ATTENUATION OF PILE RADIATIONS IN SERPENTINITE SAND

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Results of an experimental study of the attenuation of pile radiations in serpentine sand having a bulk density of 1.62 g/cm³ are reported. The sand investigated contains about 11.5% chemically bound water liberated at temperatures upwards of 450°C.

The attenuation of fast flux and thermal flux, attenuation of neutron and gamma dose rate, and fast-neutron spectra in serpentinite sand were measured. Relaxation lengths of fast neutrons computed from experimental data are compared to relaxation lengths of fast neutrons in boron carbide, serpentinite concrete, and iron-ore concentrate.

Serpentine rock presents some interest as a structural material used in biological shielding of nuclear reactors and consists almost entirely of serpentine. This mineral belongs to the group of hydrated magnesium silicates; its composition is given by the chemical formula Mg₆[Si₄O₁₀](OH)₈. The oxide ratio (wt.%) are: MgO 43; SiO₂ 44.1; H₂O 12.9. The usual impurities present are FeO, Fe₂O₃, and NiO. The specific weight of serpentine is 2.5 to 2.7 g/cm³.

Serpentinite blocks are widespread in the USSR in the Ural mountains, in the northern Caucasus, in the Transcaucasian districts, in Siberia, and in Kazakhstan. Serpentinite deposits are usually accompanied by asbestos deposits. At the present time the world's largest asbestos deposit at Bazhenovo is being worked; other important deposits in the Soviet Union are found in the Kazakh SSR and in the Tuva autonomous district. At mills in the Bazhenovo deposit site the yield of commercial asbestos per ton of processed ore is 80 kg [1]; the remaining mass consists of serpentinite for the most part. It has been reported [2] that veins of pure serpentinite containing no asbestos have been discovered in a quarry located in the central strip of the Bazhenovo deposit. According to a statement by the present authors, mining of monolithic blocks incurs no additional costs and may be carried out in parallel with the working of the asbestos deposits. In many places the serpentinite shows only insignificant cracking, so that monolithic blocks ~ 1 cubic meter or more in volume can be quarried.

Serpentinite contains bound water in addition to magnesium, iron, and silicon; the bound water is released only when the serpentinite is heated to temperatures upwards of 450°C [3], so that serpentinite can be properly regarded as a high-temperature material suitable for use in the biological shielding of nuclear reactors. The concentration of hydrogen nuclei in serpentinite is about 1.5 wt.% which is entirely adequate to attenuate intermediate neutron flux and fast flux identically.

Serpentinite may be used as aggregate in shielding, or may be used as fill in blocks sawed whole. The specific weight of monolithic serpentinite is about 2.6 tons per cubic meter; the thermal conductivity is 2.16 to 2.56 kcal/m · h · deg C [4]. Serpentinite shows excellent retention of the sawed edge, so that shapes of high dimensional accuracy can be fashioned from the material with a compressive strength ranging from 400 to 600 kg/cm².

The results of an experimental study of the shielding properties of serpentinite concrete are described in the literature [5]. Data on the attenuation of pile radiations in serpentinite fill are not found in the literature.

Increased interest in ore and rock of possible use in the biological shielding of nuclear reactors has been noted in recent years. The shielding properties of standard iron-ore enriched concentrate containing ≥60 wt.% Fe, ≥30 wt.% O, and trace amounts of Si, Mg, Ca, Al, and other elements have been studied in [6]. Experiments at the BR-5 reactor...
TABLE I. Oxide Content in Serpentinite

<table>
<thead>
<tr>
<th>Oxides</th>
<th>SiO₂</th>
<th>MgO</th>
<th>FeO + Fe₂O₃</th>
<th>Al₂O₃</th>
<th>CaO</th>
<th>SO₃</th>
<th>H₂O</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content</td>
<td>wt.%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>38.83</td>
<td></td>
<td>37.39</td>
<td></td>
<td>8.47</td>
<td>1.60</td>
<td>0.18</td>
<td>11.48</td>
<td>0.93</td>
</tr>
</tbody>
</table>

Fig. 1. Macroscopic interaction cross sections of neutrons for serpentinite (Σ<sub>t</sub>) and its constituents.

have demonstrated that the neutron relaxation length in this material ranges from 14 to 25 cm (at ρ = 2.8 tons per cubic meter) depending on neutron energy. Since iron-ore concentrate contains no hydrogen, the relaxation length of thermal and epithermal neutrons is much higher; 20-21 cm (using copper and indium indicators). When roughly 3 wt.% water is introduced into the concentrate, the relaxation length decreases to 11-13.3 cm, depending on neutron energy. As the authors of [6] noted, however, the water component in iron-ore shielding is unstable at elevated temperatures.

In an earlier article [7], data were reported on the attenuation of pile radiations from the ASTR reactor in sand, clay, and other abundant materials. The relaxation lengths of fast neutrons, which we evaluated from published results of Hurst dosimeter measurements at material thickness from 0 to 152 cm are: 18.1 cm for dry sand (ρ = 1.71 g/cm³), 11.2 cm for wet sand (ρ = 2.02 g/cm³; 8.1 wt.% water). The relaxation length computed from the fast flux attenuation function for clay seems to us a bit low. It should be about 17 cm for clay having a bulk density of 1.35 g/cm³.

A study of the shielding properties of serpentinite was performed on a water-cooled water-moderated research reactor. Serpentinite from the Bazhenovo deposit in the form of a fine sand fraction of 0-2 mm mesh with asbestos fiber inclusions was used in the study. The chemical composition is listed in Table 1. Boxes of serpentinite sand were placed in a stepped recess in the reactor shielding right up against the core tank (boxes were 680 by 680 by 300 mm or 940 by 400 mm). The maximum thickness of a serpentinite layer was about 180 cm. When the serpentinite was charged into the boxes no tamping or vibratory compaction, was attempted, nor were asbestos fibers removed. The bulk density of the serpentinite was 1.62 ton per cubic meter.

Measurements were conducted in "semi-infinite" and in "barrier" geometry. In the first case indicators and sensors were placed in thin-walled duralumin tubes installed in the boxes. Attenuation functions of fast flux and intermediate flux were studied by determining induced activity in this geometry, and scintillation dosimeters were employed to determine the gamma-ray dose rate [8]. Al (n, α); Al (n, p); P (n, p); In (n, n') threshold indicators were placed in boron-cadmium filters. Attenuation of thermal flux and epithermal flux measured using dysprosium (Dy<sup>36</sup>) indicators with or without cadmium.

In barrier geometry, the energy distributions of fast neutrons passed through layers of serpentinite of different thicknesses were studied, as was the attenuation of neutron dose rate. Fast-neutron spectra were measured with a single-crystal spectrometer separating pulses due to neutrons or to gamma photons by setting up a space charge across the last dynodes of a photomultiplier tube [10]. Measurements were carried out behind serpentinite layers of thickness 0, 30, 60, 90, 100, and 140 cm.

Attenuation of Fast Flux

The macroscopic removal cross section of fast neutrons was computed to obtain a preliminary estimate of the shielding properties of serpentinite sand having a bulk density ≈ 1.62 tons per cubic meter and the chemical composition indicated in Table 1, and was found to be 0.0602 cm<sup>-1</sup> (Table 2). The principal contribution to the fast neutron removal cross section of serpentinite is that of oxygen (~45%) and hydrogen (~21%). In Fig. 1 we see the neutron energy dependence of the total cross section for serpentinite and its basic constituents. The irregularities (peaks and valleys) in the behavior of the total cross section are ascribable mostly to the neutron energy dependence of the total cross section of oxygen.