Exposure to Radon from Concrete with Fly Ash: a Proposed Model, *In-Situ* and Laboratory Measurements

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Abstract: Most building materials of terrestrial origin contain small amounts of Naturally Occurring Radioactive Materials (NORM), mainly radionuclides from the ^{238}U and ^{232}Th decay chains and the radioactive isotope of potassium, ^{40}K.

Lastly in Israel there is an increased use of fly ash (FA) in concrete and as an additive to cement.

The higher ^{226}Ra activity concentration, the mineralogical characteristics of the FA and of the concrete may influence on the radon exhalation rate and consequently on the radon exposure of the public.

The free radon exhalation rate measured in the laboratory decreases with addition of FA, while in the *in-situ* measurements performed in Dwelling Shielded Spaces (DSS) showed no clear influence on radon exhalation. Lower curing time reduce significantly the radon exhalation in concrete containing FA.

The uncertainty of the measurement (*in-situ* and laboratory) was assessed to be up to ±30%. The measurement conditions in the *in-situ* measurements and the calculation method are the major factors influencing on the uncertainty budget.

A mathematical model based on the assumption that under normal living conditions the material exhalation rate is constant, was developed. The annual average radon concentration in a DSS was assessed.

Methods and results: Concrete samples containing different concentrations of FA (0 to 150 kg/m³ of concrete) were prepared at the concrete plant, and used in DSS (room made of massive concrete).

The natural radionuclides content in the concrete was determined by gamma spectrometry method as indicated in the IS 5098 standard (1).

The free exhalation rate and the concrete emanation coefficient were measured according to IS 5098 procedure in laboratory samples of 10 cm x 10 cm x 20 cm by the close chamber method.

The exhalation rate was calculated by two methods:

1) Non-linear regression of the radon concentration ingrowths curve

$$E_{0,av} = \frac{V}{\sum_n S_n} \cdot (C_{\max} \cdot \lambda_{eff} - N \cdot C_o)$$

2) Linear regression of the slope for the first hours of the measurement

$$E_0 = \frac{V}{\sum_n S_n} \cdot [a + \lambda_{eff} \cdot C(0) - N \cdot C_o]$$

Where C(0)~0 or C(0)<< C_{max} and $C_o \rightarrow 0$ then

$$E_{0,av} = \frac{V \cdot C_{\max} \cdot \lambda_{eff}}{\sum_n S_n} \quad \text{or} \quad \frac{a \cdot V}{\sum_n S_n}$$

The slope of the radon concentration dependence for the first hours is obtained by $C(t) = a \cdot t + b$

Figure 1 shows the decrease in the exhalation rate with increasing FA content and for lower curing period.

FA content [kg/m³]	$E_{0wall,av}$ [Bq/m²h]	Standard Deviation	Range [Bq/m²h]
0	7.16	27.4%	3.6-9.4
120	8.30	10.6%	6.3-10.3
140	7.54	23.6%	4.9-11.7

Table1 – Average wall exhalation rate measured at DSS's

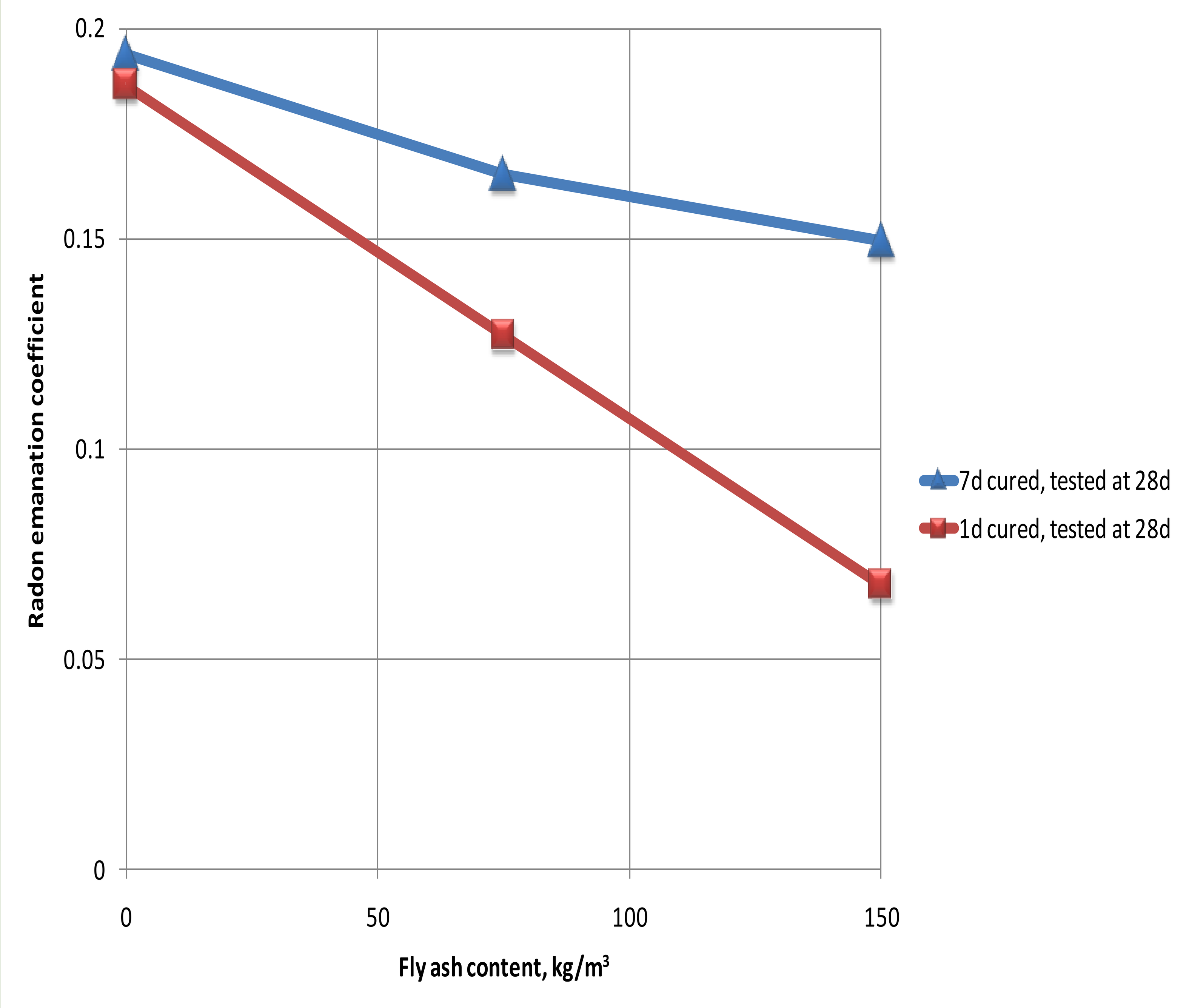

Figure 1 – Exhalation rate as function of FA content and curing period

Results of the free wall exhalation rate were determined under sealed conditions (with apparent air change rate of $9.6e^{-4}$ – $7.1e^{-3}$ h^{-1}) at the DSS are shown in Table 1.

The annual average radon concentration was predicted using a mathematical model based on the radon transport from the building product surface into the room. The annual average radon concentration from the building materials in a DSS is estimated to be 40-50 Bq/m³.

References: (1) Israeli Standard IS 5098, *Content of natural radioactive elements in building products*, The Standards Institution of Israel (2009) (in Hebrew).

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