in dwellings is much lower than in mines. There are opinions that the incidence of excess lung cancer among early uranium miners may be explained by synergistic effects of heavy smoking, ore dust, toxic fumes, etc. and extremely high radon exposures. Nevertheless, the data on miners may be useful provided differences are kept in mind between the exposure implications for the two groups of populations under two different situations.

In the late 1980s, the IAEA and Commission of the European Communities initiated a 5-year co-ordinated research programme (CRP) on radon in the human environment. More than 50 countries now have ongoing projects, an indication of the high level of interest in this subject. The CRP concludes later this year. This article presents selective results from radon surveys in some countries and describes the international framework for continuing co-operative research in this field.

Origin of radon

Principally, soil is the source of radon-222. It is the daughter product of radium-226 which belongs to the uranium-238 decay chain. Thoron (radon-220) is produced by the alpha decay of radon-224 which belongs to the decay chain of thorium-232. Radon and thoron are noble gases which can migrate from the soil either by molecular diffusion or by convection and enter the atmosphere. The distribution of radon in the air depends on meteorological conditions. The daughter products of radon and thoron are isotopes of heavy metals and can easily attach themselves to aerosol particles in the air. They decay by alpha and/or beta/gamma emissions. Aerosols laden with radon and thoron daughters are removed from the air by dry deposition, or by rain and other precipitation processes.

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Radon has a half-life of 3.8 days, while thoron is very short-lived with a half-life of only 55 seconds. Among the daughter products, some are short-lived, while some have long half-lives. The short-lived daughter products constitute the highest fraction of the radioactivity concentration at the ground level among all natural or man-made radioactive contaminants in the air. *(See table.)*

Building materials such as granite, Italian tuff, and alum shale lightweight concrete may contain significantly high concentrations of radon-226 which can be a source of radon migration into the indoor air. Outdoor air can play an important role for radon entry into the buildings through open doors and windows, mechanical ventilation and infiltration, and also uncontrolled leakage of air through cracks in the building. Additionally, radon contained in water and natural gas used at home can, to some extent, be transferred into the room air.

Concentration ranges of natural and artificial radionuclides in the air

Radionuclide		Half-life	Activity concentration (millibecquerel per cubic meter)
Natural	Tritium	12.3 years	≈ 20
	Carbon-14	5736 years	≈ 40
	Beryllium-7	53.6 days	1 -7
	Radon daughters*	164 µs - 26.8 minutes	1000 - 5000
	Lead-210	22.3 years	0.2 -1.0
	Polonium-210	138.4 days	0.03 - 0.3
	Lead-212	10.6 hours	20 - 1000
	Bismuth-212	60.6 minutes	10 - 700
Artificial	Iodine-131	8.04 days	< 0.0001 (4000**)
	Caesium-137	30.1 years	0.0005 - 0.005 (4000**)
	Ruthenium-106	386.2 days	0.0001 - 0.002 (2000**)

* Radon daughters are: polonium-218, lead-214, bismuth-214, and polonium-214.
** After the nuclear accident in Chernobyl, the highest value in Göttingen, Germany, 2-3 May 1986.
Source J Porstendorfer, Properties and Behaviour of Radon and Thoron and Their Decay Products in the Air, Proceedings of the Fifth International Symposium on the Natural Radiation Environment Tutorial Session, published by the Commission of European Communities, Luxembourg Office, 1993, ISBN92-826-5604-7

Selected major indoor radon studies

An avalanche of attention has been noted over the past decade among almost all countries of Europe and North America and many East European countries concerning radon in dwellings. Nationwide surveys have been undertaken to determine radon levels in homes and to assess consequent risks of lung cancer. Many countries in temperate zones, including China and Japan, have put into place large programmes on radon in dwellings and in workplaces. Among tropical countries, significant interest has been noted and radon survey programmes on varying scales have been undertaken.

The high level of interest in radon further can be noted from the scientific literature. At the International Symposium on the Natural Radiation Environment (NRE IV) held in Lisbon, Portugal, in 1987, 65% of the 110 published papers dealt with radon alone. Similarly, at NRE V held in Salzburg, Austria, in 1991, about 70% of the 163 papers dealt with radon issues.

Moreover, as previously noted, some 55 countries are participating in the IAEA/CEC co-ordinated research programme on radon. While it is not possible to present survey results from radon studies from so many countries, several are particularly worth noting.

United States. A survey carried out in the late 1980s by the United States Environmental Protection Agency (EPA) and announced by the US Public Health Service has indicated that indoor radon problems in the USA are more serious and widespread than previously suspected. According to the US Public Health Service, an estimated 5000 lung cancers among non-smokers each year are believed to be due entirely to indoor radon exposure; among smokers, indoor radon exposure played a role in 15 000 deaths from lung cancer. Some later estimates indicate even higher figures. The statistics indicate that indoor radon's human toll "probably exceeds by 10 times the problem of outdoor air pollution", the US Public Health Service said. EPA's recommendation for a further survey to test more houses was supported by the US Surgeon General, the American Medical Association, the American Lung Association, and other health organizations.

A national residential radon survey programme carried out by EPA from 1989 to 1991 estimated the frequency distribution of average annual radon concentrations in occupied housing units across 50 states. A 22-page questionnaire collected information on various factors. The results indicated that the arithmetical average annual radon concentration was 46 plus or minus 2 becquerels per m^3. It also indicated that about 6 million housing units exceeded the action level of 150 becquerels per m^3.

Another study in the USA compiled the results of measurements from available sources such as the EPA, the University of Pittsburgh, and agencies in various individual states. This study comprised radon measurements in homes for 1730 counties, well over half of all US coun-

The International Radon Metrology Programme

A system of reference, technical support, and regional co-ordinating laboratories has been established to assist in assuring comparability of radon measurements obtained by different institutions worldwide. It is called the International Radon Metrology Programme (IRMP). The programme is being co-ordinated by the IAEA and the Commission of the European Communities, with the University of Salzburg serving as the scientific secretariat. The laboratories assume the following responsibilities:

- Reference laboratories provide guidance on the scientific issues concerning the metrology of radon (radon-222), thoron (radon-220,) and their decay products, in particular in the areas of laboratory and field calibration of measurement devices, field sampling, and survey methods and analytical procedures. Such laboratories have been designated for three regions: Europe — the National Radiological Protection Board in the United Kingdom; North America — the US Department of Interior, Bureau of Mines, and the Environmental Measurements Laboratory; Asia and the Pacific — the Australian Radiation Laboratory.
- Technical support laboratories provide technical support in the form of calibrated exposure chambers, which are used to conduct intercomparison exercises for radon-222, thoron, and their decay products under defined laboratory conditions. Three technical support laboratories have been designated for the IRMP. These are two US Environmental Protection Agency offices in Montgomery and Las Vegas, USA, for radon-222; and CANMET in Elliot Lake, Canada, for thoron.
- Regional co-ordinating laboratories will provide logistical assistance in the co-ordination and conduct of regional activities related to quality assurance programmes concerning radon-222, thoron, and their decay products. These laboratories, which have been designated for four specific regions, are the Institute of Radiation Protection in Brazil for South America; the Australian Radiation Laboratory for Asia and the Pacific; the Atomic Energy Commission of Ghana for Africa; the Institute of Epidemiology in the Czech Republic for Europe and the Middle East; and the Institute of Uranium Mining in Hengyang, China, for Asia.

The operational programme functions in the following way. End users requiring calibration of passive detectors will pass them to their national laboratories. The national laboratories may calibrate the detectors or pass them to the regional co-ordinating laboratory for calibration by the technical support laboratory, which will run regular calibration exercizes and intercompare their measurement techniques with the reference laboratories. Laboratories at any level can calibrate their equipment using radon gas sources provided by national standards laboratories, such as the US National Institute of Science and Technology and the UK National Physical Laboratory.

ties and comprising about 90% of the US population.

An analysis of the health effects was carried out by Bernard Cohen on the health implications of exposure to indoor radon at the low levels observed. It strikingly found that the linear no-threshold theory of radiation carcinogenesis greatly overestimates the risk of low-level radiation. The analysis, which was reported in 1992, further concluded that even if the linear no-threshold theory is valid, the public fear of low-level radiation is grossly exaggerated.

United Kingdom. An estimate made by the National Radiological Protection Board (NRPB) in 1989 on the incidence of lung cancer from indoor radon exposure in the United Kingdom suggested that "radon may be responsible for anything up to 2500 or more lung cancers in a year out of the total of 4100". Indoor radon accounts for half of the average exposure of the UK population to ionizing radiation.

Up to the summer of 1991, measurements of radon in 58 000 homes were carried out in anticipation of follow-on epidemiological studies, plus implementation of remedial and preventive measures. Radon exposure in the home is now recognized by the government as a risk to health. Radon concentrations above the action level of 200 becquerels per m^3 have been discovered in so far in about 10% of homes in the UK. Despite this successful start, about 90% of potentially affected homes remain to be identified.

China. An epidemiological investigation was started in 1972 in areas having high levels of background radiation near Yangjang, China. A high background radiation area (HBRA) was chosen where natural radiation levels are three times higher than in a nearby control area. About 80 000 inhabitants in each area whose families have lived there for two or more generations were studied. The annual averaged effective dose equivalents in the HBRA were 5.4 mSv and 2 mSv in the control area from combined exposure to external gamma radiation and radon and its daughters. Environmental carcinogens and mutagens other than natural radiation, as well as host compounding factors, were studied. The investigation covered 1 million person years of observation to investigate cancer mortality in the two areas.

Results of the study found no increase of cancer mortality in the HBRA as compared to the control area. On the contrary, there was an observable trend of lower cancer mortality in the HBRA. The incidences of hereditary diseases and congenital defects were similar in both areas. The frequency of chromosomal aberrations in circulating lymphocytes was higher in the HBRA than in the control area.

National and international action levels

Over the years, governments and international bodies have set "action levels" for radon exposures. According to the International Commission on Radiological Protection (ICRP), they are meant for initiating intervention in order to help in deciding when to require or advise remedial action in existing dwellings. The choice of an action level is complex, depending not only on the level of exposure, but also on the likely scale of action, which has economic implications for the community and for individuals. The best choice of an action level may well be that level which defines a significant, but not unmanageable number of houses in need of remedial work. It is thus not to be expected that the same action level will be appropriate in all countries.

Action levels that have been adopted appear to differ. Similarly, the upper bound of radon concentrations for future new buildings differs from country to country. *(See table.)*

The IAEA, in its current revision of the Basic Safety Standards, recommends 200 becquerels of radon-222 per m^3 as the action level for dwellings and 1000 becquerels per m^3 for workplaces.

IAEA programme on radon

In the 1980s, the IAEA, in response to concerns among its Member States, decided to make an assessment of the situtation with regard to radon exposures in dwellings and work sites. One objective was to identify the types of guidance that would be needed for instituting any required control measures. In 1988, it initiated a co-ordinated research project (CRP) on radon in the human environment jointly with the CEC, and the programme took effect in late 1989. It attracted some 140 proposals from 55 countries, a rather overwhelming show of interest.

Following its review of the proposals, the IAEA awarded 14 research contracts and 37 research agreements, making a total of 51 projects. In addition, the CEC placed 25 research contracts, which it awarded to its Member States.

Subsequently, the former International Intercomparison and Intercalibration Programme (IIIP), which was run by a few specialized radon laboratories, became a part of the joint CRP at no cost to the IAEA. This gave an added dimension to the CRP by providing opportunities to many developing countries. It enabled them to take part in the intercomparison and intercalibration exercises at practically no cost to them and it afforded them access to all data. The IIIP recently was renamed as the International Radon Metrology Programme (IRPM). *(See box.)* It remains a part of the CRP.

Work through the CRP has progressed well, with a good number of projects now completed and others nearing completion. Results will be reported at the final research co-ordination meeting being scheduled for the fall of 1994. Thereafter, given the continuing high levels of interest, research through the IAEA's co-ordinated research programme likely will focus on the mitigation of radon exposures. ❐

National and international values of action levels and upper bounds for radon in dwellings

	Action level (Bq per m^3)	Upper bound (Bq per m^3)	Year established
Australia	200	NR	NR
Canada	800	NR	1989
CSFR (former)	200	100	1991
China	200	100	NR
Germany	250	250	1988
Ireland	200	200	1991
Luxembourg	250	250	1988
Norway	200	< 60-70	1990
Sweden	200	70	1990
United Kingdom	200	200	1990
United States	150	NR	1988
USSR (former)	200	100	1990
CEC	400	200	1988
ICRP	200-600	—	1993
Nordic countries	400	100	1986
WHO	100	100	1985

CEC= Commission of the European Communities, ICRP = International Commission on Radiation Protection; Nordic countries = Sweden, Finland, Norway, and Denmark; WHO = World Health Organization, NR = Not yet reported to the IAEA.