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Review

The world's high background natural radiation areas (HBNRAs) revisited: A broad overview of the dosimetric, epidemiological and radiobiological issues

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HIGHLIGHTS

- Some of the challenging issues of HBNRAs have not been resolved.
- A literature review of the most recent studies of HBNRAs has been conducted.
- An overview of some of the challenging issues and viable solutions are presented.

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ABSTRACT

The residents of the world's high background natural radiation areas (HBNRAs), such as Ramsar (in Iran), Guarapari (in Brazil), Orissa and Kerala (in India) and Yangjiang (in China) have lived in these areas for generations under extraordinary radiation fields. The failure of earlier epidemiological studies to report any substantial increase in cancer incidence in HBNRAs has raised some controversy regarding the validity of the linear no-threshold hypothesis. This paper reviews some of the most recent studies of HBNRAs with the intent of stimulating greater research interest in the dosimetric, epidemiological and radiobiological issues related to the world's HBNRAs and proposes solutions to the challenges facing HBNRA studies. This paper may serve as a useful reference for some of the harder-to-find literature.

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1. Introduction

Life began in a radiation field that is more intense than that of today (Mortazavi, 2012); the radiation level today is ten-fold lower than that during the Precambrian era (Karam and Leslie, 2005; Møller and Mousseau, 2013). One of the radionuclides in man's environment that contributes a large proportion of the radiation dose to the population is radon (Bavarnegin et al., 2013). Nearly eighty percent of the annual effective dose attributed to radiation exposure originates from background natural radiation, which is predominantly produced by cosmogenic and primordial radionuclides (Schnelzer et al., 2010).

Inhabitants of the world's HBNRAs and radon prone areas receive radiation doses that are relatively higher than the doses in the normal background radiation areas (NBRAs) (Sohrabi, 2013a,b). Some of the world's HBNRAs are found in Kerala (India), Guarapari (Brazil), Yangjiang (China), and Ramsar (Iran), a northern coastal city in Iran (Mortazavi et al., 2002; Mortazavi and Mozdarani, 2012).

Based on the inhabitants' annual effective dose (H_E), Sohrabi (2013a) has classified the world's HBNRAs as follows: low

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(H_E = 5 mSv y^{-1}), medium (H_E = 5–10 mSv y^{-1}), high (H_E = 20–50 mSv y^{-1}) and very high (H_E > 50 mSv y^{-1}). This classification is based on the dose limits of the ICRP and the 2.4 mSv y^{-1} global mean dose value reported by UNSCEAR (ICRP, 1991; 2007; UNSCEAR, 2000a,b). The specific characteristics of HBNRAs depend on the stability of the natural radioactivity. There are areas in which the radiation dose is constant over time and other areas in which the dose varies with time (Sohrabi, 2013a).

The failure of earlier epidemiological studies to report any substantial increase in cancer incidence in the HBNRAs has raised some controversy regarding the validity of the linear no-threshold (LNT) hypothesis. Hence, a scrutiny of the current literature that presents a broad overview of the major issues and proposes viable solutions to the greatest challenges is timely and relevant.

A number of excellent studies and reviews have been conducted regarding the radiological issues related to HBNRAs. For instance, Sohrabi (1998) reviewed the literature concerning the sources of naturally occurring radioactive material (NORM) and human exposure and has presented criteria for the classification of HBNRAs. These classifications are presented in the author's recent paper, which considers the health implications in Ramsar and the need to protect the Ramsar residents from radiation (Sohrabi, 2013a).

In their study, on of the lessons learned regarding health risks as a result of human exposure to elevated levels of background radiation, Hendry et al. (2009) note that there is an established association between long-term radiation exposure in the general population and disease incidence in radon-prone areas. However, these authors also observed that studies in non-radon HBNRAs are based on ecological design and provide little information. The authors recommend the monitoring of environmental dose rates and the establishment of a database in which the individual dose estimates for residents can be recorded; these dose estimates should be based on retrospective internal and external dosimetry. The authors also recommend that data concerning the effects of non-radiation clastogens should also be collected because these effects have produced a confounding effect in a Chinese study conducted by Hayata et al. (2004) involving a large sample size, in which the effects of low levels of radiation on chromosomes were concealed.

Møller and Mousseau (2013) have assessed the effects of variations in background radioactivity on humans, animals and other organisms. The authors expected that the hormetic effects of radiation should be more pronounced in HBNRAs because of adaptation to such enhanced levels of radiation; they also predicted that exposure to natural radiation should have positive effects on humans and other organisms if hormesis operates at naturally occurring low doses of radiation. However, the results of the meta-analysis were inconsistent with the general hypothesis of hormesis related to low levels of natural background radiation; instead, the authors observed generally negative effects of radiation on mutations, immunology and life history. The results of Møller and Mousseau (2013) support the argument of Mossman (2001) regarding the “deconstruction of radiation hormesis,” namely, that data purported to support radiation hormesis in human populations is deficient and based on epidemiological findings and that evidence of hormetic effects is weak and inconsistent. In an alternative opinion, (Doss, 2014) argued that in the early 1980s, radiation hormesis was proposed to reduce the incidence of cancers, but scientists have failed to investigate hormetic effects in human. The current study has no intention of summarizing all the various controversial arguments for or against the LNT model; it is, however, important to investigate of radiation hormesis in humans.

The International Conference on High Levels of Natural Radiation and Radon Areas (ICHLNRRA) conference is held every four years. This serves as the largest gathering at which researchers interested in the HBNRAs convene to share knowledge. The most recent was the 8th ICHLNRRA, which was held on 1–5 September 2014 at Czech Technical University. Some ICHLNRRA conferences that have been held in the past include Brazil (1977), India (1981), Iran (1990), China (1996), Germany (2000), Japan (2004) and India (2010). The proceedings of the 3rd, 4th 5th and 6th ICHLNRRA conferences are available through Science Direct (Sohrabi et al., 1993; Wei et al., 1997; Burkart et al., 2002; Sugahara et al., 2005). This paper reviews some of the most recent studies of HBNRAs with the intent of stimulating greater research interest in the dosimetric, epidemiological and radiobiological issues related to HBNRAs.

2. The world HBNRAs considered

2.1. Yangjiang (China)

In China, the Yangjiang area in Guangdong province is a known HBNRA. Most of its residents have lived there for over 5 generations (Tao et al., 2000a). The average annual dose of external radiation from natural sources, including thorium, in this HBNRA has been estimated to be 3.5 mSv y^{-1} (Zou et al., 2005). The primary source of the elevated level of radiation is monazite that contains ^{232}Th, ^{238}U, and ^{4}K. The average annual internal effective dose received by the inhabitants from natural sources of exposures in the HBNRAs of Yangjiang has been estimated to be 4.27 mSv (Zou et al., 2005).

A health survey of the inhabitants of the HBNRAs of Yangjiang, China, was conducted over a span of two decades, and the results are available in literature (Hayata et al., 2000, 2004; Sun and Carr, 2005; Tao et al., 2000b; Wang et al., 1990; Wei and Sugahara, 2000; Zhang et al., 2003, 2004, 2008; 2010; Zou et al., 2000).

Wang et al. (1990) have studied thyroid nodularity caused by chronic radiation exposure in Yangjiang's female residents aged 50–56 years. The authors compared their results with those obtained from women of the same age group who were exposed to normal background radiation. The cumulative dose to the thyroid in the HBNRA residents was two-fold higher than that of the residents of the NBRAs. However, the prevalence of nodular diseases in the two groups of residents was comparable. A higher prevalence of mild diffuse goiter was observed in the HBNRA residents, and this was attributed to their low iodine consumption. The study concluded that a lifetime exposure to low-level radiation does not result in any discernible increase in thyroid nodularity in the investigated HBNRA. However, such exposure may cause chromosomal damage. An interesting feature of the work of Wang et al. is its ability to consider the influence of diet. Other issues that could be considered to be limitations of this study are the small sample size and the consideration of only female residents. However, this work paved the way for further radiobiological studies of the HBNRA residents.

With the objective of studying the health effects of long-term exposure to low-level radiation, Hayata et al. (2004) analyzed the chromosomes of peripheral lymphocytes from the residents of HBNRAs in Yangjiang and compared their results with those obtained from control areas with normal background radiation. The authors found an increase in the frequency of dicentric and ring chromosome aberrations in the HBNRA residents. In an earlier study, Hayata et al. (2000) used chromosome painting analysis to measure the effects of chronic exposure in 9 HBNRA residents and 8 NBRA residents. Dose effects were detected in dicentrics, and the frequency of translocation varied among adults. The study found no statistically significant increase in the frequency of chromosome aberration in the HBNRA residents.

An epidemiological study of cancer incidence among residents of Yangjiang was conducted by Zou et al. (2005). This study observed no significant difference in cancer-related mortality rates

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