

# Indoor Radon Exhalation Rates from Concrete with Fly Ash

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## 1 Introduction

Radon ( $^{222}\text{Rn}$ ) is one of the most pervasive and serious global indoor air concerns. Concrete exhalation of radon and progenies contribute to an estimated 30% of the total indoor radioactive pollution (Gadd and Borak 1994). Concrete constituents of aggregate, and portland cement contain uranium ( $^{238}\text{U}$ ), radium ( $^{226}\text{Ra}$ ) and thorium ( $^{232}\text{Th}$ ) radionuclides, which have decay chain products of exhalable Radon gas ( $^{222}\text{Rn}$ ) and non-exhalable progenies, Polonium-218 and Polonium-214 ( $^{218}\text{Po}$ ,  $^{214}\text{Po}$ ) (Cohen et al. 1998). Non-exhalable progenies are credited to be the second leading cause of lung cancer for Americans (US EPA 2003). A common cement replacement, fly ash (FA), formed from 90% inorganic, incombustible, residue from the burning of coal, can amplify the naturally occurring radioactivity in concrete. FA contains up to ten times the concentrated levels of uranium and thorium compared to un-burned coal (Hvistendahl, 2007).

This study reviews the literature to determine the relationship between the  $^{222}\text{Rn}$  exhalation rate and  $^{226}\text{Ra}$  specific activities of concrete and for the individual concrete constituents. The motivation for this work is to provide a better assessment of indoor radon exposure expected by fly ash concrete.

## 2 Materials/Methods

Data drawn from 9 publications were tabulated including the (i) concrete radon exhalation rates and, (ii) concrete and constituent  $^{226}\text{Ra}$  specific activities. A regression analysis was then used to create predictive trends associating the usage of FA in concrete with total concrete  $^{226}\text{Ra}$  specific activity

## 3 Results

The radon exhalation rate from concrete is dependent upon the  $^{226}\text{Ra}$  specific activity of the constituent material and the material porosity. The  $^{226}\text{Ra}$  specific activity values of each constituent were obtained from the literature (Stranden 1983, Siotis and Wrixon 1984, Van Der Lugt and Scholten 1985, Mahur et al. 2008). The average  $^{226}\text{Ra}$  specific activities of FA, cement, and aggregate were 310, 34, 8 Bq/kg (8.37, 0.9, 0.2 pCi/g) respectively, and the standard deviations were 117, 11, 0.6 Bq/kg (3.1, 0.3, 0.01 pCi/g) respectively. These averages are comparable to those provided by the US EPA for fly ash and cement, of 1 to 8 pCi/g and 1 pCi/g, respectively (US EPA 1983). To obtain the contribution of each component for the total  $^{226}\text{Ra}$  specific activity of a typical concrete comprised of 70wt.% aggregate, 3wt.% FA (30wt.% cement replacement) and 7wt.% cement, the average constituent activity was multiplied by the weight percent of that component. Figure 1 shows the resulting contribution of each component to the total  $^{226}\text{Ra}$  specific activity of the concrete. The figure demonstrates how 3wt.% FA can contribute to more than half of the total  $^{226}\text{Ra}$  specific activity of a typical concrete.

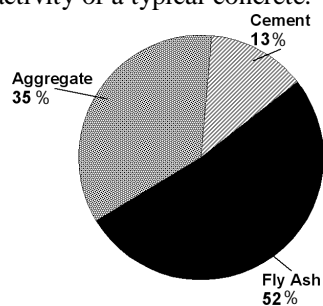


Figure 1. Percent  $^{226}\text{Ra}$  specific activity of FA, Aggregate and Cement Constituents.

The results are supported by Yu et al. (1992, 1994, 1996, 1997) who used uranium ( $^{238}\text{U}$ ) containing granite, as the aggregate constituent. Usage of uranium ( $^{238}\text{U}$ ) containing aggregates dictated total concrete  $^{226}\text{Ra}$  specific activities and  $^{222}\text{Rn}$  exhalation rates, mainly because aggregates comprise most of the concrete mass. The radon exhalation rates of these samples ranged from  $70\text{-}105 \times 10^{-4} \text{ Bqm}^{-2}\text{s}^{-1}$  ( $175\text{-}263 \times 10^{-4} \text{ pCi ft}^{-2}\text{s}^{-1}$ ) (Yu et al. 1992, 1994, 1996, 1997), approximately five times greater than similar concretes that did not contain radioactive aggregate.

Siegel et al. (2006) demonstrated  $^{222}\text{Rn}$  exhalation rates will linearly increase with the increasing product of the fly ash  $^{226}\text{Ra}$  specific activity and wt.% fly ash addition, neglecting mixtures with uranium ( $^{238}\text{U}$ ) containing aggregates. However, no significant correlation was determined solely between wt.% fly ash addition and  $^{222}\text{Rn}$  exhalation rates. They hypothesized that the fly ash specific activity was an important factor. Another factor may be the decrease in the average material pore size with increasing additions of FA, shown for some concrete mixtures (Poon 2000, Niu 2009, Poon 2010). A reduction in material pore size could reduce the adsorption of emanated radon and reduce the interconnectedness of pores, internally limiting the  $^{222}\text{Rn}$  exhalation rate. The connection between concrete porosity and  $^{222}\text{Rn}$  exhalation rate deserves further exploration.

#### 4 Conclusions

From this literature review, radon exhalation rates from concrete with uranium-containing aggregate were higher than samples containing fly ash. This was mainly attributed to the higher mass of aggregate in concrete (60-75%) relative to fly ash (3-4%). The correlation between  $^{222}\text{Rn}$  exhalation rates and FA-concrete porosity deserves further examination.

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