Nuclear Engineering and Technology xxx (2018) 1–7

Contents lists available at ScienceDirect

Nuclear Engineering and Technology

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

Original Article

Radon and thoron concentrations inside ancient Egyptian tombs at Saqqara region: Time-resolved and seasonal variation measurements

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ARTICLE INFO

Article history:
Received 9 September 2017
Received in revised form
23 February 2018
Accepted 25 March 2018
Available online xxx

Keywords:
Ancient Egyptian Tombs
Radon
Saqqara
Thoron

ABSTRACT

For complete assessment of inhalation doses of radon and its progeny inside the three main ancient Egyptian tombs in Saqqara, seasonal radon concentrations have been measured by using a new electronic device that allows for measurement of real-time–resolved radon concentrations. Measurements were complemented by very fast measurements of thoron concentrations, which turned out to be low. Based on these measurements, annual residence time inside these tombs and the newest International Commission on Radiological Protection–recommended radon dose conversion coefficients or seasonal effective doses were calculated. The results indicate that workers receive highest annual effective doses of up to 140 mSv, which exceeds the annual limit of 20 mSv, whereas lower values up to 15 mSv are received by guides. In contrast, much lower doses were obtained for one-time visitors of the investigated tombs. The obtained results are somewhat different but still consistent with those previously obtained by means of fixed passive dose meters at some of the investigated places. This indicates that reasonable estimates of the effective dose of radon can be also obtained from short-term radon measurements carried out only twice a year (summer and winter season). Increasing the ventilation, minimizing the working times, etc., are highly recommended to reduce the annual effective dose.

1. Introduction

Exposure to ionizing radiation contributes to the overall radiation dose to the public worldwide. In this respect, while radiation exposures from artificial sources such as those from emission of facilities of the nuclear fuel cycle are minor, those from natural sources are of particular interest [1–4]. In fact, it is particularly the radioactive chemical element radon, a natural radioactive noble gas, that is of major importance. The radioisotope ^{222}Rn of this element (in the following called "radon" for simplicity) contributes significantly to the dose of the population from natural sources of ionizing radiation, and about 50% of the public's natural radiation exposure in many countries is due to radon [5,6]. The parent nuclide of radon, ^{238}U, is usually found in the Earth's crust on a concentration level of one or several parts per million (ppm). According to the report of the United Nations Scientific Committee on the Effects of Atomic Radiation in 2013 [7], both low LET radiation and radon have been shown to increase the risk of lung cancer among humans. As for radon and its radioactive daughter nuclides, a significant increase of the risk for lung cancer was shown if their concentrations exceed above 200 Bq/m^3 [8,9]. In contrast, negligible contribution to the effective dose from the isotope thoron (^{220}Rn) was found in the past [10–12]. Because of its short half-life of less than a minute, thoron is unable to penetrate into reasonably airtight buildings. Recently, however, thoron has gained attention because increased concentrations were found in cave dwellings dug into clay soil and in houses with earthen architecture [13–17].

In the present study, radon and thoron measurements were performed in the tombs of the oldest Egyptian ancient cemetery region, 28 km southwest of Cairo, close to Saqqara. Note that the effective doses from radon to individuals who are working at those sites were already estimated in previous studies [18,19] using stationary passive track detectors (CR-39 dosimeters) located inside the tombs to measure radon concentrations in air and assuming a 10 h working day. This approach may include high uncertainty, however, because it does not directly quantify the actual exposure of a person present at those locations. In the present work, we used a portable radon personal exposure meter, which has recently been developed at the German Research Center for Environmental

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https://doi.org/10.1016/j.net.2018.03.017

Health (Helmholtz Zentrum München) and which allows measurement of individual radon exposures for those wearing the device [20]. The device was already successfully used in a pilot study at other Egyptian archeological sites [21]. The results obtained in the present study will be helpful in constructing a suitable ventilation system and developing guidance rules for workers, tourist guides, and visitors to this region.

2. Experimental work

2.1. Measurement locations

Saqqara is a vast ancient burial ground, located 28 km southwest of Cairo, carved into mountains of limestone and sedimentary rocks (Fig. 1). Visiting these tombs or working inside may result in increased health hazard due to the higher-than-average levels of natural radiation and the low ventilation rates. For example, previously, annual effective doses of about 66 mSv were obtained for safety guards in the Valley of the Kings tombs in Luxor; these doses exceeded the annual dose limit [21]. Some of these tombs are open to visitors, whereas other tombs are closed for renovation work, which affects the ventilation rates and, accordingly, the radon and thoron concentrations in air. The structure of the studied tombs and the locations of measurement are shown in Figs. 2–4.

Four measurement locations were chosen in the Serapeum tombs (Fig. 4), whereas only one location was available for measurement inside the South and Zoser pyramid tombs (Figs. 2 and 3). Selection of the measurement positions and the number of

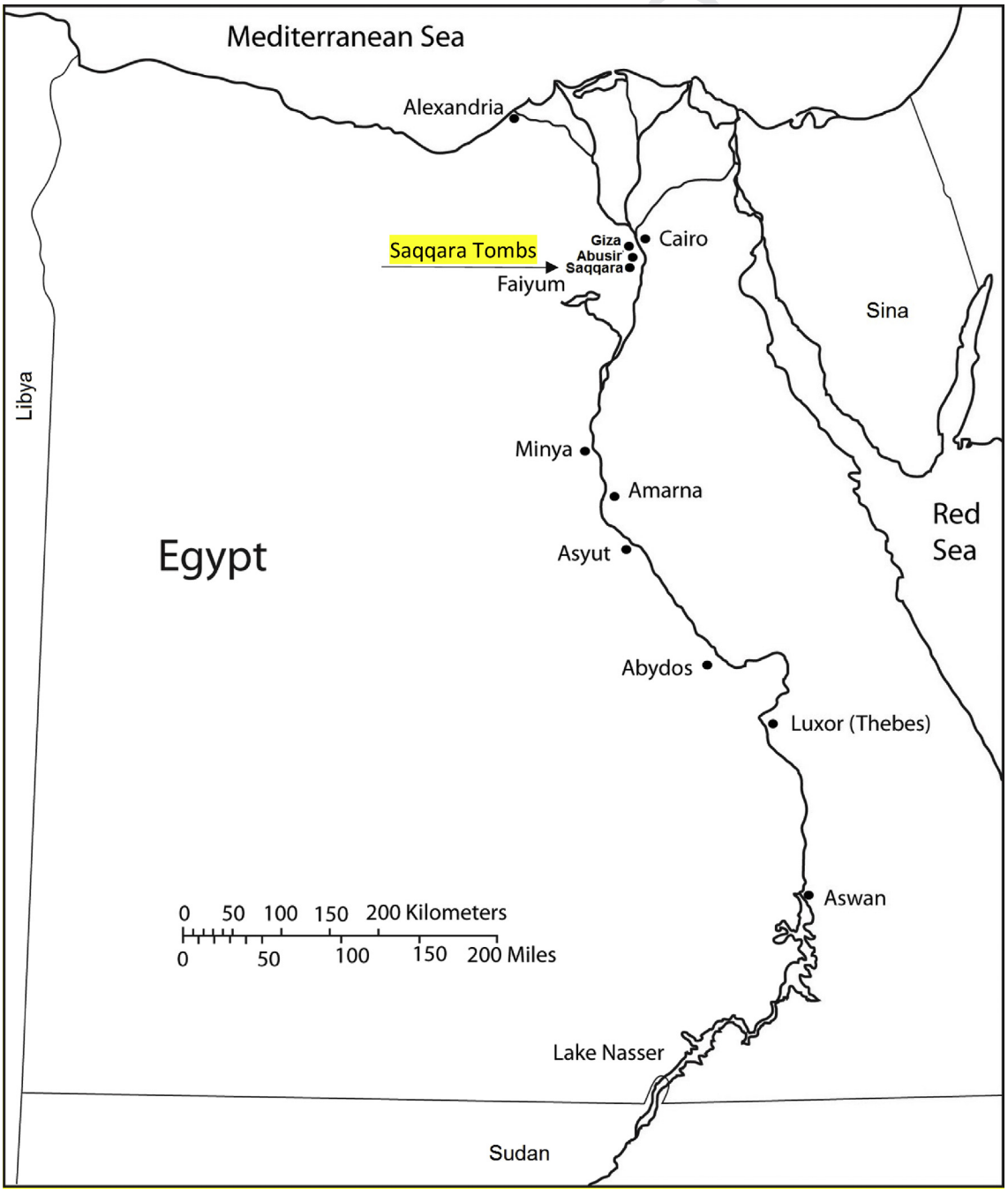

Fig. 1. Location of Saqqara in Egypt.

Please cite this article in press as: E. Salama, et al., Radon and thoron concentrations inside ancient Egyptian tombs at Saqqara region: Time-resolved and seasonal variation measurements, Nuclear Engineering and Technology (2018), https://doi.org/10.1016/j.net.2018.03.017