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Thoron exposure in Dutch dwellings – An overview

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ABSTRACT

In the Netherlands considerable attention has been given to the exposure from thoron progeny in dwellings. For this purpose a nationwide survey on the thoron exhalation and thoron progeny concentration has been completed in 2015. Furthermore, extensive laboratory studies have been performed to measure activity concentrations and thoron exhalation rates from regular Dutch building materials. The purpose of this study is to demonstrate if the findings from both field experiments and laboratory results are consistent. For this reason measured properties of building materials and surface barriers, in-situ measurements on air ventilation and thoron(progeny) in dwellings as well as advanced computational modelling on indoor air and aerosol behaviour have been used. The results demonstrate that median and mean thoron progeny concentrations of 0.53 and 0.64 $Bq{\cdot}m^{-3}$ found in the survey are comparable with the mean concentration of 0.57 $Bq{\cdot}m^{-3}$ obtained from laboratory testing and calculation. Furthermore, upper thoron progeny concentrations from the survey and the calculations are with respectively 13 and 14 $Bq{\cdot}m^{-3}$ also in good agreement. Such elevated concentrations lead to an effective doses of around 4 mSv per year. The study also includes worst-case scenarios on the application of surface materials high on ^{232}Th, and the expected reduction in thoron progeny when using mainstream mitigation measures.

1. Introduction

Thoron (^{220}Rn) gas is a decay product of ^{224}Ra and is part of the ^{232} Th decay series, as shown in Fig. 1. ^{232}Th is together with ^{238}U, ^{235}U and ^{40}K one of four primordial nuclides, and is typically found in all materials of natural origin, such as construction products and building materials. Thoron is studied considerably less than its counterpart ^{222}Rn as it was assumed that the contribution from thoron's decay products to the total exposure from radon isotopes is mostly limited to around 10% (UNSCEAR, 2006). Nevertheless, some studies (Doi et al., 1994; Bochicchio et al., 1996; Ma et al., 1997) have demonstrated that in certain cases exposure to thoron progeny in dwellings may be significant and sometimes even exceed that of radon. For example studies performed in thoron prone areas e.g. in China (Wang et al., 1996) and India (Sreenath Reddy et al., 2004) have demonstrated that exposure due to thoron progeny can be well in excess of 4 mSv per year.

Due to thoron's short half-life of only 56 s, the thoron progeny originates purely from the applied materials on the warm side of the building envelope. These typically include concrete, calcium silicate bricks and plaster materials, which in some cases were found to have elevated rates of thoron exhalation (De With et al., 2014). Other materials typically responsible for high thoron exhalation are unfired mineral building materials like clay, adobe and mud bricks (Sreenath Reddy et al., 2004). These mineral materials are usually covered with wall paper or decoration paint that acts as a diffusion barrier against thoron exhalation.

Recent work has demonstrated a renewed interest in thoron exposure (Smetsers et al., 2018; De With and De Jong, 2011; Mc Laughlin et al., 2011; Tschiersch et al., 2007; Tokonami et al., 2005; Colgan et al., 2008). In 2015 a nation-wide survey including around 2500 dwellings was completed in the Netherlands (Smetsers et al., 2018). From this study it is concluded that the average thoron progeny concentration (Equilibrium Equivalent Thoron Concentration, EETC) in the Dutch housing stock is around 0.65 $Bq{\cdot}m^{-3}$ with a median value of 0.53 $Bq{\cdot}m^{-3}$. The results of that survey, which also include the measurement of the annual averaged radon concentration in dwellings, show that about 70 per cent of the radiation detriment can be attributed to radon, and 30 per cent to thoron. This outcome is consistent with computational studies on the thoron concentration in the Netherlands performed by De With and De Jong (2011, 2016), which indicated that thoron is responsible for approximately 35% of the effective dose from both radon isotopes.

Combining the findings from both computational and experimental approaches would highlight the broader understanding of the

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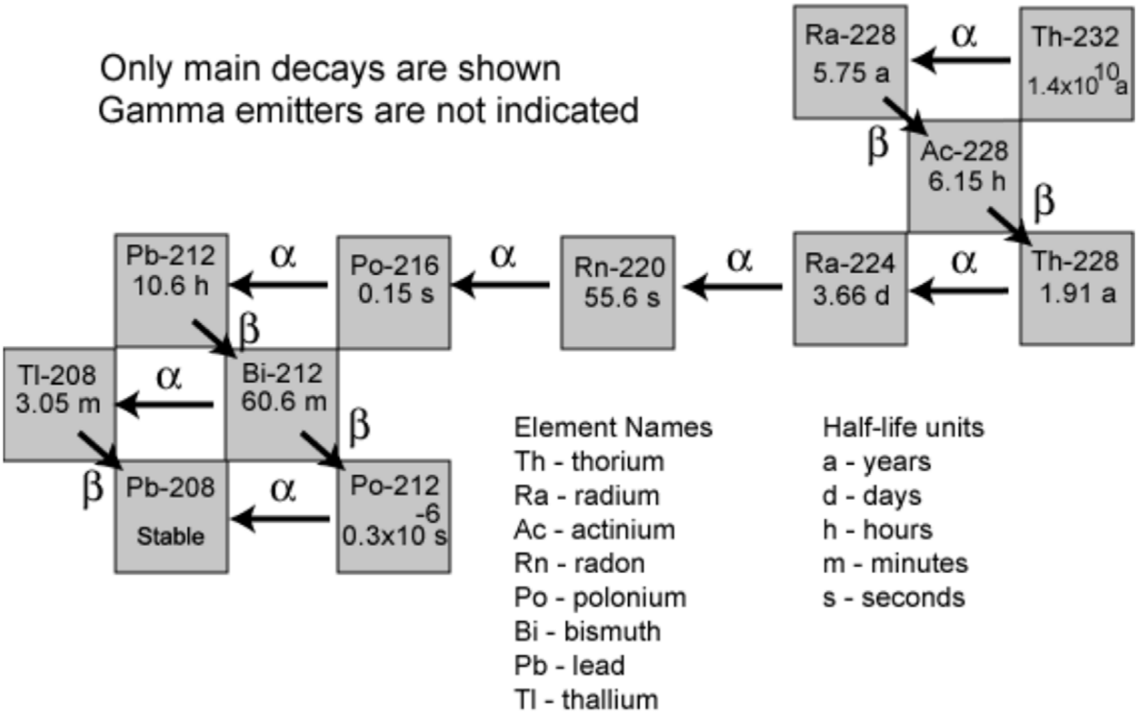

Fig. 1. The ^{232}Th decay chain.

underlying mechanisms and any (in)consistencies. For this reason the objective of this study is threefold: i. to compare the computed EETC's with the findings from the experimental survey, ii. apply the computational models to demonstrate worst-case scenarios and mitigation options and iii. assess implications of existing guidelines and legislation on thoron (progeny) exposure.

2. Background

Since the early 2000 considerable work has been performed on the exposure from thoron in Dutch dwellings. This work has started with a theoretical investigation to estimate the exposure in typical Dutch dwellings (De With and De Jong, 2009), which was followed by experimental studies of Blaauboer (2010, 2012). This has recently resulted in a comprehensive survey on the thoron progeny concentration in Dutch dwellings (Smetsers et al., 2015, 2018). This work was accompanied by laboratory studies on the exhalation of thoron from typical building materials (De With et al., 2014; De With and De Jong, 2016). Such material studies are a continuation of earlier surveys on Dutch building materials that were executed since the 1980's (Ackers et al., 1985; De Jong et al., 2006). Furthermore, national surveys were performed to gain understanding of the Dutch building design and the use of building materials in the Dutch housing stock (De Jong and Van Dijk, 2008). Experimental studies were carried out to measure the air exchange in modern Dutch houses (De Gids and Op't Veld, 2004; Bader et al., 2009). All these studies, each in its own way, have contributed to a better understanding of the radiation detriment in the Dutch housing stock. Conceptually, this can be presented in the form of a trail as shown in Fig. 2. The trail starts with a solid understanding of the building materials involved and its radiological and mechanical characteristics. These form the foundation for the estimated release of thoron in the indoor environment. This also includes the impact from surface barriers, as for example the application of paints and wall paper, to mitigate or reduce the thoron release (De With and De Jong, 2016). The trail follows with an accurate description of the building design, which includes geometrical and ventilation features as well as other issues essential to describe the dispersion of thoron and its decay products. This part of the trail also considers mitigation by extraction of thoron (progeny) by means of ventilation and deposition. These features combined with a known thoron source will lead to a progeny concentration responsible for the radiation dose. The question is if the findings from all the above mentioned studies together provide a consistent picture of the thoron exposure in the Netherlands, starting from the choice of materials, building design all the way down to the presence of the hazardous thoron progeny and the possible effects of mitigating measures.

3. Experimental and theoretical methods

3.1. Construction materials and thoron exhalation

Key to a good understanding of the thoron progeny concentrations in dwellings is the total influx of thoron into the living space; in other words the thoron source term. As the infiltration of thoron from the soil

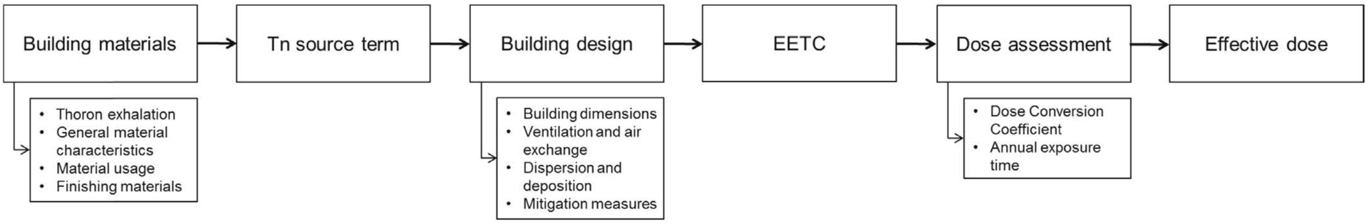

Fig. 2. Summary of the thoron source-to-risk trail.