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DOSE CALCULATION DUE TO UNDERGROUND EXPOSURE: THE TAV TUNNEL IN VALLE DI SUSA

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ABSTRACT

Radiological impact due to indoor exposure, particularly due to permanence underground, is considered by Italian and European laws, which suggest accurate measurements and define action levels. Risk connected to exposure is circumscribed by setting limits on indoor air concentration of nuclides and on consequent doses. Particularly, inhalation of radon – a radiological decay product of uranium - and its progeny can lead to neoplasms damaging the respiratory apparatus. Harmful concentrations of gas in indoor air can be reached because of its continuous production from uranium, and its tendency to stratification and other particular conditions. The estimate of radon potential concentrations and absorbed doses is useful to verify whether dose limits can be respected or not. In every underground building, there could be radioprotection problems, and such situations should be controlled. RESRAD-BUILD (RESidual RADioactivity in BUILDings) is a computer model designed for evaluating radiation exposures within structures. Natural radiation exposures in an underground building will be illustrated through a case study. In this work, the RESRAD-BUILD model is used, in fact, to evaluate the dose received by an individual being inside a contaminated underground tunnel: the TAV (Traforo Alta Velocità, High-speed Rail Tunnel) which will be situated in Valle di Susa (Piedmont). In the area we are considering, the presence of natural radionuclides slightly exceeds the worldwide mean value, particularly the concentration of ^{238}U. The scheme of the tunnel is made considering a 15 meters length portion, 4x4 meters section, made of three compartments. The three compartments are in series, and inside them there are nine sources and one receptor. Parametric studies have been performed by means of this model, checking the influence of different parameters on the radon indoor concentration and the consequent dose to the individual. RESRAD-BUILD final results show that an air flux of 0.1 m^3/h, entering the first compartment, can be sufficient to lower the dose received by the exposed receptor below 1 mSv/y, which is the population dose limit. An air flux of 0.1 m^3/h is a quite small value: it means that the building`s inner air should be totally changed every 2400 hours (100 days). This air exchange can be obtained easily both in the construction and exercise phases. Results show the order of magnitude of the dose the exposed workers receive, notwithstanding the simplifications adopted. They can be useful to make an early estimate of radiological risk. The proposed practical application shows how limits imposed by regulations can be respected in the presence of concentrations of radionuclides slightly exceeding the world average, by means of modest air exchanges.

KEYWORDS:
radioprotection, radon, dose assessment, RESRAD, tunnel

INTRODUCTION

The danger arising from ionizing radiation in indoor exposure, particularly due to permanence underground, is considered by Italian legislation, D. Lgs. n. 230 [1]. Since 1990, European Union issued radiation protection legislations regarding indoor radon exposure (90/143/Euratom) [2]. Italian law suggests accurate measurements and establishes action levels. It emphasizes the risk due to the gas presence. In workplaces, opportune measurements and, in some cases, adequate countermeasures become obligatory.

Radon is a radioactive gas. It is colorless, odorless, and chemically inert. Radon is formed by the radioactive decay of uranium in rock, soil, and water. Radon has a half-life of about four days. When radon undergoes radioactive decay, it emits ionizing radiation in the form of alpha particles. It also produces metallic short-living decay products, like: ^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po, ^{210}Bi, and ^{210}Pb. Their chemical reactivity and electric charge make them attach to dust and other tiny particles in air. These dust particles can easily be inhaled into the lung and fixed to pulmonary mucosae. The deposited atoms decay and eventually damage cells in the lung. A considerable amount of evidence has established that prolonged exposure to the α- emitting decay products of radon increases the risk of lung cancer. According to EPA estimates, such inhalation is considered to be the second cause of insurgence of this kind of cancer, after smoke that is the first one.

Harmful concentrations of gas in indoor air can be reached because of its continuous production from uranium, as well as its tendency to stratification or in presence of particular conditions (in general, where the gas is unable to disperse).

According to ICRP Recommendations, Italian law establishes a reference level for radon exposure in indoor workplaces: 500 Bq/m [1, 3-5]. Estimates of radon`s potential concentrations and absorbed doses are useful to verify whether dose constraints can be respected or not.

The values of radon precursor concentrations in rocks or soil adjacent the building, or their mean value, should be known to make a dose assessment. The mechanism of gas and precursor emanations as well as transport through soil, rocks, pores and underground water should be analyzed with attention. The phenomenon of radon migration trough soils is not well-known, because of the complex interaction between soil characteristics (porosity, permeability, temperature, humidity), atmospheric factors (like the presence of wind, rain…) and geological factors. The gas can easily pass from liquid to gaseous phase, and then be transported by diffusion and convection in the water and through the pores. This can happen when the medium is not yet saturated and the pores are interconnected.

MATERIALS AND METHOD

The code RESRAD-BUILD can be used to estimate the dose received by an individual who spends a certain amount of time in an underground building. It has been developed by DOE (*Department of Energy*) to analyze the radiological doses resulting from human activities in buildings contaminated with radioactive material (RESidual RADioactivity in BUILDings) [3, 6, 7]. The building can have up to three compartments, and sources up to four geometries (point, line, area and volume sources), ten sources and ten receptors. Between source and receptor, a certain amount of shielding material can be interposed, made of up to eight different materials. It affects the amount of external radiation to the receptor. The transport of radioactive material from one compartment to the adjacent is calculated considering many factors: the presence of radioactive dust and airborne materials, air exchange between the compartments and from the outside, deposition and resuspension, gathering and radioactive decay. Receptor's parameters can model a variety of individuals spending a certain time inside the contaminated building; their internal exposure is calculated considering homogenous air inside the compartments; while external exposure is calculated considering the presence of a shielding material, its properties and dimensions. The potential uses of a building are referred to as exposure scenarios, and different exposure scenarios are composed by different combinations of site, occupation and receptor parameters. The dose received as a consequence of building occupation is linked to the building's use, to its conditions, position, size, dimensions, and kind of contamination.

Seven exposure pathways are considered in the code:

- external exposure directly from the source;
- external exposure to materials deposited on the floor;
- external exposure due to air submersion;
- inhalation of airborne radioactive particulates
- inhalation of aerosol indoor radon progeny and tritiated water vapor;
- inadvertent ingestion of radioactive material directly from the source;
- ingestion of materials deposited on the surfaces of the building compartments.

RESRADBUILD evaluates the external radiation doses as the effective dose equivalent (EDE), and the internal exposure as the committed effective dose equivalent (CEDE). The total radiation dose, which is the sum of the external and internal doses, is expressed as the total effective dose equivalent (TEDE).

RESULTS AND DISCUSSION

Dose assessments may be prospective or retrospective, and can be always thought to be an iterative process. Prospective doses are estimated for individuals whose exposure has not yet occurred, while retrospective doses are generally estimated for groups that are known to have received exposure. The assessment generally begins with more conservative assumptions for sources, parameter values, and habit data. The results from each iteration are used for determination, if more realistic information is needed, particularly when the magnitude of the doses calculated approaches the dose constraint. Uncertainties associated with estimation of dose may be taken into account either deterministically by selecting appropriated single values for parameters, or probabilistically by incorporating distributions for parameter values. With either methodology, the goal is always to perform a sufficiently robust evaluation to support judgments and decisions to be made on radiological protection and to set compliance with law [8].

Natural radiations in an underground building can be illustrated through a case study: a tunnel built in Piedmont. The dose assessment we are performing is prospective and deterministic. In the area we consider, where the TAV (Traforo Alta Velocità, High-speed Rail Tunnel) will be situated (Valsusa), the presence of natural radionuclides slightly exceeds the worldwide mean values, particularly the concentration of ^{238}U [7]. In each underground building, there could be radioprotection problems, and such situations should be controlled.

The scheme of the tunnel is made considering a 15-m length portion, 4x4 m section, made of three compartments. The scheme adopted (15 m length) has been validated against a reference case, where the depth is the real one (about 50 km): the model adopted and the reference case give similar results; the depth we choose is sufficient and the model adopted allows more easily parameter calculations.

Natural radionuclide concentrations are worldwide mean values: ^{232}Th: 0.028 Bq/g; ^{40}K: 0.37 Bq/g; except for ^{238}U: 0.0265 Bq/g. This concentration of ^{238}U has been measured on samples of rocks in 1997 by ARPA, as reported in ref. [7]. All sources in our model are from 100 cm depth: the dose received by the receptor is influenced by the source depth until it is almost 1 m, as observed when making parameter calculations.

The three compartments are in series, and inside them there are nine sources and one receptor. The sources cover the entire internal surface of the last compartment, completely exposed to the rocks, and the superior and inferior surfaces of the remaining two, partially exposed. They all contain the same concentrations of radionuclides. The receptor is placed in the middle of the third compartment, as shown in Figure 1. External air enters the building only through the first compartment, while the exchange of air between the three compartments is caused by constant internal air fluxes.

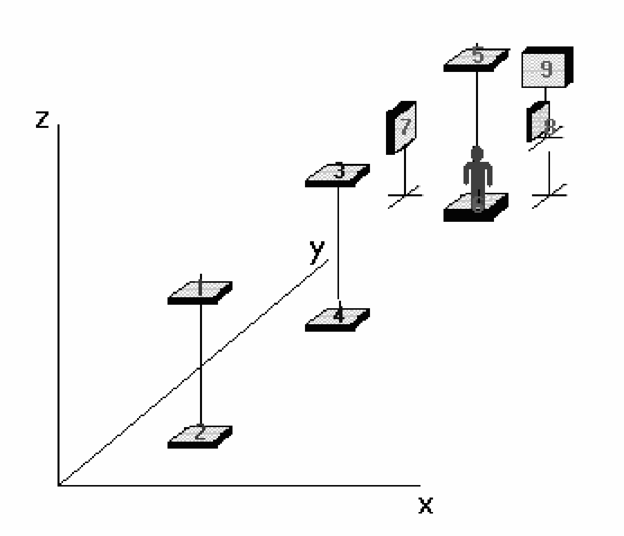

FIGURE 1 – Sources-Receptor scheme.

All the results are expressed in mSv/y: this means that 8760 hours of exposure per year are considered. The single dose received by an individual should then be calculated regarding the actual hours of exposure.

The code shows no sensitivity to variations in the value of source porosity.

Figure 2 shows that an air flux of 0.1 m^3/h entering the first compartment can be sufficient to lower the dose received by the exposed receptor below *1 mS/y* –the population`s dose constraint [1, 6] This result is quite the same, even when radon emanation factor changes its value in this particular case. An air flux of 0.1 *m*^{3}*/h* is a quite small value: it means that building inner air should be totally changed every 2400 h. This air exchange can be obtained easily both in the construction and exercise phases. Finally, we should remember that results refer (100% of relation) to the time spent inside the tunnel. This assumption is very conservative, but reasonable considering the magnitude of calculated doses. The real values of dose can be obtained linearly from those presented here, regarding the real amount of h spent inside the underground building.

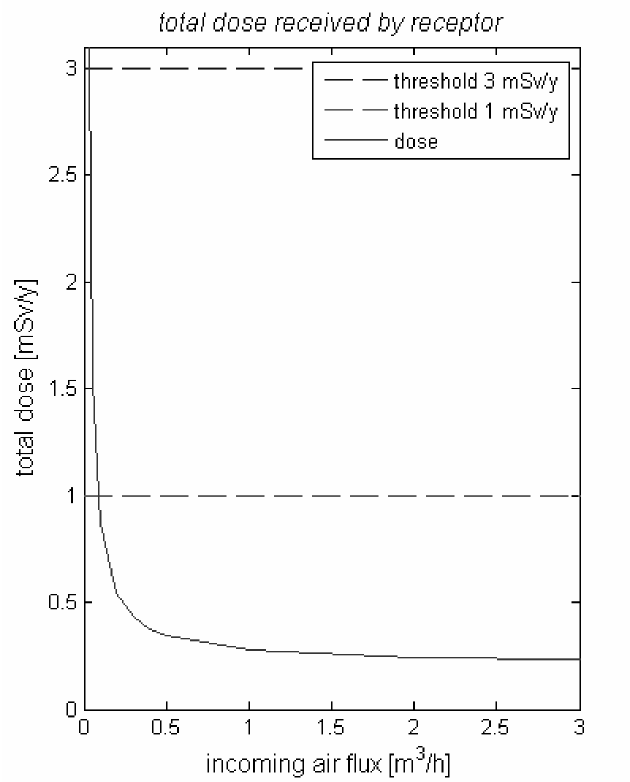

FIGURE 2 – Total dose received by the receptor as a function of incoming air flux.

CONCLUSIONS

Employing a code like the one presented here means acceptance of hypothesis, acceptance of uncertainties due to the model used to reproduce the physical phenomenon of transport as well as assumption of radionuclides and exposition, acceptance of limitations inherent to measurements of concentrations or of other parameters. In addiction, variability - in the sense of heterogeneity in nature - is unavoidable in any process of defining environmental and receptor characteristics and in estimating doses. In our particular case, it is important to remember the reader that the sources considered are homogeneous, and that all influencing gas release parameters are assumed to be constant, and the same can be said about erosion and deposition velocities, in the form of resuspended powders. A unique value for these last parameters is adopted to describe the behavior of all radionuclide species. Inner air is modeled as a homogeneous medium, well-mixed with contaminants and notwithstanding differences in density. In the end, it is not possible to recreate pressure gradients between inside and outside, nor link gas incoming to environmental conditions (temperature, pressure, humidity).

This means that the presence of pores or leaks that make the exhalation of gas easier is not explicitly considered. But it can be modeled using RESRAD-BUILD: the user can insert localized sources and characterize them with high emanation factor, considering that much of the produced radon escapes from the source.

Generally, RESRAD code models each phenomenon acting on radon incoming in buildings through opportune values of gas emanation factor and diffusion coefficients.

RESRAD-BUILD results show the order of magnitude of the dose received by the exposed workers, notwithstanding the simplifications adopted. They can be useful to make an early assessment of radiological risk, but it is necessary to verify them with accurate measurements in workplaces, as established by law. The practical application proposed shows how law constraints can be respected in the presence of concentrations of radionuclides being slightly upon world average, by means of modest air exchanges.

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