INVESTIGATION ON RADIATION PROTECTIVE CAPABILITY OF
METAMORPHIC ROCK USED IN CIVIL ENGINEERING
CONSTRUCTION

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ABSTRACT
Along with the growing economy and increasing economic solvency of the population of Bangladesh,
the houses made by concrete walls are being decorated by modern building materials like marble
stone. The building materials must provide adequate protection to keep acceptable probability of
harmful effects on personnel at a reasonable cost. In this study, an attempt was made to investigate the
gamma-ray attenuation co-efficient of decorative marble materials leading to their suitability as
shielding of ionizing radiation. A number of commercial grades marble stones (Rose Pink, Crema
Nova, Carrara, Marmara Zebra, Perlato Bianco and Rosalia) were collected from home and abroad
following their large-scale uses. A well-shielded HPGe γ-ray spectrometer combined with associated
electronics was used to evaluate the attenuation coefficients of the investigated materials for high-
energy photons. Some allied gamma-ray interaction parameters such as Linear Attenuation
Coefficient, Mass Attenuation Coefficient, Half Value Layer and Radiation Protection Efficiency of
the investigated marble stones were measured to assess residential safety. Among the studied samples,
the marble ‘Carrara’ imported from Italy found more suitable as a radiation shielding materials than
the other samples studied herein. Moreover, the results of effectiveness of radiation shielding, the
marble ‘Carrara’ is found comparable with the steel.

Keywords: HPGe γ-ray spectrometer; Attenuation coefficient; Radiation shielding; Marble stones.

INTRODUCTION
Ionizing radiation presents in our environment and originates from both natural and artificial sources.
Currently, the use of artificial radioactive isotopes has been increasing in nuclear research, nuclear
power, space research, medicine, agriculture etc., and thus contributing in the redistribution and
enhancement of background radiation in our environment. Exposure to radiation from natural sources
is in most cases of little or no concern to society, but in certain situations, the introduction of health
protection measures needs to be considered. Since human beings spent around 80% of their time with
in-house activity, the radiation protection inside houses should be given most priority. To obtain the
radiation protection capability of different materials, it is necessary to conduct study of gamma-ray
interactions with the materials of interest.

According to the IMF, Bangladesh’s economy is the second fastest growing major economy in 2016,
with a rate of 7.1% (Dhaka Tribune, 2014; Devnath, 2016). The per-capita income estimated by the
IMF for the year 2016 is US$ 3,840 (PPP) and US$ 1,386 (Nominal) (Rahman, 2015), which
indicates to becoming a mid-income nation. Along with increasing economic solvency of the
population of Bangladesh, the existing houses made by brick/non-brick walls with tin shade are
almost replaced by modern building materials. These building materials must afford enough
protection to keep acceptable probability of harmful effects on personnel. Following the huge
population density, the real estate and construction industry are playing an important role for human settlements in a sustainable manner, and developing fashionable structures using rod, cement, concrete, marble, tiles and glass materials throughout the country. Marble is widely used as a furnishing material in modern building construction in worldwide as well as in Bangladesh due to its polished surface and availability in a variety of attractive colors. This metamorphic rock in fact prized for the beauty and richness of its finished surface. The escalating uses of stones as decorative agents in construction industry, it is imperative to assess the suitability of various kinds of marbles for shielding of ionizing radiation. Assessment of mass attenuation coefficient is a basic property that indicates the radiation shielding capability of any particular material. A number of works dealing with the mass attenuation coefficient of building materials have been found in the literature (Akkurt et al., 2009; Mavi, 2012; Awadallah and Imran, 2007; Alam et al., 2001; Mann et al., 2016; Charanjeet et al., 2004; Medhat, 2009; Sahadath et al., 2016; Mann et al., 2013; Damlaa et al., 2010; Akhurt et al., 2010). However, in Bangladesh, these types of metamorphic rocks have not been analyzed for the purpose of radiation shielding. In this study, an attempt was made to measure the gamma-ray interaction parameters such as linear attenuation coefficient, mass attenuation coefficient, half-value layer and radiation protection efficiency of marble stones to assess residential safety.

**METHODOLOGY**
A total of six varieties (depending on type and origin) of marble samples used as decorative assembly in building construction were collected from marble dealers in and around Chittagong city for the measurement of properties relevant to radiation shielding. Detailed information on the used samples is summarized in Table 1. All the samples were brought to the laboratory and the samples were properly cataloged, washed and dried for complete removal of moisture. Following the diameter (7.5 cm) of gamma-ray detector envelops, the geometry of all marble samples were prepared. To be acquainted with the gamma-ray shielding effectiveness of these samples, the mass attenuation coefficients of marbles were measured using the HPGe gamma-ray spectrometer with a relative efficiency of 20%, resolution 1.8 keV (FWHM) at 1332 keV of $^{60}$Co. The detector (GC2018, CANBERRA, USA) was coupled with digital spectrum analyzer (DSA-1000) and the gamma-ray spectra were analyzed by using the program GENIE 2000. The detector is shielded by a lead cylindrical shield of 9 cm thickness and 40 cm height with an inner lining of 1.6 cm-thick steel plate, which provides an efficient suppression of the background radiation present at the laboratory environment. The diagram of the narrow beam $\gamma$-ray transmission geometry is shown in Fig. 1. The standard gamma point source $^{60}$Co provided by the IAEA was used herein. The distance between source and detector was 22 cm. Samples were positioned on a specimen holder at 1.5 cm from the detector. The intensities of photon were measured without and with placing the investigated samples between source and the detector. The intensities of incident ($I$) and transmitted ($I_0$) photon were measured for a time duration of 80,000 seconds by selecting a narrow symmetrical region with respect to the centroid of the photo peak. The net peak area presents the intensity of gamma-rays with statistical accuracy better than 0.3%.
Table 1 Investigated Samples and their related information (Alibaba, 2017)

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Stone Name (Marble)</th>
<th>Local brand name</th>
<th>Place of Origin</th>
<th>Thickness</th>
<th>Color</th>
<th>Marble Type</th>
<th>Prize/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Rose Pink Marble</td>
<td>India</td>
<td>1.58 cm</td>
<td>Pink</td>
<td>Calcite</td>
<td></td>
<td>US $20-40</td>
</tr>
<tr>
<td>02</td>
<td>Crema Nova</td>
<td>Turkey</td>
<td>1.74 cm</td>
<td>Cream</td>
<td>Calcite</td>
<td></td>
<td>US $10-50</td>
</tr>
<tr>
<td>03</td>
<td>Carrara Marble</td>
<td>Itali</td>
<td>1.77 cm</td>
<td>White</td>
<td>Dolomite</td>
<td></td>
<td>US $20-50</td>
</tr>
<tr>
<td>04</td>
<td>Marmara Zebra</td>
<td>Turkey</td>
<td>1.75 cm</td>
<td>Grey</td>
<td>Dolomite</td>
<td></td>
<td>US $15-25</td>
</tr>
<tr>
<td>05</td>
<td>Perlato Bianco</td>
<td>Albania</td>
<td>1.89 cm</td>
<td>White</td>
<td>Calcite</td>
<td></td>
<td>US $10-35</td>
</tr>
<tr>
<td>06</td>
<td>Rosalia</td>
<td>Turkey</td>
<td>1.48 cm</td>
<td>Pink</td>
<td>Calcite</td>
<td></td>
<td>US $54-55</td>
</tr>
</tbody>
</table>

**Assessment of Interaction Parameters**

A narrow beam of mono-energetic photons when penetrates a layer of material with mass thickness $t$, can follow the attenuation law given by Lambert-Beer

$$I = I_0 e^{-(\mu/\rho)t} \quad (1)$$

where $I_0$ and $I$ are the incident and transmitted intensity of photons, respectively, $\rho$ is the mass density, $\mu$ is the linear attenuation coefficient which varies with the density of the absorber.

The mass attenuation coefficient, $\mu/\rho$ for a compound is given by

$$\mu/\rho = \sum w_i (\mu/\rho)_i \quad (2)$$

where $w_i$ and $(\mu/\rho)_i$ are the weight fraction and mass attenuation coefficient of the $i$-th constituent element, respectively.

The half value layer (HVL) of the sample material was calculated by using the following Eq. (3):

$$x_{1/2} = \frac{\ln 2}{\mu} \quad (3)$$

where $x_{1/2}$ and $\mu$ are the HVL and linear attenuation coefficient, respectively.

The radiation protection efficiency of building materials (in this case marble) is calculated by using the following equation:
RESULTS AND DISCUSSIONS

Figures 2, 4 and 6 show the results of the studied shielding properties with the uncertainties (± 1σ), in various marble samples used in Bangladeshi dwellings. The two photon energies 1173.4 and 1332.7 keV emanated from ⁶⁰Co point source, were applied to different types of investigated marbles. The mass attenuation coefficients of these materials were measured at the two mentioned energies with their uncertainties as shown in Fig. 2. At the elevated energy 1332.7 keV the mass attenuation coefficients of the marble samples increased except the two samples Marmara Zebra and Perlato Bianco, where it happens to down. Out of these six marbles, the Carrara sample has unparalleled value about 2.2 times higher than the others do.

Fig. 2 Experimental results of mass attenuation coefficient (μ/ρ) with uncertainties for marble samples at 1173.4 and 1332.7 keV

Fig. 3 shows the advanced shielding quality of marble with measure up to concrete (Dhaka Tribune, 2014), soil (Devnath, 2016), brick (Alam et al., 2001) and cement (Akkurt et al., 2009).
Fig. 3 A comparison of mean mass attenuation coefficient of marble with the literature.

The half value layer (HVL) of any materials is the thickness of an absorber that will reduce the radiation to half (Akkurt et al., 2009; Mavi, 2012; Akhurst et al., 2010) of its initial amount and depicts the effectiveness of gamma-ray shielding. Like the attenuation coefficient, it is a photon energy dependant parameter. Increasing the penetrating energy of a stream of photons will result in an increase in a material's HVL. Fig. 4 of HVL and Fig. 2 of mass attenuation coefficients illustrate that the HVL is inversely proportional to the attenuation coefficient. Consequently, the marble Carrara showed better shielding than the others do. The range of half value layer (in cm) of these investigated marble samples was found 1.7-4.6.

Fig. 5 gives us an idea about the shielding quality of studied marble sample where it was found better than the concrete materials.

Fig. 4 Half value layer of the investigated samples at 1173.4 and 1332.7 keV photon energies.
Fig. 5 A comparison of the average value of half value layer of the studied marble samples with the samples Concrete, Steel, Lead and Tungsten due to $^{60}$Co found in literature (HVL-Shielding-NDE/NDT Resource center).

Fig. 6 shows the evidence for higher value of radiation protection efficiency of marble stone Carrara because of its higher value of mass attenuation coefficients.

CONCLUSIONS
This experimental work has been done to determine the mass attenuation coefficients and other parameters of some marble stones that are commonly used as decorative building materials in Bangladeshi dwellings. The results give an idea about a comparison of the investigated marble stones in terms of radiation shielding. The marble sample ‘Carrara’ imported from Italy found more suitable as a radiation shielding materials than the other marble samples studied herein. In general, the investigated marble sample showed better shielding effectiveness than the concrete material. In fact,
the Civil Engineering constructions will be benefited in the issue of radiation shielding by using the marble stones.

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REFERENCES