Atmospheric Environment 105 (2015) 7–13

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Measurements and CFD modeling of indoor thoron distribution

Neetika Chauhan [a,*], R.P. Chauhan [a], M. Joshi [b], T.K. Agarwal [b], B.K. Sapra [b]

[a] *Department of Physics, National Institute of Technology, Kurukshetra 136119, India*
[b] *Radiological Physics and Advisory Division, BARC, Mumbai 400 085, India*

HIGHLIGHTS

- Indoor thoron distribution studied out using CFD modeling.
- Thoron wall flux was measured and used as the key input for modeling.
- Passive and active measurements were performed to validate the CFD codes.
- Thoron concentration was found to decay exponentially from wall to center.

ARTICLE INFO

Article history:
Received 22 November 2014
Received in revised form
12 January 2015
Accepted 14 January 2015
Available online 14 January 2015

Keywords:
Indoor thoron distribution
Thoron flux
Ventilation
CFD

ABSTRACT

Few studies have been undertaken to measure indoor thoron concentration in Indian dwellings. The distribution pattern of thoron inside room conditions is complex due to short half-life. The internal radiation exposure due to inhalation of indoor thoron and decay products can be quite large near to the wall. In this work, Computational Fluid Dynamics (CFD) technique was utilized for prediction of indoor thoron concentration and distribution pattern. Thoron flux was measured experimentally to be used as input and CFD runs were performed for closed and open room conditions. Thoron concentration inside the room was also experimentally measured using Scintillation Thoron Monitor, STM (active) and pin-hole dosimeters (passive). For open room conditions, thoron concentration was found to be smaller and relatively homogenous compared to closed room conditions. CFD predictions were found to be reasonably matching with active and passive results. A separate profile experiment increased confidence towards validation of CFD for indoor thoron distribution (prediction) applications. CFD can be used as a tool to predict thoron concentration and its distribution in indoor conditions.

1. Introduction

Radon (^{222}Rn), thoron (^{220}Rn) and their decay products are significant contributor to background radiation dose (UNSCEAR, 2000). Construction building materials having noticeable amount of radium and thorium, are the main sources of indoor radioactive gases (Kumar et al., 2005; Mahur et al., 2008). The study of distribution behavior of these gases is important towards estimating the radiation dose. Several studies have been performed world over for enhancing knowledge about understanding of indoor radon distribution. Measurements, models and more recently CFD techniques have been employed for this purpose (Bochicchio et al., 1996; Chauhan et al., 2014; Manic et al., 2006; Nazaroff and Nero, 1988; Virk, 1999, Jelle, 2012; Vasilyevet al., 2013; Zhou et al., 2001; Urosevic et al., 2008). The importance of studying indoor thoron distribution is highlighted for the workplace and dwellings containing noticeable thoron source term (Malathi et al., 2008; Ramachandan et al., 2011; Ramola et al., 2013). Few studies have been undertaken in recent past measuring indoor thoron levels in Indian dwellings. For instance, Ramachandan and Sathish, 2011 measured indoor thoron levels in 25 different locations in India, using solid state nuclear track detectors based twin cup and found thoron concentration values between 3.5 and 42.8 Bq m^{-3}. Thoron enters indoor air from soil and construction material having thorium content via emanation–exhalation mechanism (Nazaroff and Nero, 1988; UNSCEAR, 2000; Zarcone et al., 1986). The focal quantity i.e. activity distribution of indoor thoron and their decay products has been assumed as homogenous in past (Bochicchio et al., 1996; Porstendorfer et al., 1978; Jacobi, 1972). However some studies have discussed scenarios where such assumptions may not remain valid (Katase et al., 1988; Yamasaki et al., 1995). The shorter half-life of thoron results in rapid exponential decrease of

* Corresponding author.
E-mail address: neetika.nit@gmail.com (N. Chauhan).

http://dx.doi.org/10.1016/j.atmosenv.2015.01.029
1352-2310/

activity concentration away from the wall which may affect exposure-dose calculations (Zhuo et al., 2001). The internal radiation exposure due to inhalation of thoron decay products may be considerable near to the concrete wall (Katase et al., 1988). Complexity of incorporating such concentration gradients for studying indoor thoron distribution makes measurements and modeling, a challenging but exciting domain.

Computational Fluid Dynamics (CFD) models have advantage over other techniques by providing data at any (relevant) point of computational domain. In a recently published work (Chauhan et al., 2014), indoor radon distribution for a typical indoor environment was studied using CFD technique. The results from CFD model were compared with measurements (active and passive). It was shown that difference in source term of room surfaces led to in-homogeneity of radon distribution but on an average, simulation results were found to be close to experimental measurements. CFD model based results of indoor thoron distribution have not been validated experimentally (Urosevic et al., 2008; With et al., 2011). The objective of this study is to measure indoor thoron distribution and compare the results with CFD model predictions for a typical model room.

Computational fluid dynamics (CFD) based code was used in this work to simulate the spatial distribution of thoron concentration in model room. The thoron source term (wall and floor thoron flux) was measured for this room and used as input in CFD code (Fluidyn MP software). The active measurement of indoor thoron levels in test room were performed using STM while the passive measurements were performed using the pin-hole dosimeters. These measurements were carried out for two different ventilation conditions (closed room and open room). Results from the experimental measurements were compared with CFD model based predictions. Locations for deploying measurement devices were kept same as our recent work (Chauhan et al., 2014) for additionally comparing this case with indoor radon distribution inferences.

2. Material and methods

2.1. Model room geometry

The test room of dimension 3.01 m × 3.01 m × 3.0 m shown in Fig. 1 was used to study the thoron concentration distribution. The room geometry has three doors of dimensions 0.9 m × 1.99 m (width × height). The small opening between the door and floor surface with dimension 0.9 m × 0.02 m (width × height) was used for the inlet and outlet boundary condition implementation in the closed door condition (door opening which is directly in contact with the outer environment was considered as inlet and other two were considered as outlet). In open door condition, door 1 was considered as inlet and other two door's opening was outlet. Different representative locations (corner 1–4 and center as shown in Fig. 1) were selected in model room for active and passive measurements.

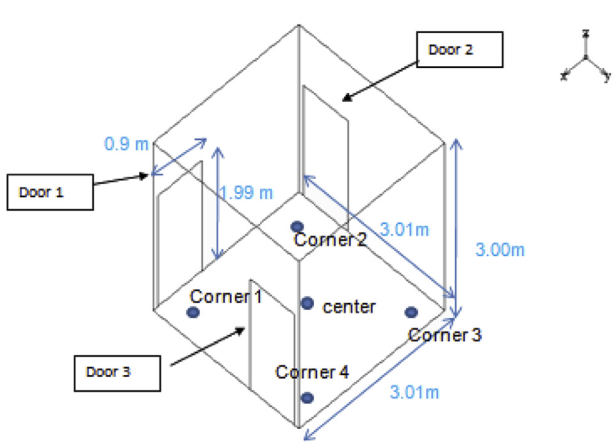

Fig. 1. Model room geometry.

2.2. CFD procedure

CFD model based on finite volume method was used to simulate the thoron distribution inside the room. In the simulation process, steady state flow field was established in the room followed by thoron dispersion. The governing equations for simulation are given below.

2.2.1. Governing equations

The indoor air flow was assumed to be incompressible and temperature inside the room was considered constant and uniform for the simulation simplification. Steady state flow field was established in the room using mass and momentum conservation equations (1) and (2) then thoron dispersion was simulated using equation (3) (Agarwal et al., 2014).

$$\nabla \cdot u_i = 0 \tag{1}$$

$$\rho\left(\frac{\partial u_i}{\partial t} + \nabla\cdot(u_j.\ u_i)\right) = -\nabla\cdot P + \nabla\cdot(\mu_e \nabla u_i) + S \tag{2}$$

Where, P is the pressure (N m^{-2}), u is the velocity vector (m s^{-1}), μ_e is the effective viscosity (N s m^{-2}), S represents the source term, and i,j are the index for the three velocity components. The effective viscosity μ_e is the sum of dynamic viscosity μ and turbulent viscosity μ_t. The Reynolds number for both cases (closed and open room condition) was greater than critical number. Standard k-ε model is incorporated to consider the effect of the turbulence.

Dispersion of thoron gas inside room was simulated using the following equation

$$\frac{\partial C}{\partial t} = \nabla\cdot(D^*\nabla C) - \nabla\cdot(uC) - \lambda C + S \tag{3}$$

Where, C represents ^{220}Rn activity concentration in the room volume (Bq m^{-3}), D is ^{220}Rn diffusion coefficient (m^2 s^{-1}), u is mean air flow velocity (m s^{-1}), S is ^{220}Rn source term (Bq m^{-3} s^{-1}) and λ is ^{220}Rn decay constant (0.0126 s^{-1}).

2.2.2. Boundary conditions

Inlet boundary condition was defined at the inlet of the door which was directly in contact with the outer environment. Pressure static boundary condition was implemented on outlet 1 and 2 such that the zero pressure difference existed at the indoor–outdoor interfacing. Measured thoron flux value was assigned at the walls; floor and ceiling.

2.2.3. Calculation of parameters

The inlet velocity corresponding to the ventilation rate and ventilation area was calculated from equation (4).

$$v = (\lambda_v * V_{room})/A_{vent} \tag{4}$$

The occupied air volume in the empty room was considered as the room volume (V_{room}) while A_{vent} and λ_v (h^{-1}) represents ventilation area and ventilation rate, respectively.

Thoron generation rate (Bq m^{-3} s^{-1}) was calculated using the following equation (5)