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# A correlation study of radon in dwellings with radium content of soil

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**Various national and international surveys have demonstrated an increase in radon (Rn) levels in dwellings and consequently there is a continuous growing concern about its health effects on the population. Rn progeny levels in dwellings are likely to be a multiple of outdoor levels. The main sources of indoor levels are the ground, the building materials, tap-water and domestic gas supplies. In houses with high concentration, the main source of Rn is the soil gas of the subjacent ground. Rn in soil gas depends on the radium content of the soil and the soil density. In India the first set of measurements were made in about 800 houses, which were identified as high background areas, and soils in these areas contain comparatively high levels of uranium and thorium. These measurements have given a geometric mean of 10.6 mWL for potential alpha energy concentration corresponding to a mean effective dose equivalent of 3.31 mSv. The second set of measurements consists of 1200 dwellings confining to mostly normal background areas. The measurements have given a mean value of 3.4 mWL corresponding to a dose equivalent of 1.16 mSv. The results of high background areas show about 2.8-fold increase compared to the background areas.**

**The results of the soil radioactivity content in some high background areas when compared with the measured Rn levels in dwellings in nearby locations show that as soil activity increases, Rn levels tend to increase. In some cases a positive correlation has been obtained between Rn concentration in dwellings and the radium content of the soil. However, this trend is not observed always. This may be due to the influence of meteorological parameters, that affect the emanation rate. The relation between the emanation rate and the Rn and its progeny concentration in dwellings have been discussed.**

Rn-222 occurs widespread throughout nature, arising from radium-226 present in practically all natural formations. Rn gas, generated within the soils, diffuses into the atmosphere in measurable amounts. The rate of emanation depends on many factors like type and meteorological parameters. Various national and international surveys have demonstrated an increase in Rn levels in dwellings and consequently there is a growing awareness about its health effect on the population. Rn progeny levels in a dwelling are likely to be a multiple of outdoor air.

The main sources of indoor levels are the ground, the building material, tap-water and domestic gas supply. In houses with higher concentrations, the main source of Rn is the soil gas of the subjacent ground. Rn in soil gas depends on the radium content of the soil and soil density.

The physical characteristics of soils, density of the gas and void fractions, influence the transport of Rn and exhalation rate of Rn in the atmosphere. The present study was undertaken with a view to finding out whether a correlation exists between the Rn levels in dwellings with radium content of the soil.

## Measurement procedure

Indoor Rn levels in dwellings were measured using a passive technique. The method consists of exposing small strips of LR-115 Type II solid state nuclear track detector (SSNTD) of 2.5 × 2.5 cm affixed on a rectangular card in the dwelling. The detector card is suspended from the roof or ceiling of the dwelling environment for a known period of exposure time ranging from 40 to 60 days.

The detector cards after the exposure period were retrieved and were chemically etched in a suitable alkali solution and recorded tracks were scanned under an optical microscope. The first set of measurements were made in about 800 houses located in areas identified as high background areas by the Atomic Minerals Division of the Department of Atomic Energy. The soils in these areas were found to contain comparatively higher concentration of uranium and hence radium. The second set of measurements were made in about 1200 houses confining mostly to the normal background areas.

The data of the radium content in the soil samples from the neighbourhood areas were made available by the measurements carried out by Mishra[1] on the natural and fallout radioactivity content of soil, which is outlined briefly as follows. The soil samples were collected using a post-hole anger of 6 inch diameter for 0–6″ depth from the undisturbed areas of the above locations. The soil samples thus collected were counted by using a low level gamma spectrometric set-up consisting of a 12.5 × 10 cm NaI (T1) integral assembly coupled to a multichannel analyser. The details regarding the calibration and measurement procedures are given elsewhere[2, 3].

## Results

The results of the first set of measurements made in about 800 dwellings, which were identified as high background areas have been discussed in detail elsewhere[4]. The estimated geometric mean concentration for the total potential alpha energy concentration (PAEC) due to Rn daughters was 10.6 mWL (WL = working level). The results of the second set of measurements confining to the normal background areas have been discussed elsewhere[5]. The estimated geometric mean of the PAEC concentration has 3.7 mWL. The results of the high background areas show about a 2.8-fold increase compared to the normal areas. The effective dose equivalent was estimated using the conversion factor of 9 mSv/WLM as obtained from ICRP-50 (ref. 6), for a breathing rate of 16 lpm and occupancy factor of 16 h per day.

Table 1 gives the estimated soil radioactivity content in some high background areas and the measured Rn levels in dwellings of those areas. Here the Rn concentration was estimated using the equilibrium factors estimated for Indian dwellings.

The equilibrium factor $F$ is evaluated using the relation

$$F = \frac{\mathrm{WL} \times 3700}{C_{\mathrm{Rn}}},$$

where $C_{\mathrm{Rn}}$ is the Rn concentration in Bq m$^{-3}$. This is estimated by measuring both Rn and PAEC concentrations by way of exposing two detector configurations, viz. bare mode and the cup with membrane mode. The details of the measurement procedure of $F$ are given elsewhere[7]. In the locations wherever the Rn and PAEC concentrations are measured, the actual Rn concentration measured was taken. In other locations of the same area, the average $F$ value obtained from the study has been used for calculating the Rn concentration.

**Table 1.** Measured radium-226 content in soil and the radon-222 levels in dwellings.

| | Radon levels | | |
|---|---|---|---|
| Location | (mWL) | (Bq m$^{-3}$) | Ra-226 in soil ($\mu\mu$c/g) |
| Bombay | 1.2 | 13.5 | 0.25 |
| Calcutta | 10.4 | 98.7 | 0.55 |
| Chandigarh | 8.8 | 83.5 | 0.40 |
| Chirrapunji | 10.6 | 100.6 | 0.57 |
| Delhi | 5.7 | 54.1 | 0.52 |
| Dehra Dun | 10.8 | 102.5 | 0.69 |
| Hyderabad | 15.1 | 143.3 | 0.41 |
| Jaipur | 6.7 | 63.6 | 0.30 |
| Jodhpur | 4.5 | 35.4 | 0.29 |
| Kanpur | 6.1 | 57.9 | 0.65 |
| Meerut | 6.7 | 63.6 | 0.61 |
| Nagpur | 8.6 | 86.6 | 0.32 |
| Ranchi | 3.0 | 28.5 | 0.07 |
| Shillong | 6.7 | 63.6 | 0.42 |
| Srinagar | 6.1 | 57.9 | 0.49 |
| Trivandrum | 9.2 | 87.3 | 0.56 |

A comparison of Rn levels with radium content in soils measured at different locations in the high background areas is given in Figure 1. The results show a correlation coefficient of 0.16 for the entire data. The significant value of correlation coefficient for testing null hypothesis works out to be 0.42. Hence there is no correlation between the radium content in the soil and the Rn levels. However, the data when separated out into two groups, the group consisting of measurements carried out during January to April of the year gives a correlation coefficient of 0.74. The significant value for testing null hypothesis works out to be 0.67. Hence it can be concluded that there exists a correlation between the radium content in the soil and Rn levels in the dwellings for the measurements done during January to March of the year.

The data group for the measurement carried out during April to July gives a correlation coefficient of 0.49. The significant value for testing null hypothesis works out to be 0.62. Hence it can be concluded that no correlation exists between the radium content of the soil and the Rn levels in the dwellings.

The above observations can be explained on the basis of the seasonal variations of Rn in houses[8] and the rate of mixing of Rn in houses with outside air depending on the ventilation rate. The correlation observed between indoor Rn concentration and the soil radium content during January to April is likely to be

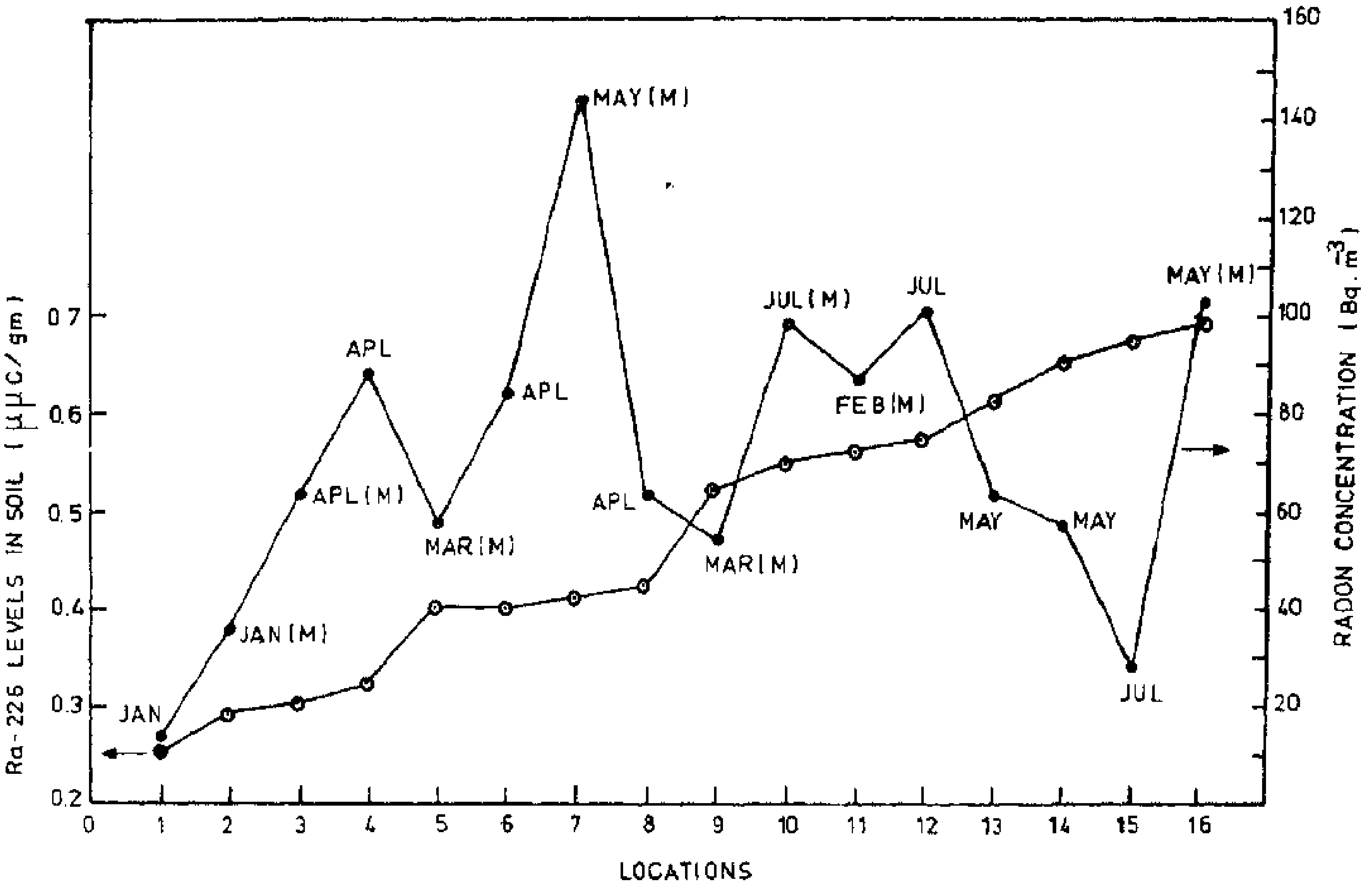

**Figure 1.** Comparison of radon levels in dwelling with Ra-226 levels in the soil measured at different locations.

due to the higher Rn concentration expected to be present in houses during this period. This is true as observed in the study of the seasonal variations of Rn in houses as shown in Figure 2.

Figure 2 gives the typical monthly variation of indoor Rn levels for the period from January to September of a year. It can be seen that during January to April, Rn in houses is the highest. The mixing of Rn in houses is minimum probably due to the decreased ventilation rate during this period. When the Rn in houses is high due to the reasons outlined above, the correlation between indoor Rn concentration and the soil radium content is observed. Rn emanating from the soil accumulates in the house by entering through leaks and cracks in the basement and the ground floor; and also during this season the Rn concentration in the houses remains more or less undisturbed.

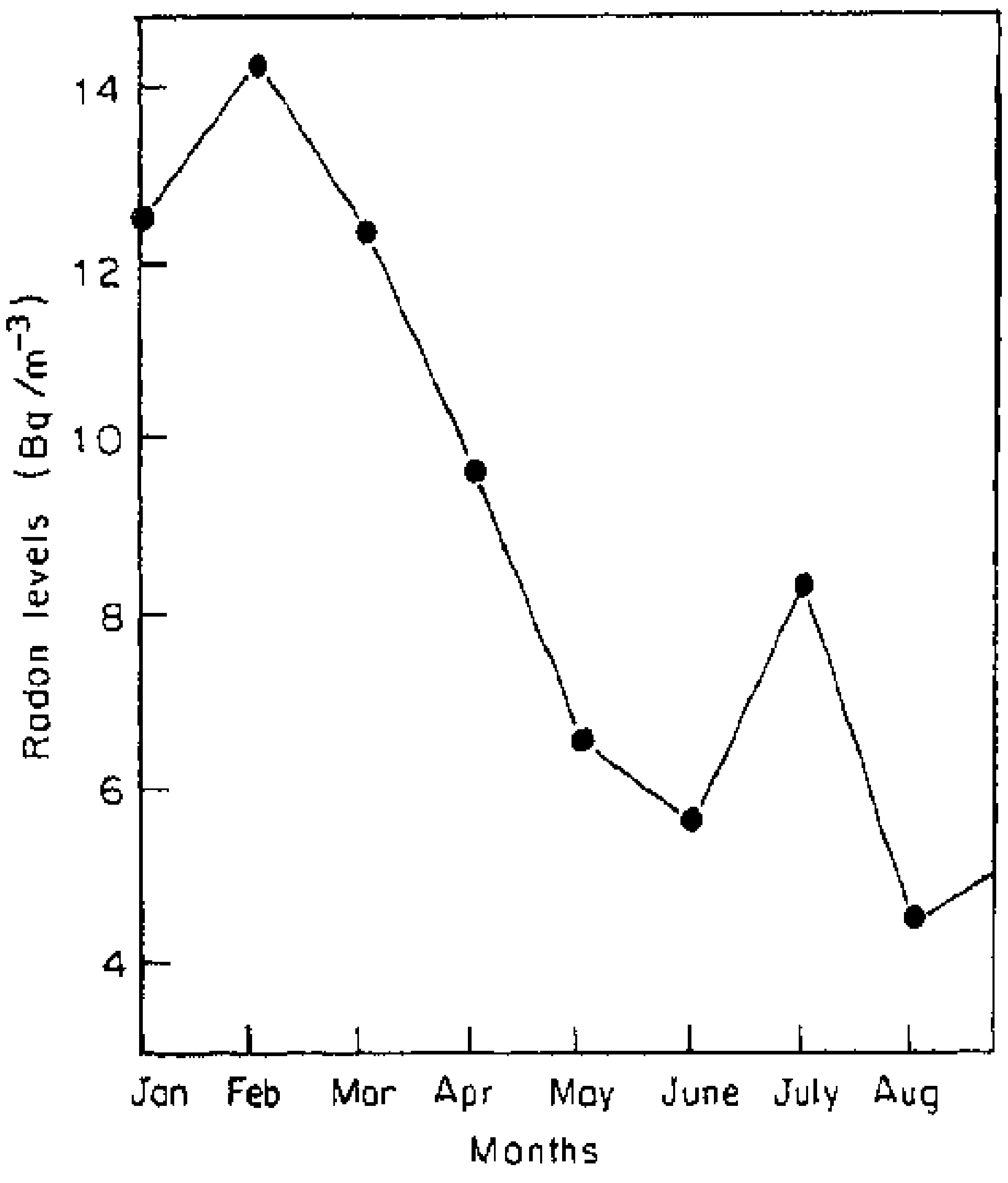

**Figure 2.** Typical monthly variation of indoor radon concentration in a dwelling.

Hence, we find a correlation between indoor Rn and the soil radium content. During April to July and onwards, the indoor Rn concentration has been observed to vary as shown in Figure 2. These variations must be due to a large scale mixing of the indoor Rn with outside air depending on the natural ventilation rate. The fluctuations in the indoor Rn concentrations are quite rapid during this period, and hence no correlation between indoor Rn and the soil radium content could be observed as outlined previously.

In addition to the behaviour of indoor Rn resulting in variations observed in the correlation coefficient between indoor Rn and the radium content in the soil, it is also possible that the variations in the Rn exhalation rate from the soil and the entry rates into the house also vary depending on meteorological conditions like wind-speed, temperature and barometric pressure. Studies of the Rn emanation from the soil and its exhalation from the earth–air interface have been carried out earlier[9].

## Conclusion

In conclusion, it can be said that high radium content in the soil in the neighbourhood of the houses need not necessarily result in high indoor Rn concentration. Depending on the time of observations in a year and fluctuations in the meteorological parameters, radon entry into the house and the Rn concentrations in the house vary. During meteorologically stable conditions, it is possible to encounter more than high Rn concentrations in the houses situated in the neighbourhood of the areas containing more than normal radium content in the soil. For a proper interpretation of the results obtained from the measurements of indoor Rn concentrations in the high background areas, it appears that one should study the seasonal variations of indoor Rn levels in these areas and relate them with meteorological parameters. Also it is necessary to make a study of the radon entry into the house from the soil via cracks and joints in the floor and loose pipe fittings through the basements and leakages at the wall-floor joints.

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# Performance characteristics of a hypercube-type parallel computer

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**We present a status report on a project to build a hypercube-type parallel computer. LINPACK benchmark results for three pilot models are reported, and comparisons made with a similar system made by Intel Corporation. The influence of interprocessor communication speed on the LINPACK ratings achievable is discussed. Plans in progress to achieve the target system are also briefly outlined.**

PROJECT PACE has the objective of designing, developing and building a high-speed concurrent (parallel) computer. Funded by the Defence Research and Development Organization (DRDO) of the Government of India, the project aims at meeting the needs of our fluid dynamicists. Computational fluid dynamics (CFD) is among the most demanding of calculations performed on computers, a typical one calling for $10^{12}$ arithmetical floating-point operations in about $10^4$ seconds, implying a speed of $10^8$ floating-point operations per second or 100 megaflops (MFLOPS). Moreover, such speeds must be available with double-precision arithmetic, and for FORTRAN programs. Notwithstanding the primary objective of our project, we believe that our system would be useful for a number of other scientific applications as well, which is the reason for this report.

## System architecture

Historically the standard route to heavy number crunching has been via the so-called supercomputer, of which the famous CRAY is the canonical example. While a technical marvel, supercomputers require very sophisticated technologies for their manufacture. Fortunately, thanks to advances in microprocessor technology, the notion of parallel computing long