RADIUM IN VEGETABLE GARDENS

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The contamination of soil in a town in which the refining of radium and uranium has been carried out for 40 years has raised the question of the maximum concentration of radium that may be permitted in the soil of a domestic vegetable garden.

The soil may be contaminated with all the members of the uranium series, but radium is likely to make the major contribution to the dose commitment of people who eat vegetables grown in this soil. Work on the uptake of the four long-lived radionuclides of the uranium series by red kidney beans showed that the concentration of radium in the roots was two to three times lower than that of the other nuclides, but the upward transport of radium was between 50 and 200 times greater[1]. This evidence is consistent with the observation of Mayneord[2] that the contribution of radium to the alpha activity of plants is much greater than that of thorium.

An evaluation of the maximum permissible concentration of radium in soil requires knowledge of the transfer of radium from soil to plants, the gastrointestinal absorption of radium from food, the rate of consumption of food, the maximum permissible amount of radium in the body, and the retention of radium by the body.

A Belgian study[3] of the uptake of radium by plants grown in contaminated fields provides data most pertinent to our concerns. Effluents from a factory that extracted radium from uranium ores for 40 years discharged into a stream that from time to time overflowed its banks. Land that was being developed for agriculture was flooded with contaminated water when dikes were breached during heavy rains. The concentration of radium by plants grown on this land, expressed as the ratio of the concentration of radium in dry plant to that in dry soil, is used here as the best estimate of the transfer of radium from soil to plant.

The gastrointestinal absorption of radium from food was found to be 20% in a four-year old boy[4]. An absorption of 20% has also been reported in elderly people[5]. Other observations on adult males have been extremely variable, ranging from zero to 60%[4].

Estimates of the annual consumption of food by Canadians have been taken from the reports of Statistics Canada[6].

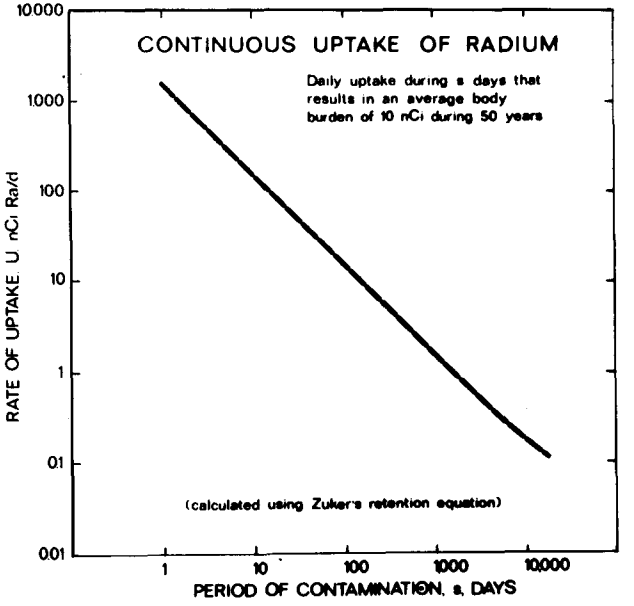
The maximum permissible body burden of 0.1 μCi ^{226}Ra for occupationally exposed people was established by an advisory committee of the United States' National Bureau of Standards in 1941[7]. It was based on a study that began in 1932. Subsequent investigations of cases involving dial painters, radium chemists, and patients treated with radium have not affected this standard[8]. In 650 cases studied up to 1970, no radiation injury was detected in people with a residual body burden of less than 0.5 μCi ^{226}Ra. Following the International Commission on Radiological Protection, we may take 0.01 μCi ^{226}Ra as the maximum permissible body burden for people who are not occupationally

exposed.

An exponential equation for the retention of radium by man, a refinement of the equation given in ICRP Publication 10A, has been used to calculate the daily uptake of radium for various periods of time that would lead to a body burden of 10 nCi ^{226}Ra. The exponential equation was used for simplicity of computation of the values used in the present work. It graduates the data as well as the function given in ICRP Publication 20 , giving the same values of retention and time integrals. Daily uptakes of radium were calculated that would lead to a body burden of 10 nCi at the end of a period of contamination, or averaged over the duration of the period of contamination.

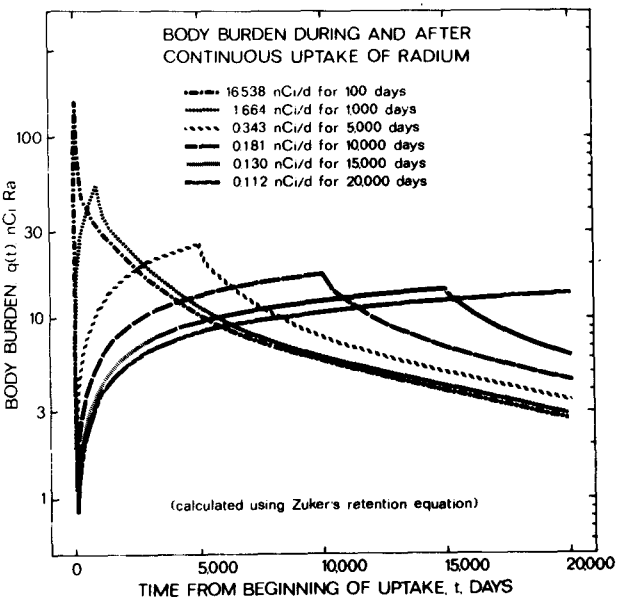
The daily rate of uptake, U, during a period of s days, followed by a period of uptake at the normal dietary rate, N, that would lead to an average body burden of 10 nCi during 50 years was also calculated and it is presented in Figure 1.

FIGURE 1



The variation with time of the body burden of radium during and after various initial periods of contamination is illustrated in Figure 2. Each of these patterns of contamination results in the same integrated activity of 200 μCi-days, although the body burdens at the end of 20,000 days vary by a factor of 5.

FIGURE 2



The following assumptions were made in order to calculate the concentration of radium in soil that will lead to an average body burden of 10 nCi during 50 years due to consumption of vegetables grown in the soil:

- the ratio of concentrations of radium in dry vegetable and dry soil is 0.025 for potato tuber and 0.25 for other vegetables.
- the ratio of fresh weight to dry weight for potatoes is 4.5 and for other vegetables is 11[9].
- the average Canadian consumes 69 kg of potatoes a year and 86 kg of other vegetables, including tomatoes, a year.
- gardeners grow enough potatoes to satisfy their annual consumption and enough other vegetables to satisfy their consumption for 15 weeks a year.
- the gastrointestinal absorption of radium is 20%.

The annual uptake of radium, A nCi, is given by

$$A = G(W_p \times F_p \times C_p \times S + W_v \times F_v \times C_v \times S)$$

where S is the concentration of radium in soil in nCi/kg,
W_p and W_v are the annual consumption per capita of domestically-grown potatoes and other vegetables,
C_p and C_v are the concentration factors,
F_p and F_v are the ratios of dry to fresh weight, and
G is the gastrointestinal absorption of radium.

The concentration of radium in soil is thus

$$S = \frac{A}{G(W_p \times F_p \times C_p + W_v \times F_v \times C_v)}$$

and substituting the values given in the assumptions above,

$$S = 5.3 \times A \text{ nCi/kg dry soil.}$$

Consider, as examples, three cases of contamination for total periods of 50 years:

- contaminated food for 25 years, S = 360 nCi/kg
- contaminated food for 5 years, S = 1.7 μCi/kg
- contaminated food for 1 year, S = 8.2 μCi/kg.

These examples illustrate the way in which the permissible concentration of radium in soil may vary depending on the duration for which a vegetable garden is to be used. The most stringent condition would be the use of a garden for 50 years, which requires contamination of the soil of less than 220 nCi/kg.

There are many approximations in these calculations, but the results provide a clear idea of the scale of the problem of contamination of vegetable gardens by radium. The calculated concentrations of radium in soil depend on the accuracy of estimation of 5 quantities: A, which in turn depends on the retention equation, C, F, G, and W. The variability of the data on the retention of radium about the fitted equation given in ICRP 20 is between 10 and 20%. In a controlled experiment with healthy men[10], the coefficient of variation of radiation dose due to internal contamination with radiocobalt was 20%. This measure of biological variability will be used as the accuracy of the calculated uptake of radium that results in a given dose commitment. The accuracies of the other variables are also estimated to be about ±20%, which leads to an accuracy of ±45% for the concentration of radium in soil. This estimated accuracy may perhaps be put in context by remembering the somewhat arbitrary factor of 10 that is applied to the permissible occupational burden to obtain a permissible burden for people who are not occupationally exposed.

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