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Natural radioactivity and radiological hazards assessment of bone-coal from a vanadium mine in central China

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HIGHLIGHTS

- High natural radioactivity in bone coal from a vanadium mine has been determined.
- The ^{238}U and ^{226}Ra were the main contributors to the high radioactivity.
- The radiological hazard index was shown higher than an unacceptable level.
- The hazard of radon inhalation should arouse attention.

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ABSTRACT

A comprehensive utilization project of bone-coal in a vanadium mine was proposing in recent years in central China. Based on the analysis of 31 representative bone-coal samples from 9 boreholes at various depth drilled in planning initial minery, the average activity concentrations of ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K were determined in the range of 196.4–653.3 Bq/kg, 200.2–564.4 Bq/kg, 9.4–64.6 Bq/kg and 71.5–345.4 Bq/kg, respectively. The major natural radionuclides were identified as U-series nuclides with the activity concentrations obviously higher than common coal. The estimated absorbed dose rates in the air varied between 107.1 and 310.5 nGy/h. The averaged external annual effective dose due to the radioactivity in the bone-coal was predicted as 0.37 mSv/a, and the main contribution is 87.5% for U-series. The radium equivalent activity, the external and internal indices of most of the samples were shown with high values of an unacceptable level, which indicated the bone-coal would carry a considerable radiation hazard to the workers and the local individuals. The hazard of radon inhalation should be focused during mining and following processes. Further radiological assessment should be carried out as the natural radioactivity in the bone-coal would be technically enriched during the combustion process of the bone-coal and utilization of the byproducts.

1. Introduction

The protection of the public and workers from the harmful effects of ionizing radiation has been a long concern of radiation protection professionals. Estimation of radiation exposure from naturally occurring radioactive materials (NORM) concentrated is focused on in the past 20 years because the processing or consumption of coal, oil and gas, and some minerals becomes an important environmental concern to the public and national authorities of many countries (Eisenbud and Gesell, 1997; IAEA, 2003; O'Brien and Cooper, 1998; Sohrabi, 1998).

Coal or mineral contains radionuclides of U-series, Th-series as well as ^{40}K. Extraction, processing of the material would result in release of the radionuclides to the environment, and deliver radiation dose with subsequent impact to workers and to local populations living around minery or industry site (Dowdall et al., 2004; Emirhan and Ozben, 2009; Tsikritzis et al., 2008). It was reported that typical activity concentrations of ^{238}U, ^{232}Th and ^{40}K in the coal used in China were in the range of 3.4–9020 Bq/kg,

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1.8–4600 Bq/kg, and 5–1200 Bq/kg, respectively, and the corresponding average based on the weighted statistics of yields in various provinces were estimated as about 64.9 Bq/kg for ^{238}U, 37.5 Bq/kg for ^{232}Th and 106.0 Bq/kg for ^{40}K, depending on the geological distribution (Liu et al., 2007). The dose equivalent of public individuals from coal-power chain was estimated at 50 times as high as that from nuclear power chain in China (Pan et al., 2001).

The bone-coal is an inferior anthracite with high content of ash and low calorific value, almost rock, and in general is associated with various metal cores, such as vanadium, molybdenum and uranium (Xu et al., 1984; Zhang et al., 2011). The bone-coal is widely distributed in southern and central region of China, and more than 90% amount across China deposits in five provinces of Hubei, Hunan, Jiangxi, Zhejiang and Anhui (Kong et al., 2006; Li et al., 2005; Ye et al., 2004). In the investigations of natural radioactivity background in China, the activity concentrations of ^{238}U and ^{226}Ra in bone-coal were found as generally higher than that in common coal, the average activity concentrations in bone-coal obtained from above five provinces were investigated as averaged at about 1278 Bq/kg for ^{238}U, and 1302 Bq/kg for ^{226}Ra, while the activity concentrations of ^{40}K and ^{232}Th were in normal scope (Kong et al., 2006; Li et al., 2005; Ye et al., 2004). It was indicated that bone-coal would cause more radioactive pollution on environment and health hazards to workers or public individuals than common coal in general. For the byproduct of bone coal, the activity concentrations of natural radioactivity would be enriched and bring much more radiological hazards to the workers and local populations. Basically, knowledge about the regional distribution of natural radionuclides in material is essential in maintaining some sense of control of prevailing radiation levels. It is one of the most important tasks to investigate the distribution of radioactivity and to assess the possible radiological hazard prior to the launch of the mining and the utilization.

The aim of present work is to investigate the activity level in bone-coal and to predict the possible radiation hazard on workers and the local populations at one of the largest vanadium mines in central China, which is proposed in recent years. Based on the mine, a comprehensive utilization project of bone-coal would be developed. The bone-coal would be stripped and crushed, then mix-combusted with anthracite for electricity generation on coal fired power plant (CFPP). The ash and slag would be used for vanadium extraction or for other utilization such as for building materials production. Beyond mining, the industries of electricity generation, vanadium extraction, utilization of lime-ash would be also the important concerns of radiological impact issues (Huang et al., 2013). As such, the studies on the distribution of activity concentration and the radiological hazard assessment will provide basic scientific values for future radiation protection and radiological safety management of the project.

In the present work, the natural radioactivity in 31 bone-coal samples from nine representative boreholes in the initial minery was measured on a NaI(Tl) gamma spectrometer and a laser fluorescence analyzer. To assess the radiological hazards of bone coal, the radiological parameters of the absorbed dose rate in the air, the external annual effective dose, the radium equivalent activity, the external hazard index, and the internal hazard index are calculated and discussed.

2. Materials and methods

2.1. Site description

The location for our research is situated around 27.05° North latitude and 109.97° East longitude, at a distance of 32 km in the NW direction from Hongjiang City of Hunan province in central China. The dominant mineral in this region is the vanadium-containing bone coal. The reserve was about 1000 M tons with about 4 M tons of vanadium oxide. The initial mining scale is about 4 M tons bone-coal per year, and the area is about 1 km^2, about 5% of the total project area. According to the proposal, the bone-coal would be mined in open pits, as the cover of surface soil and weathered layer is thin. On the northeastern of the mining area, a power plant (4×300 MWe) would be constructed for electricity generation. The ash and slag from the power plant then would be staged temporarily at an ashery site or transported to the vanadium plant on the south of the power plant for vanadium extraction. With continuous hills and steep valleys or cliffs, the topography changes greatly, and the vegetation is well protected in the mining area. The major surface runoff around the region is the Wushui River as a tributary of Yuanjiang River, which would be served as the cooling water source for the power plant. The areas of the ashery site, the power plant and the vanadium plant are about 0.8 km^2, 0.5 km^2 and 0.2 km^2, respectively. The layout of the proposed project and the topography is illustrated in Fig. 1.

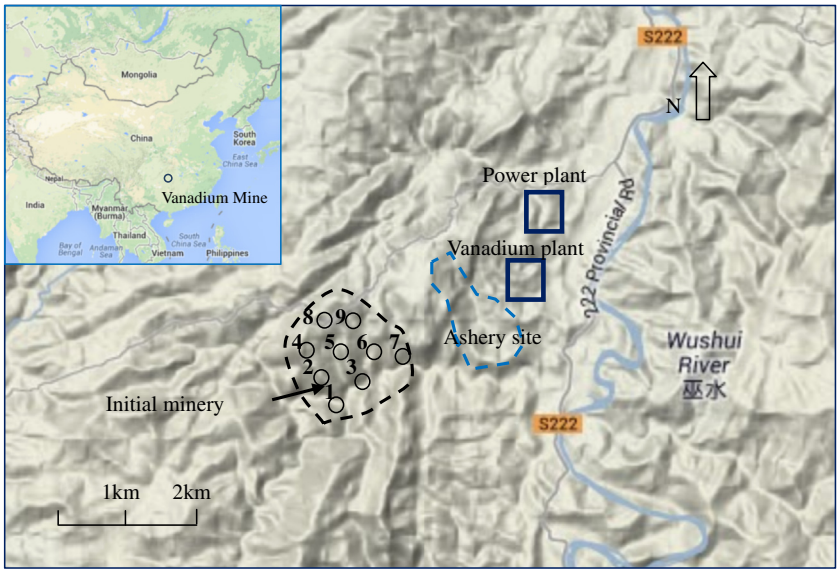

Fig. 1. The layout of the bone-coal utilization project and the topography around the minery. The open circles show survey boreholes. The numbers indicate sampling sites.