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INVESTIGATION ON RADIATION SHIELDING PROPERTIES OF SPECIAL CONCRETE IN NEUTRON FIELDS

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This paper presents the results on radiation shielding of special types of concrete, designed for nuclear reactor containments. The research focused on the study of shielding properties against neutron component of ionizing radiation. For this purpose, two types of ionizing source were used: the isotopic reference neutron field of ^{239}Pu-Be in calibration laboratory and the MARIA Research Reactor.

INTRODUCTION

As a measure of effectiveness of a given shield, a half-value layer (HVL) and tenth-value layer (TVL) were used. In addition, attenuation curves (for total dose, gamma and neutron dose components) were set for each of the investigated concrete shields. GW2 and REM-2 ionization chambers were used to collect data, and additionally F1 ionization chamber was utilized during measurements performed at the MARIA reactor to monitor the beam stability in time. Based on the measurements data, for each set of concrete samples, attenuation curves were determined. To distinguish the radiation components (n-γ), the twin detector method was used. As a detector insensitive to the neutron radiation, a hydrogen free GW2 chamber filled with CO_2 was used. REM-2 high-pressure, tissue equivalent recombination chamber was used as a detector sensitive to both components of mixed radiation—neutron and gamma[1, 2]. Finally, a combination of twin detector and recombination methods was utilized to distinguish dose components and to estimate the radiation quality behind the shield (recombination index of radiation quality RIQ)[3]. This work was aimed at developing a method to evaluate the effectiveness of neutron radiation shields.

Similar effort was done to evaluate new concrete mixes shielding properties in gamma radiation[4].

MATERRIALS AND METHODS

The measurement in standard neutron ^{239}Pu-Be calibration source was carried out in Radiation Protection Measurement Laboratory (at National Centre for Nuclear Research, Poland) on a specially adapted stand capable of holding the weight of at least 10 concrete slabs of a total weight up to 300 kg[4, 5]. During the investigation 30 mixes of special concrete were measured (in four measurement series) in calibration laboratory and 8 of them (second series) were additionally measured in reactor radiation field. Aggregate composition of examined concrete mixes are shown in Table 1.

^{239}Pu-Be neutron source and the chamber were located in a precisely defined geometry in distance of 1.38 m. In this space, a set of concrete slabs, each 5 cm thick, was placed, thus increasing the thickness of the shielding. Using recombination chambers the dose rate after passing through the shielding was measured. Due to the level of scattered radiation, examination ended when about 10 times the dark current of the chamber was achieved. As the basic quantity for plotting the attenuation curves, the absorbed dose rate was used (determinated by the much lower uncertainty, than equivalent dose), and then using received data the HVL was calculated. Similar to the ^{239}Pu-Be source shield testing, it was decided to use twin detector method using REM-2 and GW2 recombination chambers at the MARIA research reactor[6]. Additionally, for monitoring of the reactor source stability, a F1 ionization chamber was used. The H2 is one of the eight horizontal channels located at MARIA Research Reactor in Świerk. Due to its location and construction, it was needed to design and set special stand, that allows the users to remotely manipulate concrete slabs in and out of the beam, without entering the measurement room for radiation protection reasons[7]. The sets of concrete mixes were changed only during technical breaks in reactor work.

RESULTS

^{239}Pu-Be Shielding Results

In order to determine the HVL thickness of each concrete mix, it was necessary to carry out measurement with two ionization chambers with different sensitivities to neutron radiation. To designate shielding properties of different concrete mixes, the two recombination chambers, REM-2 and GW2, were alternately set in the neutron radiation field, together with a dedicated computer and data acquisition system. For each

Table 1. Concrete mixes composition.

Aggregate and grain size	B11	B12	B13	B14	B15	B16	B17	B18
Sand 0–2 mm	+	+	+	+	−	+	+	+
Serpentinite 0–2 mm	−	+	−	−	−	−	−	−
Serpentinite 2–8 mm	−	+	+	+	−	−	+	+
Serpentinite 8–16 mm	−	+	−	+	−	−	−	+
Magnetite 0–5,6 mm	+	−	+	+	−	−	−	−
Magnetite 0–16 mm	+	−	+	−	−	−	−	−
Barite 0–16 mm	−	−	−	−	+	+	+	+
Density (kg/m^3)	3479	2289	3089	2708	3328	3168	2825	2606

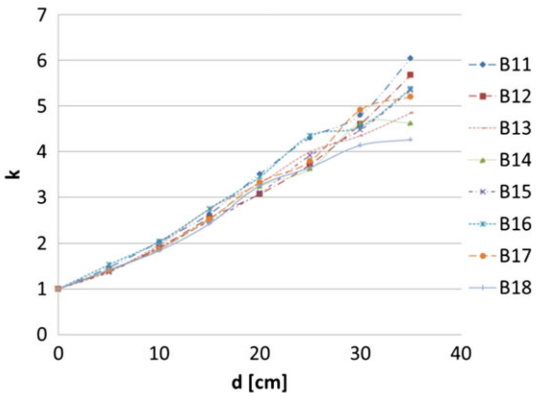

Figure 1. ^{239}Pu-Be total dose attenuation curve.

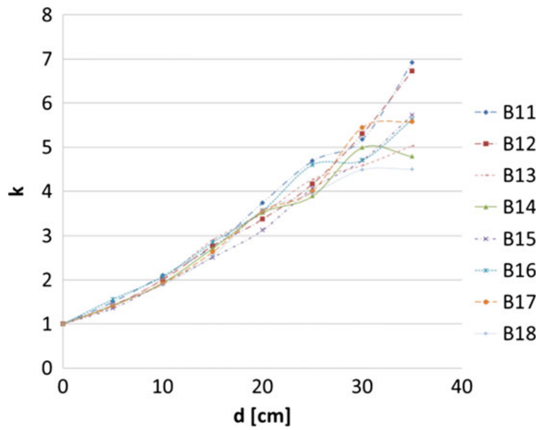

Figure 2. ^{239}Pu-Be neutron dose component attenuation curve.

concrete mix, three attenuation curves were determined: attenuation curve for total dose rate, for neutron component and for gamma component. Each of the points on the curves was presented in relative ratio:

$$k = D_0^*/D_{(d)}^*, \quad (1)$$

D_0^* is the dose rate in measured point, and $D_{(d)}^*$ is the dose rate with d thickness of concrete. Attenuation factors and curves of each: total dose rate, neutron and gamma composition (for second series) are presented in Figures 1–3.

The obtained data can be fitted numerically (e.g. with the polynomial interpolation, least squares methods, all of them gave similar agreement; in the figures, polynomial fitting is shown). From the resulting fitting curve representative HVL values can be obtained. Note that neutron backscattering was not considered in this measurements, but they were included in the determination of uncertainty. The received HVL for neutron composition of ^{239}Pu-Be source in comparison with ^{137}Cs HVL are presented in Table 2. The uncertainties of each of neutron HVL values does not exceed 15% (for neutron dose measurement 10%), for ^{137}Cs—10% (gamma dose determination 7%).

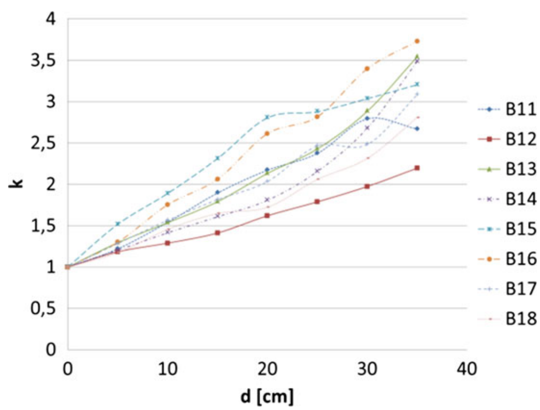

Figure 3. ^{239}Pu-Be gamma dose component attenuation curve.

MARIA Reactor H2 Horizontal Channel Results

For a number of selected sets of concrete mixes, the measurement campaign in the real reactor radiation field at the outlet of the horizontal channel H2 of MARIA reactor was conducted. Due to the special

Table 2. HVL values of different concrete mixes for ^{239}Pu-Be neutron component in comparison with ^{137}Cs[4].

	HVL (cm)	
	^{137}Cs	^{239}Pu-Be
B11	2.67	9.04
B12	4.34	10.27
B13	3.17	10.4
B14	3.71	10.87
B15	2.8	11.05
B16	2.86	8.93
B17	3.27	10.7
B18	3.65	10.58

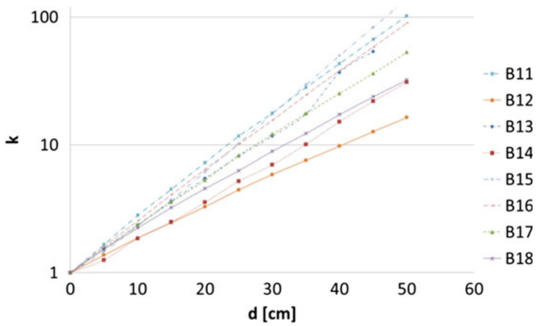

Figure 4. H2 horizontal channel total dose attenuation curve.

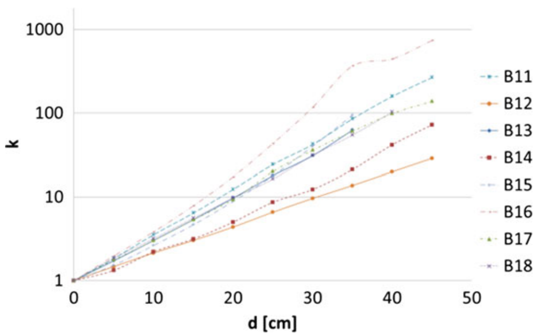

Figure 5. H2 horizontal channel neutron dose component attenuation curve.

and complex nature of this kind of source, such as reactor, it was decided to give up HVL and focused on the attenuation curves determination. HVL in this case is not a good indicator for shielding properties. Attenuation curves are giving more information about in depth changes of the radiation within the shield. The measurements showed that for thick shields HVL does not show adequate shield effectiveness.

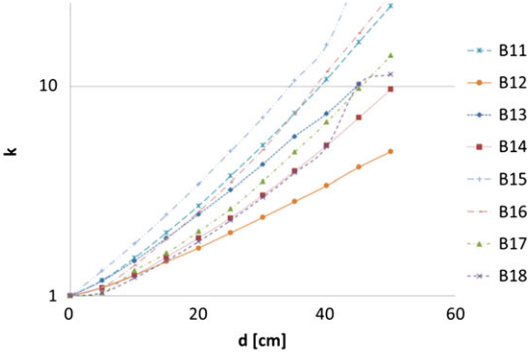

Figure 6. H2 horizontal channel gamma dose composition attenuation curve.

In Figures 4–6, the results of the same concrete mixes as in ^{239}Pu-Be source are presented.

CONCLUSIONS

Finest shielding effectiveness in ^{239}Pu-Be source in examined concrete mixes were for concrete containing barite (B16) and magnetite (B11) aggregates—the HVL obtained was about 9 cm. This value may be changed with depth due to radiation attenuation. There was no any simple correlation between the amount or type of the aggregate. The difference may have been distinguished only between light (serpentinite) and heavy (barite/magnetite) aggregate components. In source containing more thermalized neutron spectrum—H2 horizontal channel, mixes with high density (B11, B15, B16) provided finest results. Low gamma composition attenuation factor in both cases is due the secondary gamma produced by weakening of the neutron radiation component and creating secondary gamma. Relatively low gamma attenuation in neutron sources must be considered in design of proper shielding in both medical and nuclear facilities that uses neutron radiation.

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