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Radiation transmission of colemanite, tincalconite and ulexite for 6 and 18 MV X-rays by using linear accelerator

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HIGHLIGHTS

- ▸ Radiation transmission of some boron ores were measured using linear accelerator.
- ▸ Their attenuation coefficients are higher than that of Pb at pair production region.
- ▸ The boron ores can be preferred as shielding materials to prevent photon and neutron.

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ABSTRACT

Tincalconite, ulexite and colemanite are boron ores. Since these ores include boron, hydrogen and many other elements, these boron ores may be used as shielding materials instead of Pb metal and paraffin wax. In this study, measurements have been made to determine radiation transmission of tincalconite, ulexite and colemanite by transmission method for 6 and 18 MV using linear accelerator (LINAC) with ionization chamber. The experimental results were compared to the results of WinXCom X-ray computer program's. In pair production region, ores such as colemanite, ulexite and tincalconite can be preferred as shielding materials to prevent photon and neutron particle radiations.

1. Introduction

Turkey has the richest boron mining deposits of world, with about 64% of the world boron reserves. Colemanite ($Ca_2B_6O_{11} \cdot 5H_2O$), tincalconite ($Na_2B_4O_7 \cdot 5H_2O$) and ulexite ($NaCaB_5O_9 \cdot 8H_2O$) are raw borates and can be used as thermal and fast neutron shielding. These boron ores are also used in control bars of nuclear reactors. They are used in many experiments as additives to concretes because boron-bearing ores are more practical and cheaper than pure boron.

Since the mass absorption coefficients, μ_m, values are important in fundamental physics and many applied fields, the accurate μ_m values for X- and γ-rays in several materials are essential for some fields such as radiation shielding. μ_m values have been reported for 40 elements, 45 mixtures and compounds over the energy range from 1 keV to 20 MeV. These studies were reiterated and tabulated for all elements in the atomic range $1 \leq Z \leq 92$ and 48 additional substances of dosimetric interest (Berger and Hubbell, 1987; Hubbell and Seltzer, 1995). Mass attenuation coefficients of some boron ores were measured at 59.5 keV γ-ray energy (Demir, 2010). Attenuation coefficients for perspex, bakelite, paraffin, Al, Cu, Pb and Hg were measured at three different γ-ray energies (59.54, 661.6 and 1332.5 keV) (Abdel-Rahman et al., 2000). Mass attenuation coefficients of the given materials have been calculated by the WinXCom program (Gerward et al., 2001, 2004). This program which is based on the DOS-based compilation XCom (Berger and Hubbell, 1987; Hubbell and Seltzer, 1995) provides total mass attenuation coefficient and total attenuation cross section data for about 100 elements as well as partial cross sections for incoherent and coherent scattering, photoelectric absorption and pair production at energies from 1 keV to 100 GeV.

Some works on $PbO–B_2O_3$, $Bi_2O_3–PbO–B_2O_3$ (Singh et al., 2004); $PbO–BaO–B_2O_3$ (Singh et al., 2006); $ZnO–PbO–B_2O_3$ (Singh et al., 2003); $CaO–SrO–B_2O_3$ (Singh et al., 2005) demonstrated that glass systems including boron compounds may be promising as γ-ray

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shielding materials. As radiation shielding materials, barium-borate-fly ash glasses were studied (Singh et al., 2008). The γ-ray attenuation coefficients were measured for some heavy metal oxide borate glasses at 662 keV (Khanna et al., 1996). Boncukcuglu et al. (2005) and Icelli et al. (2003a, 2003b) aimed to stabilize trommel sieve waste (TSW) occurring during manufacture of borax from tincalconite. The effects of TSW on the mechanical properties and radioactive transmission of modified cement prepared by adding TSW to clinker were investigated. For shielding fast, middle and soft neutrons, heavy materials which have high atomic weights, and light elements like oxygen and hydrogen were investigated (Polivka and Davis, 1979). They asserted that materials containing boron were preferable over the others. A patent presents that Galena (a lead ore) and other lead minerals can be used for the shielding from γ-rays, and colemanite and other boron minerals can be used for neutron shielding. The family of compositions according to the invention contains by weight 65–75% of floated galena, 5–10% of colemanite and 20–25% of binding agents and additives (Grifoni, 1988).

In this work, measurements have been made to determine radiation transmission of tincalconite, ulexite and colemanite by using the transmission method for 6 and 18 MV by using a linear accelerator (LINAC) with an ionization chamber. Pb and paraffin wax (C_nH_{2n+2}) were used as standard samples. In the other words, mass attenuation coefficients of Pb and paraffin wax are reference values. Finally, mass attenuation coefficients of colemanite, tincalconite ulexite were compared with mass attenuation coefficients of Pb and paraffin wax (WinXCom). The experimental results were compared to the results of the WinXCom X-ray computer program.

2. Experimental procedure

2.1. Materials and apparatus

The following materials were used:

- Samples: colemanite, tincalconite and ulexite.
- Linear accelerator: Siemens Primus
  The klystron produces radio waves (frequency)-RF and, the electrons overlap the radio waves. Accelerated electrons hit the metal target and the energy of X-rays obtained from the target is proportional the energy (velocity square) of electrons.
- Detector: Ionization chamber
  The ionization chamber (Table 1) was calibrated by Ataturk University, Medical Faculty and Radiation Oncology Department every month and Turkish Atomic Energy Agency every year by using ^{60}Co. The ^{60}Co is the most common reference quality Q_0 used for calibration of ionization chambers worldwide.
  Sousa reported that the absolute value of absorbed dose to water can be determined with three basic methods: calorimeter, chemical dosimeter and ionization dosimeter (Sousa, 2009):
  - Calorimetry involves the use of a calorimeter, a device that measures the heat in various processes;
  - Chemical dosimeter involves the determination of dose by the measurement of chemical changes induced by ionizing radiation;
  - Ionization dosimeter involves the use of an IC, a device that can be used for detecting particles and for detection or measurement of ionizing radiation (Demir et al., 2010).
- Hydraulic press machine (SPEX P_{max} 25 t/cm^2)
- Sieve (Retsch)

2.1.1. Ionization chamber

When X-rays are generated, the direct low energy (<10 keV) neutrons are absorbed from the incident beam by the help of a flattening filter material which can absorb low energy radiations. Therefore, only X-rays come into the ionization chamber. At atmospheric pressure the ionization chamber is usually filled with air. This type of ionization chamber usually is used for X-ray measurements. Irradiation intensity (roentgen) is the amount of charge created by X-rays in the air. When appropriate conditions are fulfilled, irradiation intensity is obtained with ion current passed through detector in air-filled ionization chamber. If electron energy of incoming radiation is sufficiently high the electrons cause further ionization. These electrons are called the secondary electrons. Definition of irradiation intensity also includes ions produced by the secondary electrons. This means that the secondary electrons in the air can lead to a maximum path length greater than that for the primary electrons. When the path of the secondary electrons is few meters, the production of that sized detectors are very difficult to practically produce. So, a balancing principle is used. If the chamber/sphere in an environment that was assumed as the infinite length in air is exposed to large irradiation intensity, the balance occurs. So, ionization brought about by secondary electrons in the chamber/sphere is the same as the ionization brought about by secondary electrons out of the chamber/sphere. In order to prevent the collection of electrons in the empty electrodes, the electrodes are grounded. Ion current is collected in the sensitive region limited by the center electrode. Incoming X-ray are so narrow that the secondary electrons created in the sensitive region cannot reach the electrode. Since density of air depends on pressure and temperature of air, the measurements are normalized according to standard pressure and temperature.

2.2. Sample preparation

Powder samples are prepared as follows. The samples (colemanite, ulexite and tincalconite) were dried approximately for 1 h at 35 °C in an oven. 1–75 μm scaled sieve was used for sieving the samples to be prepared as pellets for measurement. After sieving they were mixed using a SPEX mill using a 25 ml stainless-steel cup and balls. A small metallic sample holder made of aluminum was used for forming samples as pellets. The constituted pellets

Table 1
Features of ionization chamber.

Material	Value	Cable and Connector	Value
Outer electrode (Graphite)	1.82 g/cm^3	Connector type	TNC triaxial
Inner electrode (Aluminum)	2.70 g/cm^3	Cable length	1.40 m
Build-up cap for ^{60}Co POM	1.42 g/cm^3		
Active dimensions		**Operational data**	
Volume (nominal)	0.63 cm^3	Leakage current	$< \pm 4 \times 10^{-15}$ A
Total active length	23.1 mm	Sensitivity	21×10^{-9} C/Gy
Inner diameter of cylinder	6.2 mm	Radiation quality (e^-)	1.3 MeV–50 MV
Wall thickness	0.4 mm	Polarizing voltage	+300 V
Diameter of inner electrode	1.0 mm	Reference point w/o build-up cap	13 mm from the distal end of the chamber
Wall thickness of build-up cap for ^{60}Co	3.9 mm	Reference point with build-up cap for ^{60}Co	17 mm from the distal end of build-up cap