universities must be allowed to participate in research work in these laboratories. Scientists of these laboratories must be allowed to teach and train students who could be usefully employed in similar laboratories and industries. This arrangement will be beneficial to both the institutions and research workers. Mission-oriented research projects can be carried out very effectively and economically in this system.

Universities as resource centres for industrial development

Long-term industrial technology projects should be prepared in consultation with scientists and engineers. Scientific problems of these projects can be taken up by university rsearch laboratories in a time-bound programme. Engineering institutes must take up design and fabrication jobs. Thus a project indigenously conceived and designed by Indian scientists and engineers can be patented. A part of the financial gain by the industries should be given back to universities and engineering institutes. Such collaborative programmes will generate finance and provide employment opportunities.

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SCIENTIFIC CORRESPONDENCE

Indoor radon levels and inhalation doses to population in Punjab

During recent years, an increasing concern has been expressed over the presence of radioactive elements in the human environment and their health hazards, particularly radon and its daughter elements which account for nearly 60% of the total radiation dose received by humans from all sources[1]. Radon and its daughters emit alpha, beta and gamma radiations as they decay. Internally deposited alpha radiations are the most damaging as their relative biological effectiveness is about 20 times that of beta radiations. A high dose to internal tissues is delivered not by radon but by its short-lived daughters[2,3], Po, Pb and Bi. The main health hazard associated with radon and its daughters is lung cancer. This has been concluded from various epidemiological studies on miners[4,5]. Various case control studies in different parts of the world also suggest some kind of correlation between enhanced radon levels and lung cancer[6].

In the light of these facts, an extensive survey was conducted in Punjab, India for which no comprehensive data are available. This survey has been conducted as a part of the national coordinated radon project sponsored by Environment Assessment Division (EAD), Bhabha Atomic Research Centre (BARC), Mumbai. The authors' laboratory has been engaged in radon concentration studies in dwellings in other areas too[7–9].

A time-integrated track-etch technique using a plastic detector has been used for this survey. Cellulose nitrate, commonly known as LR-115 type II has been employed. Though the survey was performed with the twin chamber dosimeter cups (Figure 1), due to the problem of calculating the concentration of thoron daughters, it has been decided to present the data only from the bare card which records the alpha tracks due to both the gases and their alpha emitting daughters.

The survey was conducted in three phases. In the first phase, from March 1997 to March 1998, 90 dwellings in six districts, viz. Bathinda, Mansa, Moga, Patiala, Faridkot and Sangrur, were monitored. In the second phase, from August 1997 to August 1998, 69 dwellings were covered in three districts of Amritsar, Gurdaspur and Jallandhar. In the third phase, from November 1998 to November 1999, 39 dwellings in the districts of Hoshiarpur, Ropar and the Union Territory of Chandigarh were covered.

The dosimeters were generally kept in the dwellings at a height of 3 m above the floor. After exposure for the specific period, the detectors were collected and replaced by fresh ones. In this way data for the whole year were collected in the form of seasonal cycles. The exposed detectors were etched in 2.5 N NaOH at 60°C for a period of 80 min in a constant temperature bath (Tempo shaker water bath). After etching, the detectors were peeled off from the plastic base and counted using a spark-counter designed by the Radiation Safety Systems Division (RSSD), BARC. It is a specially-designed counter meant for counting the alpha tracks in pelliculable LR-115 detectors. The central 1 cm^2 area of the detector film was chosen for counting for all the detectors films. This instrument (Figure 2) consists of two electrodes between which the detector film is placed and suitable voltage applied, so that sparking takes place through the holes produced by alpha particles and is developed in subsequent etching of the film.

When an alpha particle is incident on the polymeric detector, it causes damage in the molecular chains and produces what is called a latent track. This damaged region is chemically more reactive than the other parts. So, during chemical etching, the damaged region known as latent track is converted to a through hole as the thickness of the detector is only 12 μm. Before counting, the samples are pre-sparked at a voltage of 900 V. The purpose of pre-sparking the detector before counting is to convert any partially developed holes into full ones if any residual thickness is remaining after etching, which is expected due to the difference in the energies of the incident alpha particles. For this, the film was placed on the electrode which has an area of 1 cm^2, then the mylar film

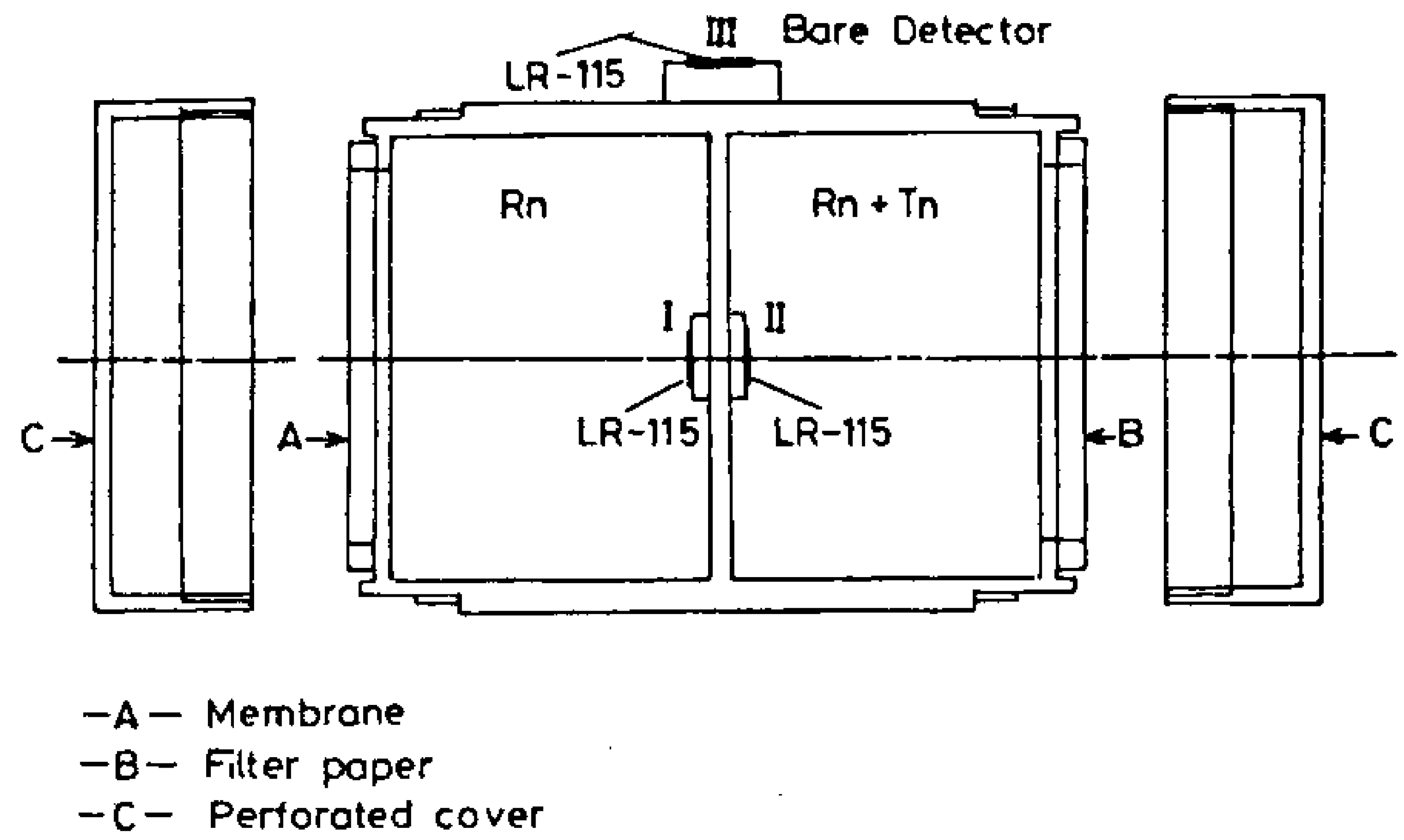

Figure 1. Twin-chamber Rn–Tn dosimeter cup.

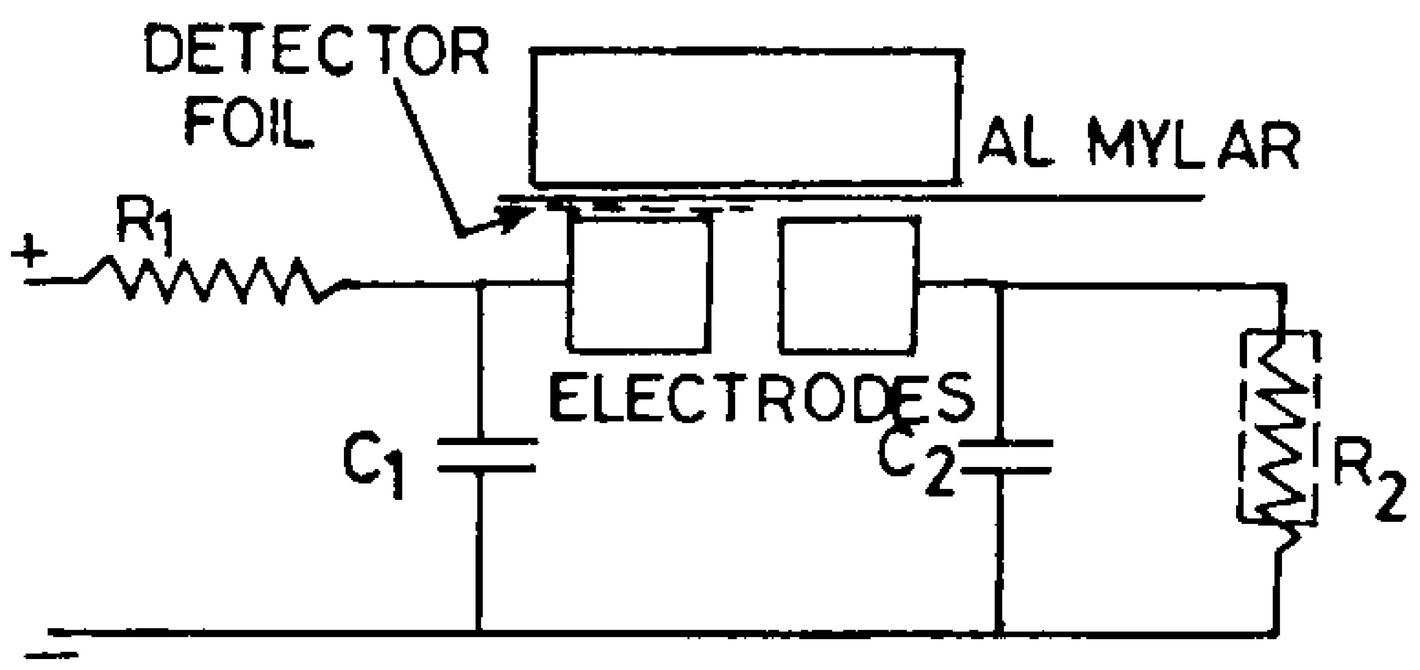

Figure 2. Schematic diagram of spark-counting set-up.

was placed so that it covers the film electrode as well as the other electrode and a high voltage of 900 V is applied. After pre-sparking is over, without disturbing the pre-sparked area, the mylar film is replaced by a fresh one and the voltage between the electrodes is set at the operating voltage, 480 V in this case, and the counts noted. The spark-counter was earlier calibrated for the operating voltage by plotting the variation of counts with voltage for a sample film and the voltage in the middle of the plateau region was selected as the operating voltage. Three readings of the same area of the detector were taken and their average was used to find the track density ($tracks/cm^2$).

Punjab lies in northern plains of India, at the foothills of Siwalik Himalaya. The soil here is the typical alluvial soil of the Indo-Gangetic plains. Majority of soil is loam or sandy loam. The soil in Bathinda and adjoining districts, neighbouring Rajasthan is sandy loam, highly granular and porous.

The radon concentration is calculated from the track density using the equation[10]

$$C_{rn}\ (\mathrm{Bq/m^3}) = T_1/k.d,$$

where T_1 represents the track density/cm^2, d represents the number of days of exposure, and k the calibration factor. The value of k used is 0.021 tracks cm^{-2} d^{-1} per Bq m^{-3} as provided in the protocol for the survey. Considering an equilibrium factor of 0.4 and an occupancy of 7000 h indoor[11], the annual exposure, effective dose and life time fatality risk from lung cancer have been calculated (Table 1) using the conversion coefficients reported by the International Commission on Radiological Protection (ICRP)[12].

A brief description of the quantities and units used in this paper is given here. Radon concentration is usually expressed in Bq/m^3. Becquerel is the unit of radioactivity which corresponds to one disintegration per second. The unit used for exposure of individuals to radon progeny is Working Level Month (WLM). The dose is a measure of average density of energy absorbed by a mass of cells and is expressed in J/kg or Sv. The effective dose is calculated by multiplying the absorbed dose with a constant factor which accounts for the biological effectiveness of the radiation and radiosenstivity of the different organs. Risk here refers to the probability that a fatal lung cancer will occur.

The yearly average indoor radon concentration measured in dwellings in Punjab is summarized in Table 2. The radon concentration is found to vary from a minimum value of 15.3 Bq/m^3 to a maximum value of 217.9 Bq/m^3 in Amritsar district. This large variation may be explained on the basis of house constructions. The dwelling with a minimum value of 15.3 Bq/m^3 has concrete flooring, cement plastered walls, large volume and good ventilation throughout the year while the dwelling with the highest value of 217.9 Bq/m^3 has *kutcha* flooring, mud-plastered walls, small size and poor ventilation with no windows. While Bathinda district recorded the maximum yearly average value of 65.1 Bq/m^3, Jallandhar district recorded the minimum yearly average value of 35.7 Bq/m^3.

Radon concentration also varies depending upon the nature of the soil and its porosity. The dwellings in Bathinda district are located mostly in sandy soil with high porosity and permeability for radon emanation. Hence Bathinda recorded the maximum yearly average value. The yearly average values of radon concentration vary from district to district in Punjab and this variation is location-dependent. The minimum to maximum variation of radon concentration within each district is generally dwelling-dependent, i.e. the type of construction and ventilation. Villages in Punjab do not have thatched huts or dwellings with wooden flooring. There are a few *kutcha* houses with mud flooring and walls and they contribute to maximum values of radon concentration compared with *pucca* houses with concrete flooring and good ventilation.

Annual exposure to radon progeny varies from 0.157 WLM to 0.286 WLM, with an average value of 0.238 WLM, while the annual effective dose varies from 0.61 mSv to 1.11 mSv, with an average value of 0.92 mSv. Life time fatality risk varies from 0.47×10^{-4} to 0.86×10^{-4}, with an average value of 0.72×10^{-4}.

The seasonal variation of radon concentration is shown in Table 3. Data have been presented for the six districts for which the survey was conducted

Table 1. Annual exposure, effective dose and fatality risk for population in Punjab

District	Annual exposure $\times 10^{-2}$ (WLM)	Annual effective dose (mSv)	Life time fatality risk $\times 10^{-4}$
Gurdaspur	28.2	1.09	0.85
Amritsar	24.6	0.95	0.74
Jallandhar	26.4	1.02	0.79
Mansa	25.7	1.00	0.77
Bathinda	26.0	1.01	0.78
Sangrur	21.6	0.84	0.65
Patiala	19.6	0.76	0.59
Moga	20.6	0.80	0.62
Faridkot	20.8	0.81	0.62
Hoshiarpur	28.2	1.09	0.85
Ropar	15.7	0.61	0.47
Chandigarh U.T.	28.6	1.11	0.86
Average	23.8	0.92	0.72

Table 2. Indoor radon concentration in dwellings in Punjab

District (No. of dwellings)	Radon concentration (Bq/m^3)		
	Minimum	Maximum	Average
Gurdaspur (31)	24.4	101.4	58.5
Amritsar (32)	15.3	217.9	60.0
Jallandhar (6)	20.3	62.4	35.7
Mansa (11)	39.0	105.2	64.0
Bathinda (13)	33.7	132.8	65.1
Sangrur (28)	20.1	123.2	49.0
Patiala (24)	23.9	93.9	44.6
Moga (11)	33.8	66.4	46.8
Faridkot (3)	32.8	65.8	47.3
Hoshiarpur (13)	35.1	140.7	64.2
Ropar (19)	34.1	114.0	56.0
Chandigarh U.T. (7)	33.3	107.1	59.1

Table 3. Seasonal variation of indoor radon levels in dwellings in different districts

District	Summer March–mid June (1997)	Monsoon mid June–September (1997)	Winter October–March (1997–1998)
Patiala	23.1	35.9	60.5
Sangrur	27.6	40.6	67.9
Bathinda	14.9	41.9	86.0
Faridkot	36.4	27.7	62.6
Moga	35.7	38.8	54.8
Mansa	27.4	39.1	101.3

simultaneously during March 1997–March 1998. It is clear from Table 3 that the radon concentration is enhanced in winter months compared to summer months and this variation is quite appreciable. The rainy season also recorded an increase in radon concentration compared to the summer season, ranging from about 8% to 55%, except in the case of Faridkot district which may be due to paucity of data. The seasonal variation observed in the indoor radon levels can be attributed to the change in ventilation inside the dwellings and meteorological variation of the exhalation rate of radon. During the winter season, the inside of a house is warmer compared to the outside. This increase in indoor temperature can lead to a slightly lower atmospheric pressure inside the house which causes an increase in the exhalation rate of radon from the floor and walls of the room. Also, the reduced ventilation in winter to conserve heat, leads to a build up of radon inside the house.

ICRP in its publication (ICRP 65) has recommended that remedial action should be taken for radon mitigation if the indoor radon values lie in the range 200–600 Bq/m^3 corresponding to an annual effective dose of 3–10 mSv. This action level corresponds to 0.88–2.63 WLM for exposure to radon progeny. As is evident from Tables 1 and 2, the radon values and annual effective dose to the population are below this action level in all the districts. So we can safely conclude that radon exposure is not a significant health hazard for the population in Punjab.

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