DISTRIBUTION OF INDOOR THORON IN DWELLINGS UNDER NORMAL AND TURBULENT FLOW CONDITIONS USING CFD SIMULATION TECHNIQUE

by

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Extensive work has been carried out on measurement of radon and thoron levels in indoor environment in last three decades. These studies are important from radiation protection point of view, if one considered the contribution of radon, thoron and their decay products to total inhalation dose. Numerous studies on radon measurement well established the behaviour of its dispersion in dwellings. But the short lives of thoron cause the difficulty to understand the distribution of thoron in dwellings. The problem becomes more complicated when thoron dispersion is studied under different inlet air flow rate. Different air flow pattern may cause different thoron level at different point in test dwellings causing uncertainty in the measurements. This work utilized the CFD simulation technique for study of indoor thoron dispersion in test dwellings under normal and turbulent flow of air. The simulation study for thoron distribution in a test room was performed for air velocities 0.10 ms^{-1}, 0.25 ms^{-1}, 0.50 ms^{-1}, 1.0 ms^{-1}, 1.5 ms^{-1}, and 2.0 ms^{-1}. The results show that the thoron distribution becomes uniform for the inlet velocity more than 0.5 ms^{-1} and appropriate to measure indoor thoron concentration. While in normal condition the measured thoron level varies depending upon the location of dosimeter. Thoron diffusion and migration length are also increased with air flow rate.

Key words: indoor thoron, thoron diffusion length, indoor air distribution, computational fluid dynamics

INTRODUCTION

The exposure to ionizing radiation produced by indoor thoron and their decay for a long time may increase the probability of various health risks [1-3]. The thoron gas is produced from the decay series of thorium with the half-life of 55.6 second. The contribution of thoron for inhalation dose is sometimes considered as negligible due to short half-life as compared to radon. Some researchers emphasized that study of the indoor thoron and its decay products are equally important as that of radon study [4-7]. The indoor thoron levels depend upon soil and building construction materials characteristics like thorium content, moisture matrix, diffusion length and porosity as well as the building characteristics like ventilation rate, dimension and air flow pattern. The ventilation is an important factor that can influence the measurement of thoron. The radon which is a gas similar to thoron with half-life of 3.824 days has different distribution behaviour when compared with thoron using CFD technique for a test room under closed and open room conditions [8, 9]. The inlet air velocity varied from 0.01 ms^{-1} (closed room condition) to 2 ms^{-1} (open room under different ventilation rate) while it takes value of only 0.5 ms^{-1} for normal living room condition. Very few studies have been performed to evaluate the factors affecting indoor thoron behaviour [10-13]. It was found that indoor air flow pattern influences the spatial distribution of thoron. The study of factors affecting the indoor thoron behaviour is a challenging task needing the advancement in measurement process and modeling. The present study is aimed to investigate the influence of inlet air velocity on thoron diffusive behaviour in different turbulent indoor environment. A computational fluid dynamics based modeling was performed to study indoor thoron behaviour as the function of inlet air velocity. The model incorporates the change in velocity at door to study the effect of inlet velocity on the distribution of thoron gas. This model includes the production from the wall and decay (due to radioactive decay and ventilation) of thoron. The exhalation of thoron gas from the room surfaces was considered as the main source measured in earlier study [14]. The present model gives the knowl-

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edge of thoron dispersion in the indoor environment to assess the indoor radiation exposure. Diffusion length and diffusion coefficient of the thoron gas were estimated from CFD results. The study may give an idea how to mitigate the indoor thoron exposure by understanding its distribution pattern.

MATERIAL AND METHODS

Details of model room

The geometry was created in CAD-GEN for CFD simulation of spatial distribution of the thoron gas. The test room under study have dimensions 3.01 m × 3.01m × 3.00 m (fig. 1) with three doors (D-1, D-2, D-3) of dimensions 0.90 m ×1.99 m (width × height) with a gap between door and floor of dimensions 0.90 m × 0.02 m (width × height). The surface area of walls, floor and ceiling for the model room was 30.9 m^2, 9.10 m^2, and 9.10 m^2. The door D-1 was considered as inlet and the unenclosed area between door and floor of other two doors (D-2 and D-3) were considered as the outlets in CFD model.

CFD modeling

The indoor thoron concentration distribution may be affected by the air flow rate at inlet. To study the effect of inlet air velocity, magnitude on the indoor thoron distribution pattern, modeling was performed on CFD platform. The measurement of thoron flux from the wall was measured with active techniques and results for the same test room are shown elsewhere [14]. The details of the geometry and mesh of the test room can be found in our earlier studies [9], however boundary conditions were changed according to the inlet velocity at the door. The three-dimensional air flow in the room was simulated at six different inlet air velocities *i. e.* 0.10 ms^{-1}, 0.25 ms^{-1}, 0.50 ms^{-1}, 1.0 ms^{-1}, 1.5 ms^{-1}, and 2.0 ms^{-1}. Finite volume discretisation technique was implemented in code to generate the grid points. The air flow was assumed to be incompressible [15]. Fine mesh was used near the doors and the openings, which gave the precise results with less computational time. On the basis of Reynolds's number calculation the present problem requires the transport equations to be solved (mass and momentum conservation equations) using turbulence model. The *k*-*ε* model is used to incorporate the effect of turbulence. Steady-state flow field was estab-

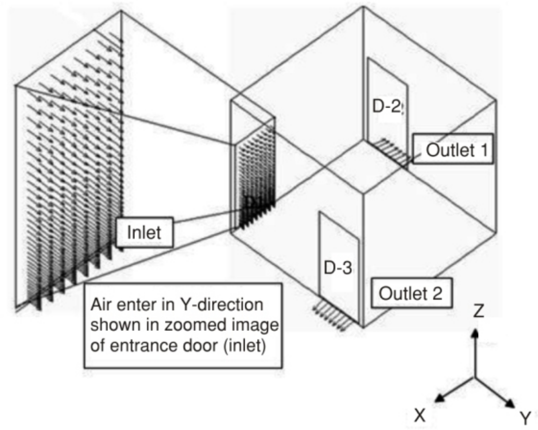

Figure 1. Description of room geometry

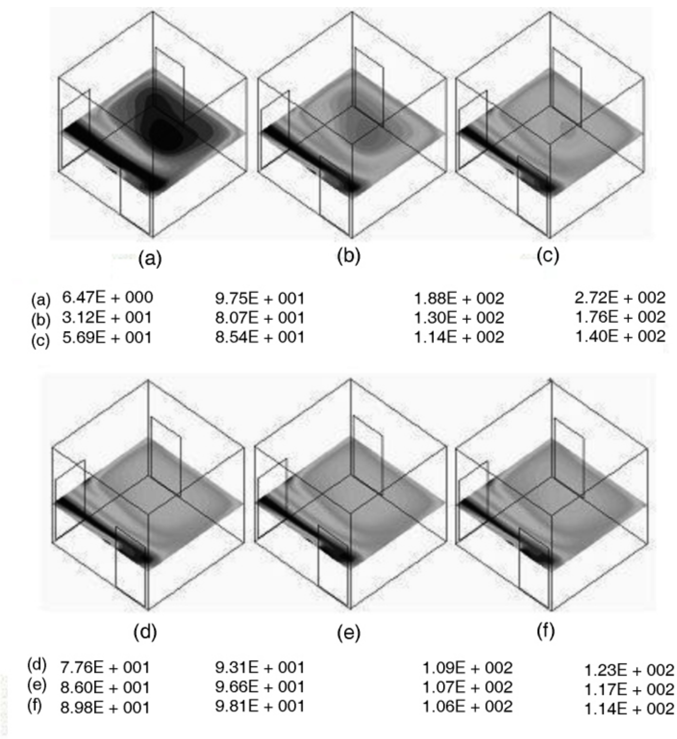

Figure 2. Indoor thoron distribution at different velocities; (a) 0.10 ms^{-1}; (b) 0.25 ms^{-1}; (c) 0.50 ms^{-1}; (d) 1.0 ms^{-1}; (e) 1.5 ms^{-1}; and (f) 2.0 ms^{-1}

lished in the room after solving the mass and momentum equations. The governing mathematical equations and simulation parameters are described elsewhere [14].

RESULTS AND DISCUSSIONS

Air velocity effect on indoor thoron dispersion

Due to short half-live of thoron gas it decays exponentially from the room surfaces resulting in thoron concentration gradient in the test room. The indoor turbulence conditions were changed by changing air flow rate at the entry of room. To study the effect of inlet air flow on the thoron distribution inside the room, CFD simulation were carried out at six different inlet air velocities *i. e.* 0.10 ms^{-1}, 0.25 ms^{-1}, 0.50 ms^{-1}, 1.0 ms^{-1}, 1.5 ms^{-1}, and 2.0 ms^{-1} which correspond to the ventilation rate of 13 h^{-1} to 266 h^{-1} in case of normal and turbulent air flow for test dwelling of volume 30.9 m^3 and ventilation area 1 m^2. Six cases were setup corresponding to the different air velocity in CFD model for the simulation purpose. The distribution patterns of indoor thoron are shown by the contour plots in XY- plane at Z = 1.22 m (fig. 2). The observed results from CFD simulation indicate that the distribution pattern of indoor thoron gas got strongly affected by the velocity rate of air at the door. Due to the increase in the turbulence the thoron gas moves toward the center of room. For lower inlet air velocity the distribution pattern was non-homogenous and tends to be homogenous for higher air flow rate. It was also observed that the distribution of thoron gas became independent to the flow rate at higher side.

Consider the case of closed room condition, the inlet air velocity takes the value of 0.01 ms^{-1} that corresponds to poor ventilation rate. The distribution of thoron at different point of the plane at Z = 1.22 m is non-homogenous as discussed in earlier studies [14]. Due to the increase in the turbulence the thoron gas moves toward the center of room. For lower inlet air velocity the distribution pattern was non-homogenous and tends to be homogenous for higher rate of air flow. It was also observed that the distribution of thoron gas becomes independent to the flow rate at higher side. The migration length is another parameter that can be used to study the thoron distribution in dwellings and was defined as the maximum distance from the source travelled by thoron before its decay to its daughter product. While the diffusion length is defined as the distance from wall at which the thoron concentration becomes 1/e times its value at that on the wall surface. The thoron produced from the wall can move towards the center only with recoil energy and follow a migration length of few cm. As inlet velocity increases to 0.1 ms^{-1}, the intermixing of thoron and migration length increases as shown in fig. 2(a). With increase in the inlet air velocity up to (a) 0.10 ms^{-1}, (b) 0.25 ms^{-1}, (c) 0.50 ms^{-1}, (d) 1.0 ms^{-1}, (e) 1.5 ms^{-1}, and (f) 2.0 ms^{-1}, the migration length increased to 5, 13, 28, 55, and 110 cm from the wall while the observed values of diffusion length (L) were 14.8, 22.3, 23.5, and 27.6 cm for first four inlet velocities.

Thoron concentration and diffusion length profile

Thoron distribution pattern in indoor environment is non-homogenous under the closed room condition with poor ventilation [15, 16]. After releasing from room surfaces thoron gets distributed in indoor environment along with spontaneous decay. The knowledge of variation in thoron concentration level with respect to distance from the source wall is useful to estimate the receiving dose due to thoron and immediate alpha emitting decay product (^{212}Po with half-life 150 μs). With increase in the inlet air velocity, thoron migration length and hence thoron concentration continuously increases towards the center of room due to turbulence effect. The indoor thoron concentration predicted by the CFD modeling as a function of inlet velocity and distance from the wall without door is shown in fig. 3. From the results shown in fig. 3 the non-uniformity in the thoron levels tends to decrease as the flow rate of air increases.

The variation in the radon migration length under different air flow rate is shown in fig. 4. The same exponential pattern but higher rate of transit of thoron gas at higher air flow rate was observed. The decrease in gap between consecutive decay profiles indicated that homogenous distribution was achieved due to the increase in air circulation.

Thoron has very short diffusion length in the steady environment and in undisturbed air it is about 2.9 cm in the absence of advection flow [17]. However, it will change when the mass transfer takes place due to convective transport mechanisms other than molecular

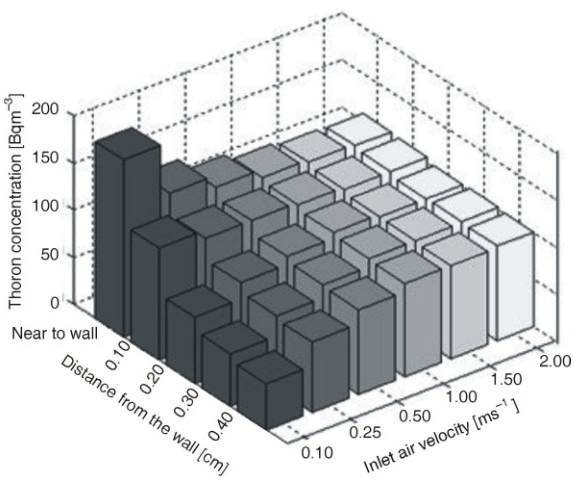

Figure 3. Distribution of thoron concentration with inlet air velocity and distance from wall [Bqm^{-3}]

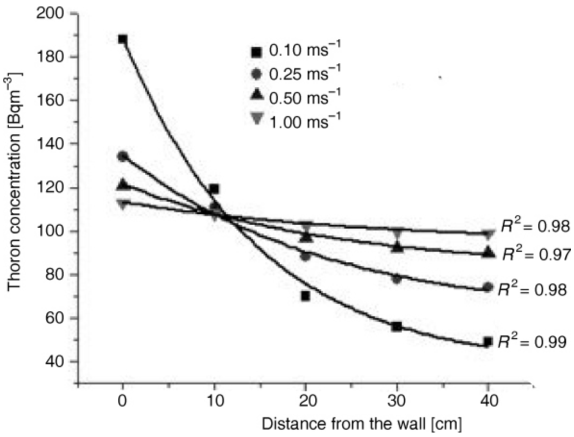

Figure 4. Decay profile of indoor thoron from CFD

diffusion. The thoron diffusion coefficient was found to be 5.4 cm^{-2}s^{-1} from measurement results in other study [4]. The corresponding diffusion length is about 20 cm in the room air. In the present study diffusion length of thoron was estimated from exponential fitting of thoron concentration decay profile from the wall with respect to distance. For the different inlet air velocity rates the observed values of diffusion length (L) were 14.8 2.4 cm, 22.3 6.4 cm, 23.5 9.0 cm, and 27.6 7.0 cm, shown in fig. 5. The uncertainty in the measurement also increases with increase in air velocity causing more complexity in the measurement of indoor thoron under turbulent condition.

The corresponding diffusion coefficients (D) were calculated using eq.

$$L \quad \sqrt{\frac{D}{\lambda}}$$

where λ is thoron decay constant. The corresponding values of diffusion coefficients were found to be 2.8 0.1 cm^{-2}s^{-1}, 6.3 0.5 cm^{-2}s^{-1}, 6.9 0.03 cm^{-2}s^{-1}, and 9.6 0.6 cm^{-2}s^{-1}. Thus, from present CFD based modeling we say that diffusion length and coefficients for the indoor thoron were found to increase with increasing air velocity. Based on the above discussion it may be noticed that for the measurement of indoor thoron in dwellings under different radioactivity mapping program of various countries [18], the dosimeter was deployed at the center of the dwellings. But under normal conditions the thoron distribution is non-uniform, thus the measurement results may not be treated as the actual. In order to find actual value, 4 to 5 dosimeters must be deployed in dwelling and average of the results from these can be considered as close to the actual.

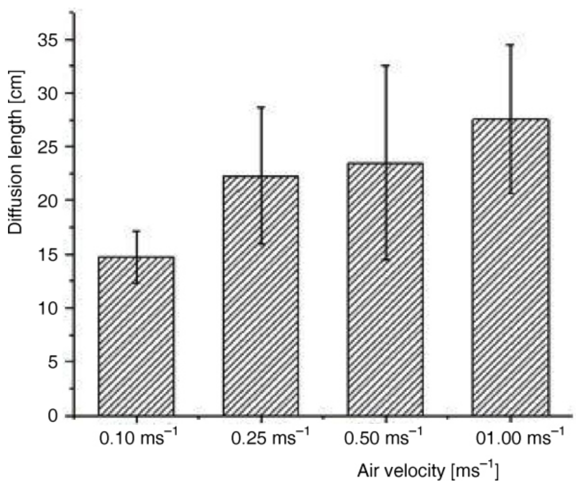

Figure 5. Thoron diffusion length estimated by CFD simulation

CONCLUSIONS

The impact of air velocity rate on distribution pattern, concentration level and diffusion length of thoron gas in living environment are studied using 3-D-CFD modeling. Following concluding points are drawn based on observations from the present study:

- The increase in inlet air velocity rate has significant impact on the distribution pattern of thoron gas. Thoron dispersion approaches to homogenous as the velocity of air increases at the door (inlet) and became independent of flow rate.
- The thoron decays exponentially with distance from the source even for high rate of air flow inside the room. The increase in velocity rate leads to the thoron concentration from a wall to the center of room resulting in homogenous distribution.
- The diffusion length of thoron was found to vary from 15 cm to 28 cm and thoron diffusion coefficient also varied in a similar way corresponding to different inlet air velocities.

AUTHORS' CONTRIBUTIONS

R. P. Chauhan supervised this work from defining the problem to final analysis of data. The coding and case set up for the present study were carried out by N. Chauhan and A. Kumar simultaneously. All authors contributed to this work and finalized this manuscript.

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РАСПОДЕЛА КОНЦЕНТРАЦИЈЕ ТОРОНА У СТАМБЕНИМ ПРОСТОРИМА ОДРЕЂЕНА ПРИМЕНОМ КОМПЈУТЕРИЗОВАНЕ ДИНАМИКЕ ФЛУИДА ПРИ НОРМАЛНИМ И ТУРБУЛЕНТНИМ УСЛОВИМА ПРОТОКА

У последње три деценије обављен је опсежан рад на мерењима нивоа концентрација радона и торона у затвореним животним срединама. Ове студије имају важну улогу са становишта заштите од зрачења, узимајући у обзир допринос радона, торона и њихових потомака укупној дози од инхалације. Бројне студије мерења радона, добро су описале начин његовог распростирања у стамбеним просторима. Међутим, кратко време живота торона отежава разумевање просторне расподеле торона. Проблем постаје комплекснији када се распростирање торона посматра при различитим брзинама протока улазног ваздуха. Различити начини протока ваздуха могу изазвати различите нивое концентрације торона на различитим позицијама унутар тестираних стамбених простора, што може допринети мерној несигурности. У овом раду употребљена је компјутеризована динамика флуида – техника симулације за изучавање дисперзије торона у затвореним стамбеним просторима при нормалним и турбулентим протоцима ваздуха. Симулације расподеле торона обављене су за брзине струјања ваздуха од 0.10 ms^{-1}, 0.25 ms^{-1}, 0.50 ms^{-1}, 1.0 ms^{-1}, 1.5 ms^{-1} и 2.0 ms^{-1}. Резултати показују да расподела торона постаје униформна за улазне брзине веће од 0.5 ms^{-1} и да је одговарајућа за мерење концентрације торона у затвореним просторима, док у нормалним условима измерени ниво торона зависи од локације дозиметра. Дифузиона и миграциона дужина торона такође расту са повећањем брзине протока ваздуха.

Кључне речи: торон у затвореној просторији, дифузиона дужина торона, расподела ваздуха у затвореној просторији, компјутеризована динамика флуида