TESTING OF A NEW HIGH-DENSITY CONCRETE AS NEUTRON SHIELDING MATERIAL

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Abstract

We present the testing as neutron shielding material of a new high-density concrete (commercially available under the name Hormirad™, developed by the Spanish company CT-RAD). The purpose of this work was to characterize the material behavior against neutrons, as well as to test different mixings including boron compounds in an effort to improve neutron shielding efficiency. Hormirad™ slabs of different thicknesses were exposed to a ^{241}Am-Be neutron source under controlled conditions in the neutron measurements laboratory of the Nuclear Engineering Department at UPM. The original mix, which includes a high fraction of magnetite, was then modified by adding different proportions of anhydrous borax ($Na_2B_4O_7$). The same experiment was repeated with HA-25 concrete slabs, looking for a reference against ordinary concrete used to shield medical accelerator facilities. In parallel to the experiments, Monte Carlo calculations of the experiments were performed with MCNP5, with some differences found, attributable to uncertainties in the elemental composition of the samples tested.

The first and equilibrium tenth-value layers have been determined for the different types of concrete tested. The results show an advantageous behavior of the Hormirad™ one, when comparing neutron attenuation against real thickness of the shielding. Although borated-concretes show a little better neutron attenuation with respect to mass-thickness, the resulting reduction in density and structural properties makes them less practical.

I. INTRODUCTION

A new high-density concrete based on magnetite has been developed by a commercial Spanish company (CT-RAD) and is available under the name Hormirad™[a]. The shielding properties of the new concrete against photons were previously studied[1] and the material is being used to build bunkers, mazes and doors in medical accelerator facilities with good overall results. The purpose of this work was to test and characterize the material behavior as neutron shielding material. The basic Hormirad™ material was compared with conventional concrete as well as with new mixings including boron compounds in an effort to improve their neutron shielding efficiency.

II. MATERIALS AND METHODS

HORMIRAD™ concrete is very rich in magnetite, which represents almost 90% of its weight. Based on information provided by the manufacturer and by the magnetite stone supplier, the elemental composition is indicated in Table I. Its main characteristic is the elevated content of iron, about 60%, compared to 48% cited in the literature for magnetite concretes[2, 3]. The manufacturing procedure is made carefully so that homogeneity of the resulting blocks is rather high. The resulting density is on the order of 4 $g \cdot cm^{-3}$. For the tests, Hormirad™ slabs of 25 cm x 25 cm and different nominal thicknesses (1, 2, 5, 10 cm) have been used in different combinations. The actual dimensions and weight were measured with calibrated instruments and the resulting density determined to be between 3.44 and 4.10 $g \cdot cm^{-3}$, 3.99 $g \cdot cm^{-3}$ on average. Thicker slabs got higher

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[a] US and European patent applications have been presented by the producer for the Hormirad™ "heavy mass for manufacturing products with a high radioprotection capacity".

density, because the thinner need some steel mesh inside to reinforce them against breaking.

The slabs were exposed to a ^{241}Am-Be neutron source under controlled conditions in the neutron measurements laboratory of the Nuclear Engineering Department at UPM[4]. The experimental configuration is shown in Fig. 1. A calibrated Berthold LB6411 monitor was used to measure and register the ambient dose equivalent rate, $\dot{H}^*(10)$. Measuring time was typically 400 s, with data recorded every 20 s, so the used values were the average between at least 20 recorded values. For all the measurements, the distance between the source axis and the center of the detector was fixed in 65 cm. The source and the detector are situated 3 m above the ground in a large room of 9 m x 15 m x 8 m in order to reduce the neutron room return as much as possible. This was determined with a shadow cone and by calculations[4] to be on the order of 4 μSv·h^{-1}.

MCNP5[5] calculations were performed to corroborate the validity of the experimental results. Models of the source, the room and the experimental setup were prepared as realistic as possible, both with respect to geometry and the atomic composition of the tested materials.

Conventional concrete slabs (ref. HA-25), with measured density 2.2 g·cm^{3} were also tested by the same procedure in order to have a reference to concretes usually employed in building clinical accelerator rooms.

Additionally, in an attempt to find better shielding materials against neutrons, other slabs were prepared by adding anhydrous borax ($Na_2B_4O_7$) to the magnetite concrete, with the following fractions in weight: 1.19% , 5% and 25.13% (equivalent to 5% in B).

Finally, we combined a fixed thickness layer of Hormirad™ (15.6 cm) with layers of different thicknesses of borated Hormirad™ and polyethylene with 5% boron.

III. RESULTS

III.A. Hormirad™ alone

A problem was found when comparing the calculated and experimental values, since they fit reasonably well for small thicknesses (higher dose rate), but deviate for thicker layers (lower dose rate). The comparison is illustrated in Fig. 2 in terms of $\dot{H}^*(10)$. For layers beyond 5 cm systematically all the calculated values with MCNP5 are smaller than those measured, with differences tending to grow as the thickness increases. This probably indicates uncertainties about the exact elemental composition of the Hormirad™ material, which in the calculation attenuates neutrons more than in the experiments.

Fig. 3 displays the relative attenuation of $\dot{H}^*(10)$ with regard to mass-thickness. As can be observed, there is a double tendency, and an exponential fitness of the first points indicates an experimental first Tenth-Value Layer (TVL) of 1091.2 $\mathrm{kg{\cdot}m^{-2}}$, in units of mass-thickness, equivalent to a real thickness of 27.4 cm. The exponential fitness of the last points suggests an extrapolated value for the second and equilibrium TVL of 897 $\mathrm{kg{\cdot}m^{-2}}$, equivalent to a real thickness of 22.5 cm.

III.B. Ordinary concrete

The corresponding experimental attenuation for ordinary concrete (HA-25) and the exponential fitness of the measured points is displayed in Fig. 4. The resulting first TVL is 875.5 kg·m^{-2}, equivalent to a real thickness of 39.8 cm. It is comparable to values indicated in Ref. 4, and clearly higher than the one for Hormirad™.

III.C. Borated mixings

The results of adding anhydrous borax to the Hormirad™ magnetite mixture in different percentages in weight is summarized in Table II. The reductions obtained in the first TVL with regard to the value for the Hormirad™ alone are indeed not significant. Moreover, these compound materials have several disadvantages that make them not good options, like the increase in cost and the poorer structural properties, especially if the fraction of borax is elevated.

III.D. Combined shielding with Hormirad™ and borated materials

The last test series consisted in combining an inner layer of 15.6 cm of Hormirad™ with outer slabs of mixed materials with boron in their composition: the borax-added Hormirad™ and also borated polyethylene (5% in B). The relative transmission is displayed in Fig. 5. It appears that the combination of an internal layer of Hormirad™ with an external layer of borated polyethylene can lead to optimized solutions for door shielding in accelerator rooms.

IV. CONCLUSIONS

For ^{241}Am-Be neutrons, the magnetite-based Hormirad™ concrete has shown a clearly advantageous behavior, when comparing neutron attenuation against real thickness of the shielding with regard to ordinary concrete. Although borated compounds show better neutron attenuation with respect to mass-thickness, the resulting reduction in density and structural properties makes them less practical.

However, more research seems necessary to better characterize the elemental composition of the materials, and also to determine its neutron attenuation properties for typical spectra of clinical accelerators.

ACKNOWLEDGEMENTS

We wish to thank Juan Manuel Caruncho and Isabel Delicado, from CT-RAD, for their collaboration in supplying the shielding materials tested and data about their composition.

REFERENCES

1. M. A. DUCH, V. PANETTIERI, Technical Reports SPR005/06 and SPR008/06. Instituto de Técnicas Energéticas. Universidad Politécnica de Catalunya (In Spanish) (2006).
2. R.G. JAEGER, E.P. BLIZARD, A.B. CHILTON, M. GROTENHUIS, A. HÖNIG, TH. A. JAEGER, H.H. EISENLOHR, *Engineering Compendium on Radiation Shielding–Volume II: Shielding Materials*, Springer, Berlin/Heidelberg (1975).
3. NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS, *Radiation Protection for Particle Accelerator Facilities*, NCRP Report No. 144, Bethesda, Maryland (2005).

4. E. GALLEGO, A. LORENTE and H.R. VEGA-CARRILLO, “Characteristics of the neutron field of the facility at DIN-UPM”, *Radiation Protection Dosimetry*, Vol. **110,** Nos. **1-4**, pp. 73-79 (2004).
5. X-5 MONTE CARLO TEAM, “MCNP – A General Monte Carlo N-Particle Transport Code, Version 5”. Report LA-UR-03-1987, Los Alamos National Laboratory, California (2005).

TABLE I. Elemental composition of Hormirad™ based on information provided by the manufacturer.

Fe	60.07%
O	31.95%
Ca	4.307%
Si	1.847%
H	0.568%
Mg	0.389%
P	0.287%
Ti	0.192%
Al	0.165%
K	0.063%
Mn	0.062%
V	0.050%
C	0.036%
S	0.007%
N	0.003%

TABLE II. TVL obtained for ^{241}Am-Be neutrons with borated mixings of different characteristics.

Shielding Material	Average density	First TVL for ^{241}Am-Be neutrons	
		Mass thickness	Real thickness
Mixed Hormirad™ with 1,19% borax	3,94 g/cm^3	1046.6 kg/cm^2	26.56 cm
Mixed Hormirad™ with 5% borax	3,62 g/cm^3	959.4 kg/cm^2	26.50 cm
Mixed Hormirad™ with 25.1% borax	2.68 g/cm^3	794.0 kg/cm^2	29.64 cm

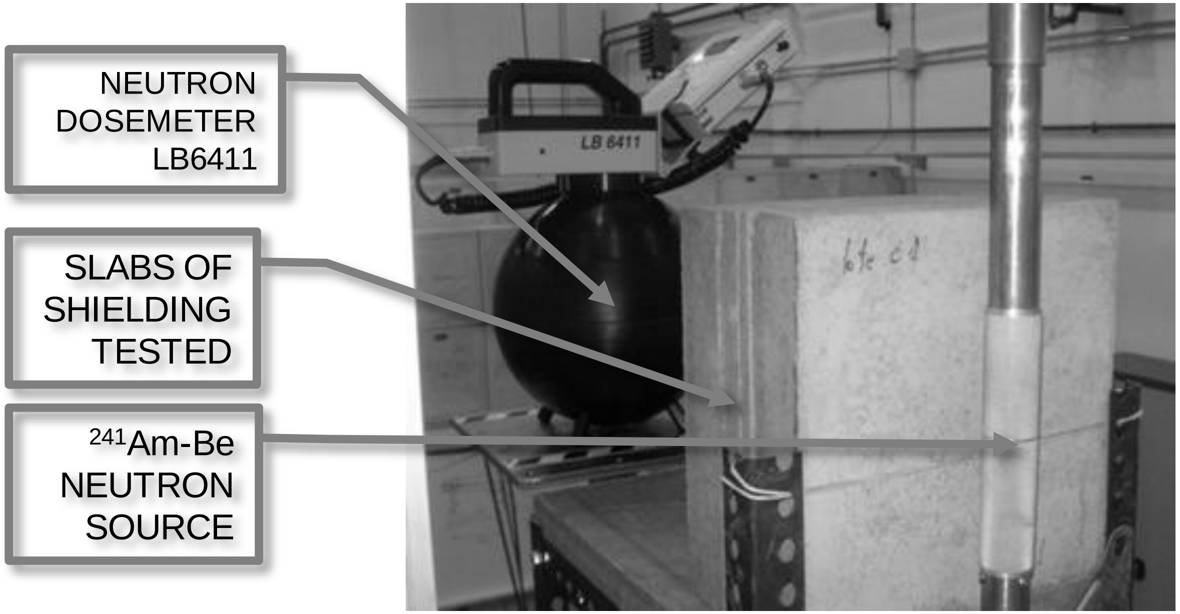

Fig. 1. View of the experimental setup.

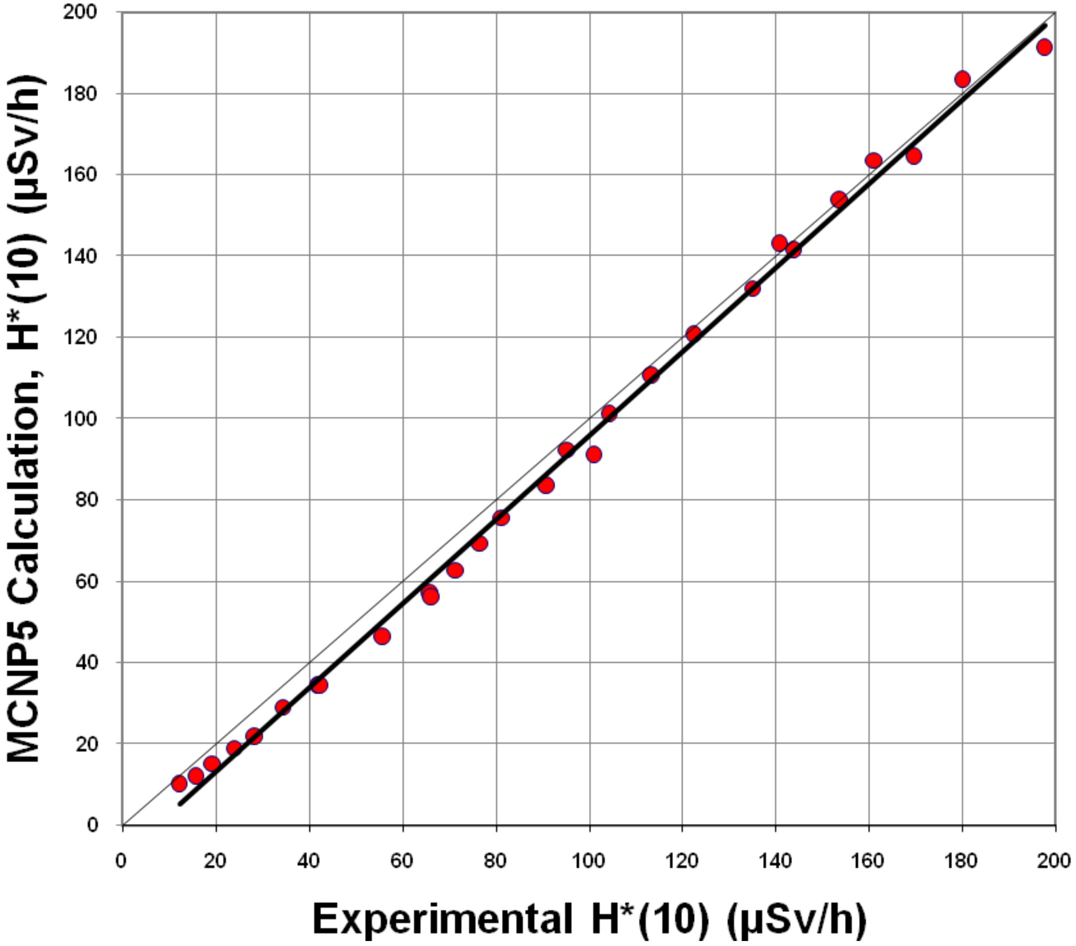

Fig. 2. Experimental versus calculated ambient dose equivalent rate for different combinations of Hormirad™ slabs.

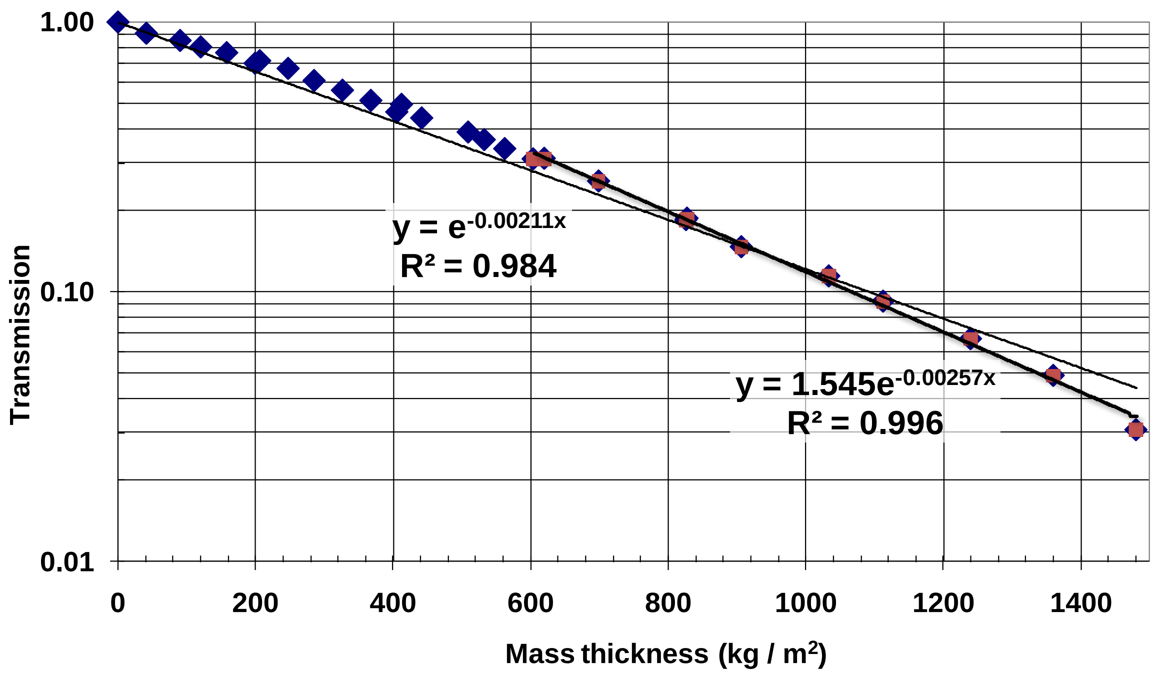

Fig. 3. Transmission of ^{241}Am-Be neutrons in Hormirad™ shielding slabs. Two linear adjustments are shown: one for the full set of data, from which the first TVL is determined; the second, for those points with mass thickness beyond 600 kg/m^2, from which the second TVL is extrapolated.

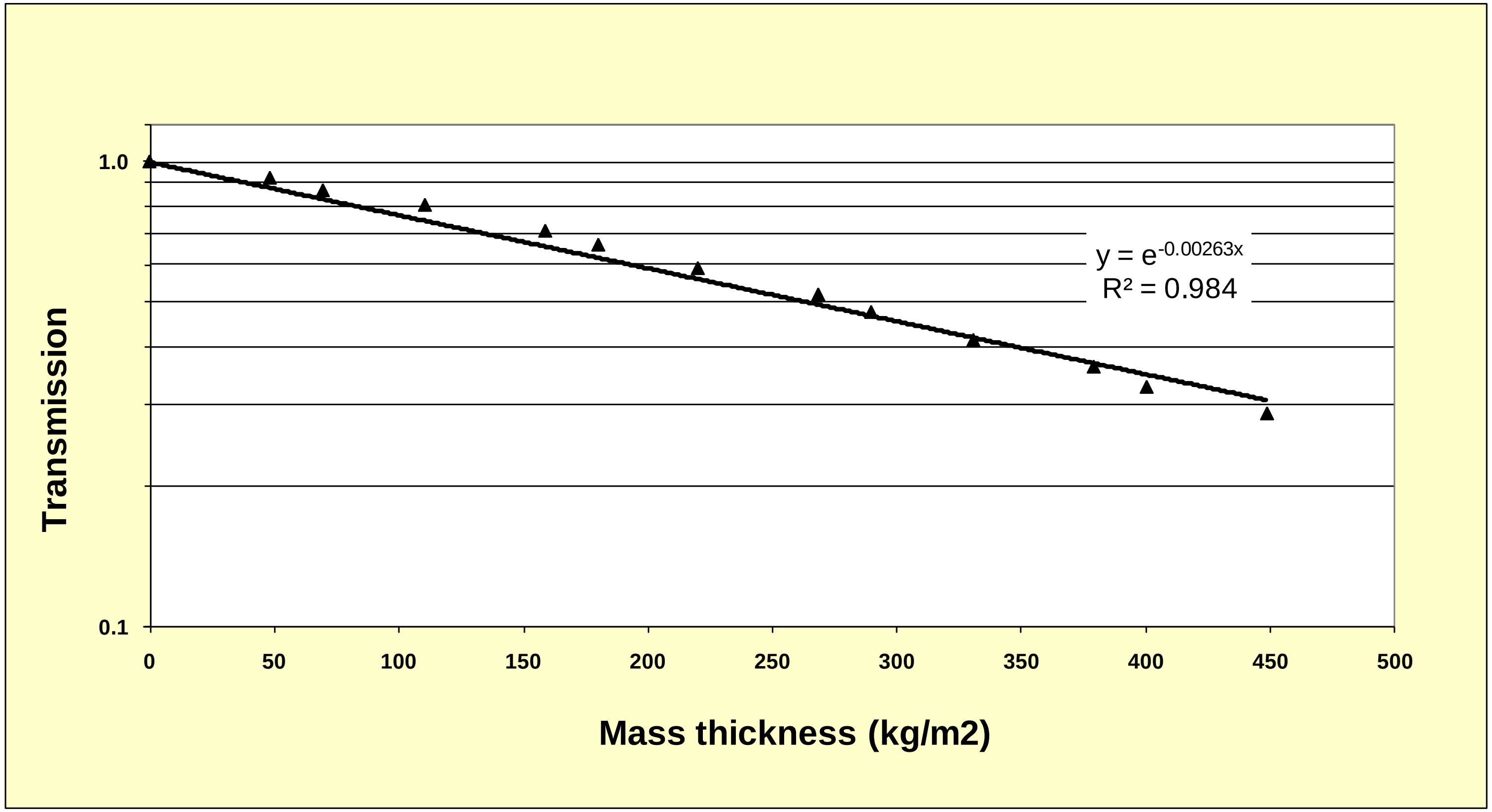

Fig. 4. Transmission of ^{241}Am-Be neutrons in ordinary concrete HA-25 (density 2.2 g·cm^{-3}) shielding slabs.

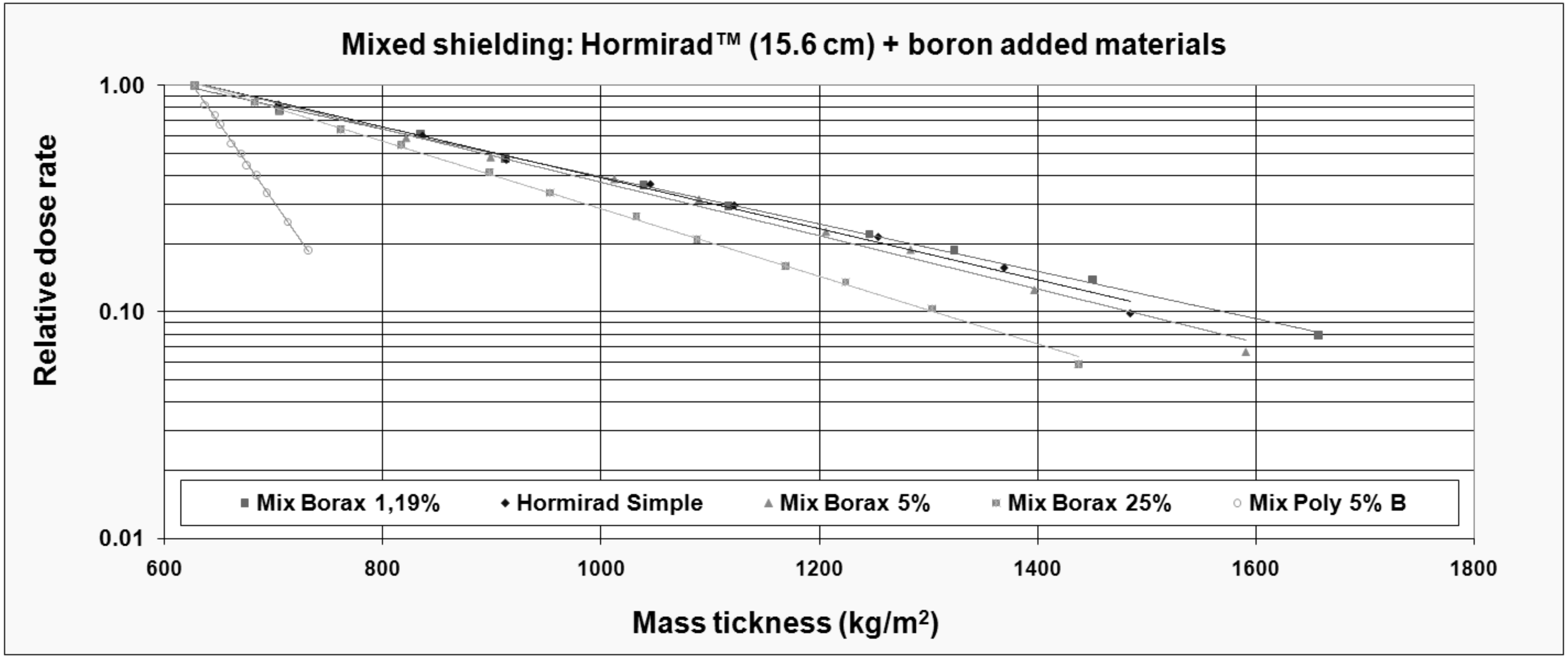

Fig. 5. Attenuation of ^{241}Am-Be neutrons in combined shielding configurations (15.6 cm of Hormirad™ plus other borated compounds).

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