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Naturally occurring radionuclides in particulate emission from a coal fired power plant: A potential contamination?

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ABSTRACT

The use of coal as fuel in coal-fired power plant (CFPP) for electricity generation results in emission of particulate which contains trace quantities of naturally occurring radionuclides, namely Uranium-238 (^{238}U), Thorium-232 (^{232}Th) including their decay series and Potassium-40 (^{40}K). These naturally occurring radionuclides may increase their natural radioactivity level in the ambient particulate matter vicinity of the plant resulting from the combustion processes. This paper presents an investigation of radioactivity level of particulate emission and maximum deposition due to natural radioactive emissions from a typical CFPP using standard Gaussian dispersion model approach. The predicted maximum ground level particulate concentration (C_{max}) and downwind distance were 55 $\mu g\,m^{-3}$ and 1600 m away from the source, respectively. The results recorded that the C_{max} released from the CFPP was significantly lower than the national and international ambient air quality limits, which means that radiological hazards from inhalation due to particulate emission released from the stack is insignificant. The air dispersion modelling results suggested that this activity does not impose any significant effect to the human population at large and potential contamination at vicinity of CFPP is remote.

1. Introduction

Minerals, like coal, mostly contain natural radionuclides from terrestrial origin, which are commonly referred as primordial radionuclides. Accordingly, it is also known as Naturally Occurring Radioactive Materials (NORM). Coal contains natural radionuclides such as ^{238}U, Uranium-235 (^{235}U), ^{232}Th including members of their decay series, trace quantities of ^{40}K and none of fission products. Radionuclides are approximately present in the same quantities as in common soil [1]. Human activities and exploitation of coal, especially in the manufacturing and power generation industries may lead to technologically enhanced and increased concentrations of radionuclides. The concept of technologically enhanced refers to the exposure of the natural sources of radiation with unintentionally generated ionizing radiation.

Coal is the world's main natural resources to produce sustainable electricity and claimed to be in the backbone of the world's electricity supply for several years ahead. Hence, this makes coal an important fossil fuel and most demanding NORM in non-nuclear industries for power generation. Coal-based electricity is set to double in the first three decades of 21st century, from 16,074 TWh in 2002 to 31,657 TWh in 2030 and will continue to play a key role in the world electricity generation [2]. In addition, the uncertainty of nuclear power industry and the declining of natural gas and petroleum resulted in coal remain to be relevant for power generation [3]. Therefore, for non-nuclear power generation industries sector, CFPP has become the most promising NORM industry compared to others.

Notwithstanding the various benefits it offers, electricity production may contribute to local environmental degradation. It is due to severe increment of pollution level at several major cities around the world. The increasing demand of electricity and rise of pollution level should simultaneously be considered as both are the wheels of the same vehicle, i.e., development [4]. The use of coal in power generation however, is not without risk and hazard. Most people tend to think of coal only as being carbon [5]. This assumption sounds reasonable if the combustion of coal involved in small quantities. Nevertheless, if one considers the tonnage usage of coal, atmospheric pollutants and generation of high volume of solid waste, it will develop serious concern. Indeed, it will become one of the major issues for consideration in power generation industries in the perspective of environmental

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Nomenclature

C	Ground level particulate concentration ($\mu g\,m^{-3}$)
C_{max}	Maximum ground level particulate concentration ($\mu g\,m^{-3}$)
ds	Stack diameter (m)
e(g)j	Relevant value of committed effective dose per unit intake ($Sv\,Bq^{-1}$)
H	Effective stack height (m)
h	Physical stack height (m)
$I_{j.inh,\ L}$	Intake corresponding to the relevant annual occupational dose limit for workers or public (Bq)
L	Relevant annual dose limit on effective dose ($Sv\ y^{-1}$)
X	Downwind distance (m)
X_{max}	Maximum downwind distance (m)
μ	Wind speed ($m\,s^{-1}$)
σy	Value of standard deviation of the concentration distribution in the crosswind direction at the downwind distance (m)
σz	Value of standard deviation of the concentration distribution in the vertical direction at the downwind distance (m)
Δh	Plume rise (m)
Pa	Atmospheric pressure (mb)
Qm	Emission rate ($g\,s^{-1}$)
Qs	Stack gas volumetric rate ($m^3\,s^{-1}$)
Ts	Stack gas temperature (K)
Ta	Atmospheric temperature (K)
Vs	Stack gas velocity ($m\,s^{-1}$)
AMAD	Activity median aerodynamic diameter
APC	Air pollution control
Bq	Becquerel
CFPP	Coal fired power plant
CO	Carbon monoxide
DAC	Derived air concentration
ESP	Electrostatic precipitator
FWHM	Full width at half maximum
HQ	Hazard quotient
IAEA	International atomic energy agency
NORM	Naturally occurring radioactive material
NO_x	Nitrogen oxides
PE	Polyethylene
PM	Particulate matter
SO_2	Sulphur dioxide
UNSCEAR	United Nations scientific committee on the effects of atomic radiation, sources, effects and risks of ionizing radiation
VOCs	Volatile organic compounds

sustainability. In future, this trend will be a culture, unless more affordable and environmentally friendly sources of electricity are available and provided for the industries [5].

Coal burning in the furnace for CFPP operation involves high temperature and potentially poses environmental, health and radiological impact [6]. Coal combustion eliminates organic components and enhances the radioactivity level in ashes. The combustion process also releases (not limited to) particulate matter (PM), sulphur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), volatile organic compounds (VOCs) and various trace elements including the natural radionuclides that are emitted into the air through the stacks which potentially contaminate over large areas. In addition, CFPP is an important source of pollution due to the generation of huge quantities of solid wastes i.e. bottom and fly ash [7].

CFPPs released gaseous and emitted fine particulate that contains radionuclides to the environment and potentially causing additional external radiation exposure to the population living in the vicinity of coal power plants [8]. Most of particulate emission is recovered by the air pollution control device and small proportion of particulate may escape to the atmosphere and finally deposited on the surface soil. Modelling particulates emission of radionuclides plume is part of important aspect in radiation protection programs to estimate the radiological impact and consequences to public. Hence, modelling of this particulate dispersion is essential due to potential radionuclides fall-out to the environment. Simple dispersion model such as Gaussian dispersion model may provide appropriate estimates for prediction of the ground level particulate concentration and downwind distance of this case.

Many studies [17,8,18] not limited to, have been performed in recent years on the particulate concentration that contains radionuclides from CFPPs to the atmosphere, but there are not much data for Malaysia. This paper presents an investigation of radioactivity level of particulate emission from a typical CFPP. In addition, the analysis of the radioactivity concentration was also determined in the burnt feed coal. The probable radiological hazard and exposure, if any to the workers, public and the environment is presented based on a simple air dispersion modelling exercise.

2. Materials and methods

2.1. The coal fired power plant

Table 1 presents the description of the CFPP in this study, which generated 3 × 700 MW of electricity burning an imported sub-bituminous coal. The CFPP burnt a total of 23,500 MT of coal on a daily basis and was equipped separately with dust and gaseous emission control consisting of low NO_x burner and electrostatic precipitator (ESP) unit, respectively.

2.2. Sampling and sample preparation

A grab sample of feed coal (FC) was taken from the CFPP for a week. The feed coal was collected at the coal feeder. Approximately 2.0 kg of FC was collected and ground to fine powder form of 200 μm in size, homogenized and air dried for about 48 h in an air circulation oven at 110 °C in the laboratory. After cooling in moisture-free medium, each sample was subjected for radiometric analysis.

Meanwhile for stack particulate emission (P), the sample was collected using a fibre thimble; dried before and after sampling where the final particulate mass was obtained. The sampling was carried out at sampling port in the stack gas downstream of an ESP dust arrestor. The sampling was performed isokinetically according to United State Environmental Protection Agency (USEPA) Method 17: Determination of particulate matter emission from stationary sources [9]. In addition, USEPA Method 4: Determination of moisture content in stack gas was used to determine the flue gas moisture content [10]. USEPA Method 2: Determination of

Table 1
Description of the CFPP.

Parameter	Info/Value
Types of coal	imported coal, sub-bituminous
CFPP capacity (MW)	3 × 700
Total amount of coal burnt per day (MT)	23,500
Air pollution control (APC) system	Low NO_x burner and ESP