Further development of a computational method to evaluate indoor gamma dose-rate from building materials using external wall measurements

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Abstract. Sometimes, when it is impossible to perform a direct measurement, it is critical to obtain an estimate of the indoor gamma dose rate with adequate accuracy and precision. With a method we set up – the IN-OUT method – it is possible to estimate the indoor gamma dose rate attributable to building materials. Gamma dose rates are measured in contact with an external wall of a dwelling, and then a “room model” elaboration accounts for the geometrical and structural characteristics of the dwelling. The method was validated over more than 200 dwellings in three Italian regions within the “SETIL” project, the Italian epidemiological study on the aetiology of childhood leukaemia, lymphoma and neuroblastoma. In a first phase, indoor gamma dose rate estimates were obtained using the detailed dwelling information contained in questionnaires filled-in and collected during the indoor measurements. These estimates were very close to the measured values. A more general, less site-dependent approach has now been implemented for 74 dwellings of one region (Latium); by assuming average values for many indoor parameters instead of using the detailed data from the questionnaires, we evaluated the predictive characteristics of this method in situations where detailed data are not available. The ratio between estimated and measured indoor values has an overall average of 1.00 and 20% coefficient of variation. The results are very similar for tuff and concrete dwellings and support the usefulness of the IN-OUT method to obtain an estimate of the indoor gamma dose rate.

KEYWORDS: indoor gamma radiation, epidemiological studies, building materials, room model.

1. Introduction

Indoor gamma exposure is an important contribution to the total exposure of the population to ionizing radiation. The main sources of such exposure are building materials, especially in multi-storey buildings. Some building materials can have a high content of natural gamma-emitter radionuclides, e.g. alum shale, tuffs, pozzolana, etc. In two Regions of Central and Southern Italy, some of these materials (i.e. tuff and pozzolana) are widely used, with the regional average gamma dose rate in dwellings above 200 nGy/h [1].

When it is impossible to enter a dwelling to measure the indoor gamma dose rate, as it can happen in epidemiological studies and surveys on randomly selected dwellings if inhabitants refuse the measurement or the dwellings are not currently occupied, it would be very useful to obtain an accurate and precise estimate of indoor gamma dose rate. We set up the so-called IN-OUT method to estimate the indoor gamma dose rate attributable to building materials [2]. This method contemplates the measurement of the gamma dose rate in direct contact with an external wall of the dwelling, and a “room model” elaboration that accounts for its geometrical and structural characteristics. In order to further validate this method, a study was carried out within the framework of the “SETIL” project, the Italian epidemiological study on the aetiology of childhood leukaemia, lymphoma and neuroblastoma. For the validation study we used the data – actual indoor dose rate measurements and detailed dwelling information contained in questionnaires collected during the indoor measurements – for a total of 209 dwellings distributed in three Italian regions: Latium, Campania and Piedmont.

In a first phase, indoor gamma dose rate estimates were obtained using the detailed dwelling information from the questionnaires. These estimates were very close to the measured values [2,3,4]. A more general and less site-dependent approach (partly described in [4]) has now been implemented, which assumes average values for many indoor parameters instead of using detailed questionnaire data, in order to evaluate the predictive characteristics of this method when most of the detailed data are not available. In this paper, the
new procedure is presented and the results obtained for the 74 dwellings of the Latium region are reported and discussed.

2. Material and methods

2.1 Validation study for the IN–OUT method

As mentioned above, the IN–OUT method was tested by comparing estimated vs. measured indoor gamma dose rates.

For each dwelling, two rooms were generally considered (three rooms in some dwellings). Characteristic geometrical and structural data of the selected dwellings were collected through questionnaires by trained interviewers, who also performed indoor and outdoor measurements, by means of a 3” x 3” plastic scintillators that are very sensitive from ~50 keV to ~7 MeV, and yield accurate and precise results of gamma dose rate in a short time (generally less than 10 min).

2.2 Outline of the IN–OUT method

The IN–OUT method along with some preliminary results have been described in detail elsewhere [2,3].

The original implementation of the IN–OUT method to estimate indoor gamma dose rate required the following data: i) one outdoor gamma dose rate measurement in contact with an external wall; ii) some simple information of the analyzed dwelling, such as the number of main/external/partition walls, and room dimensions.

Some more specific information concerning the gamma radiation field emitted by external walls was felt to be necessary, but previous spectrometric measurements (Nuccetelli and Bolzan, 2001) had shown that generally, in the central part of Italy and in Piedmont, it is possible to classify buildings into two groups, depending on the building materials used: 1) tuff and stone; 2) concrete and bricks.

The main procedure steps of the IN–OUT method applied in [2] can be described as follows:

a) the gamma dose rate is measured in contact with an external wall representative of the selected dwelling, i.e. a wall presumably with the same composition and thickness of the main or external walls of the rooms whose gamma dose rate must be estimated;

b) the activity concentration of the gamma emitters present in the external/main walls is calculated by applying a computational code (described elsewhere [5]) and using the gamma dose rate measured as in a) as input;

c) the gamma dose rate is calculated at the centre of the room, on the basis of the geometrical, structural and radioactive characteristics of the walls, floor and ceiling, with the following assumptions:

• for the external/main walls the activity concentrations of gamma emitters are assumed to be equal to those calculated in b);

• for dwellings with external/main walls made of concrete or bricks, the partition walls were assumed to be made of concrete or bricks as well, with activity concentrations taken as the mean values obtained in b); thickness and density are assumed to be 10 cm and 1000 kg m$^{-3}$, respectively;

• for dwellings with tuff walls, the partition walls were assumed to be made of tuff as well, with activity concentrations considered equal to the external/main tuff walls of the same dwelling, but 10 cm thick;

• for floor and ceiling the same activity concentrations and thickness of the partition walls are assumed, but different densities are used for buildings of different age.

In the second version of the method [4] we adopted an approach that is less dependent on the specific characteristics of each dwelling, and we accounted for the influence of soil on the outdoor measurement of the external wall. This second computational procedure of the IN–OUT model presents some major differences:
the contribution of outdoor soil to the gamma dose rate measurement in contact with the outdoor wall is evaluated on the basis of a gamma dose rate measurement in contact with outdoor soil through an iterative procedure;
• for buildings mostly made of concrete, the radioactive concentration of floors, ceilings and partition walls has been assumed to be equal to that of external walls, (but with different density and thickness), instead of the average measured concentration of external concrete walls, as assumed in the previous procedure;
• for buildings mostly made of tuff, the radioactive concentration of the partition walls has been assumed to be equal to that of external walls (but with different thickness), whereas for floors and ceilings the average measured concentration of external concrete walls was utilized, as it was done in the previous procedure for all floors, ceilings and partition walls;
• the computational procedure has been reorganized and rewritten to perform calculations for all dwellings together, with the option to change one or more parameter values in order to carry out a sensitivity study currently in progress. In the previous procedure, calculations were done dwelling by dwelling exploiting the detailed information reported in the questionnaire about the internal structure of the dwelling.

All calculations of gamma dose rate in air were done with the Mathematica@ software.

2.3 Further development of the IN-OUT method

Wherever possible, the use of this method to evaluate indoor gamma exposure should be independent of the internal structure of dwellings. In this light, the new approach contemplates the following:

The 74 dwellings, for a total of 184 rooms, were divided into two classes: tuff and concrete.
  • Mean room dimensions – obtained by averaging the dimensions of all the rooms in each class – were used instead of the actual figures.
  • The mean number of main and partition walls – obtained by averaging the relevant information of all the rooms in each class – was used.
  • In each dwelling, composition and activity concentration of main and partition walls were assumed to be equal to those of the measured external wall.

As regards ceilings and floors, we adopted a different procedure for the two classes:
  • for each concrete dwelling we used the actual values of concrete activity concentrations obtained by measuring the outdoor wall
  • for all tuff dwellings we used the mean values of concrete activity concentrations obtained by measuring outdoor walls

3. Results and discussion

Table 1 reports the results obtained using average information for some characteristics of each dwelling (sample of 74 dwellings in Latium). The indoor gamma dose rate was measured and estimated at the centre of the selected rooms and, for each dwelling, the average dose rate in the selected rooms (two or three) is used for this table. The outdoor gamma dose rate was measured in contact with the external wall at about 1.5 m from the ground.

The crude ratio of the outdoor and indoor measured value is compared with the ratio of the IN-OUT model estimate (latest procedure) and indoor measured value. The table shows that, on average, the outdoor measured value is an accurate estimate of the indoor value, but with low precision, as given by the coefficient of variation (COV), namely 38% for the complete set. In comparison, the IN-OUT method stands as a great improvement in precision: the overall COV decreases to 20%.
Table 1: Summary of results of the IN-OUT method using average dwelling characteristics in the Latium region

<table>
<thead>
<tr>
<th>Building material</th>
<th>No. of dwellings</th>
<th>Measured gamma dose rate (nGy h⁻¹)</th>
<th>Outdoor value</th>
<th>IN-OUT estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Indoor AM SD</td>
<td>Outdoor AM SD</td>
<td>Indoor AM COV</td>
</tr>
<tr>
<td>Tuff/stone</td>
<td>31</td>
<td>227 57</td>
<td>251 103</td>
<td>1.12 37%</td>
</tr>
<tr>
<td>Concrete/bricks</td>
<td>43</td>
<td>141 59</td>
<td>146 74</td>
<td>1.07 39%</td>
</tr>
<tr>
<td>All</td>
<td>74</td>
<td>177 72</td>
<td>188 101</td>
<td>1.09 38%</td>
</tr>
</tbody>
</table>

AM = Arithmetic Mean  
SD = Standard Deviation  
COV = Coefficient of Variation = SD/AM

4. Conclusions

These results support the usefulness of the IN-OUT method to obtain an estimate of the indoor gamma dose rate in practical situations where detailed information on wall, ceiling and floor characteristics of selected dwellings is not available.


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