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Authors:	Uwe Filges, Paul Scherrer Institut
	Christine Klauser, Paul Scherrer Institut

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Abstract

The research into new concrete mixes and the optimisation of laminate shielding structures is the main task of WP8. Especially the development of heavy concrete mixes or comparable materials, which are able to shield efficiently neutrons, were done at PSI. During the investigation special mixtures of mineral cast (as comparable material) was developed, which shows shielding characteristics closed to heavy concrete mixtures. The mineral cast was developed in collaboration with the Rampf System company (Germany). Furthermore, several heavy concretes were composed and tested. The heavy concretes are produced by Alpha Beton AG (Switzerland). All compositions are new product developments which presently can't be ordered on the market.

1. Heavy concrete compositions

In total 7 different heavy concrete compositions were investigated at PSI. The requirements were:

- mass density must be > 4.7 g/cm3
- the content of Boron-Carbide with the concrete must be 5 % wt

In addition, a special request was to prove whether a heavy concrete with non-magnetic (or very low magnetic) properties can be developed. The following table includes all investigated heavy concrete compositions. Sample 1,2,3 and 6 are non-magnetic mixtures.

calculated density [kg/dm3]	5.000	4.800	4.800	4.800	4.800	4.800	4.800
effective measured density [kg/dm3]	**5.200**	**4.850**	**4.770**	**4.880**	**4.860**	**4.890**	**4.740**
	sample 1	**sample 2**	**sample 3**	**sample 4**	**sample 5**	**sample 6**	**sample 7**
	[kg]	[kg]	[kg]	[kg]	[kg]	[kg]	[kg]
Barite							
Magnetite							
Hematite							
Fe-granulate St. 37							
Fe-granulate St. 37							
Fe-granulate, stainless , 1.4301							
Boron-carbide 5%							
measured attenuation factor [1/cm]	**0.313**	**0.213**	**0.204**	**0.213**	**0.208**	**0.217**	**0.207**

Table 1: Overview of the investigated heavy concrete compositions

Sample 1 and 2 is the same composition but different Fe-granulates were used. The difference is related to the grain size. Sample 1 had a broader variation of the grain size which leads to a higher filling rate. A mass density of 5.2 g/cm^3 was reached. All the other samples vary between 4.74 and 4.89 g/cm^3.

The most complicated task was to add the relative high content of boron in all samples. It was realized by the substitution of the sand component, which is usual in any concrete. The grain size of the boron-carbide powder was adjusted to the normally used sand structure to guarantee the stability of the concrete.

2. Mineral cast compositions

Heavy concrete has very good shielding characteristics but in many instrument projects the precision of the shielding dimensions must be high. In this relation concrete is limited because shrinking is usual higher as 0.25 %. That's why during the project we decided to prove whether alternatives are available on the market. A promising candidate is a composition of quartz, sand and epoxy (called mineral cast). The big advantage is that the material is stable over time (shrinking < 0.03 %). Furthermore, the used binder material epoxy has a high hydrogen content what supposes that the shielding properties are also good for fast neutrons.

In a first step we checked the available mineral casts on the market and we made a pre-investigation of EPUMENT 145 from the RAMPF system company. This standard material has shown already that shielding characteristics are significantly better as normal concrete and we decided to investigate a series of adapted samples. The list of the samples is given in table 2.

Sample Nr.	Mineral cast (base material)	Modification
1	EPUMENT 130	no (reference sample)
2	EPUMENT 130	1 % wt B_4C
3	EPUMENT 130	3 % wt B_4C
4	EPUMENT 130	without superplasticizer (flue-ash)
5	EPUMENT 130	without superplasticizer

		(flue-ash) 1 % wt B_4C
6	EPUMENT 130	without superplasticizer (flue-ash) 3 % wt B_4C
7	EPUMENT 161L	no (reference sample)
8	EPUMENT 161L	1 % wt B_4C
9	EPUMENT 161L	3 % wt B_4C
10	EPUMENT 161L	1 % wt B_4C (Sand reduced by 1 %wt)
11	EPUMENT 161L	3 % wt B_4C (Sand reduced by 1 %wt)
12	EPUMENT 145	without basalt without superplasticizer (flue-ash)
13	EPUMENT 145	without superplasticizer (flue-ash) 1 % wt B_4C without basalt
14	EPUMENT 145	without superplasticizer (flue-ash) 3 % wt B_4C without basalt

Table 2: Overview about the investigated mineral cast samples

The pre-investigation of the standard material has also shown that the mineral cast can be activated significantly. Therefore, an additional neutron absorber should be added.

Another point was that the used superplasticizer is like an “un-known” component in the mineral cast and the risk exists that long-life isotopes are produced if the material in the neutron field. That's why few samples are made without superplasticizer. Also an "unknown" component is the basalt because the composition can strongly vary depending from the mining batch. The effect of sand reduction was also investigated.

3. Measurements

The measurements were done at PSI on the ICON and BOA beamlines. Both beamlines have a fast neutron spectrum shown in figure 1.

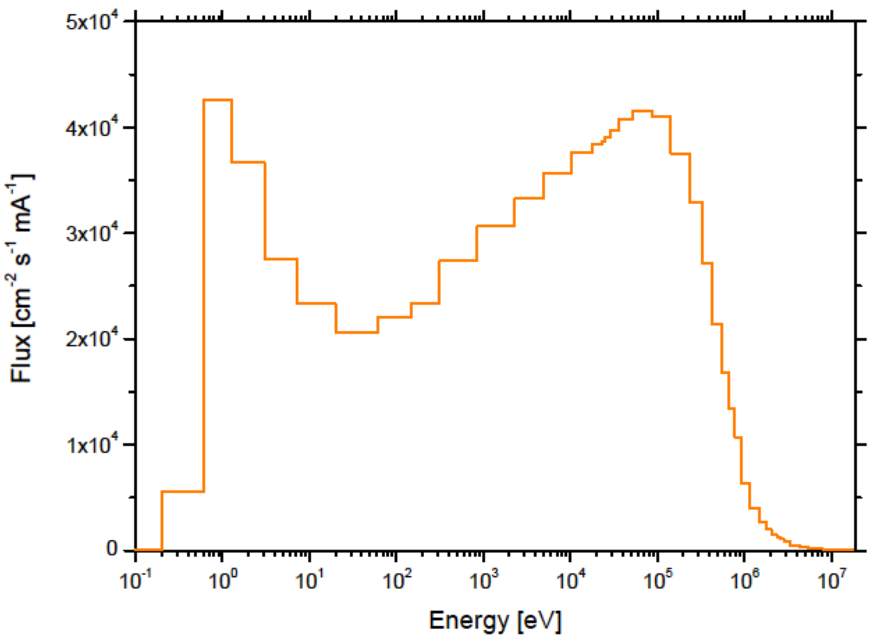

Figure 1: Measured fast neutron spectrum on the ICON beamline

The following measurements were done:

- thermal neutron transmission
- epithermal neutron transmission
- fast neutron transmission
- activation decay.

3.1. Detector systems

The used neutron detector system was the newly developed Bonner Sphere Spectrometer (BSS). A set of 3 spheres were taken to measure the neutron transmission of the mineral cast. The activation decay was measured with a Ge-detector suitable for gamma spectroscopy. The systems are described in the SINE2020 report D8.1 .

For the epithermal and fast neutron transmission measurements the spheres 3.5 and 12 were chosen. The sphere size was selected based on the response function (see figure 2). The thermal neutron transmission was measured by the BSS-He3 detector without moderator.

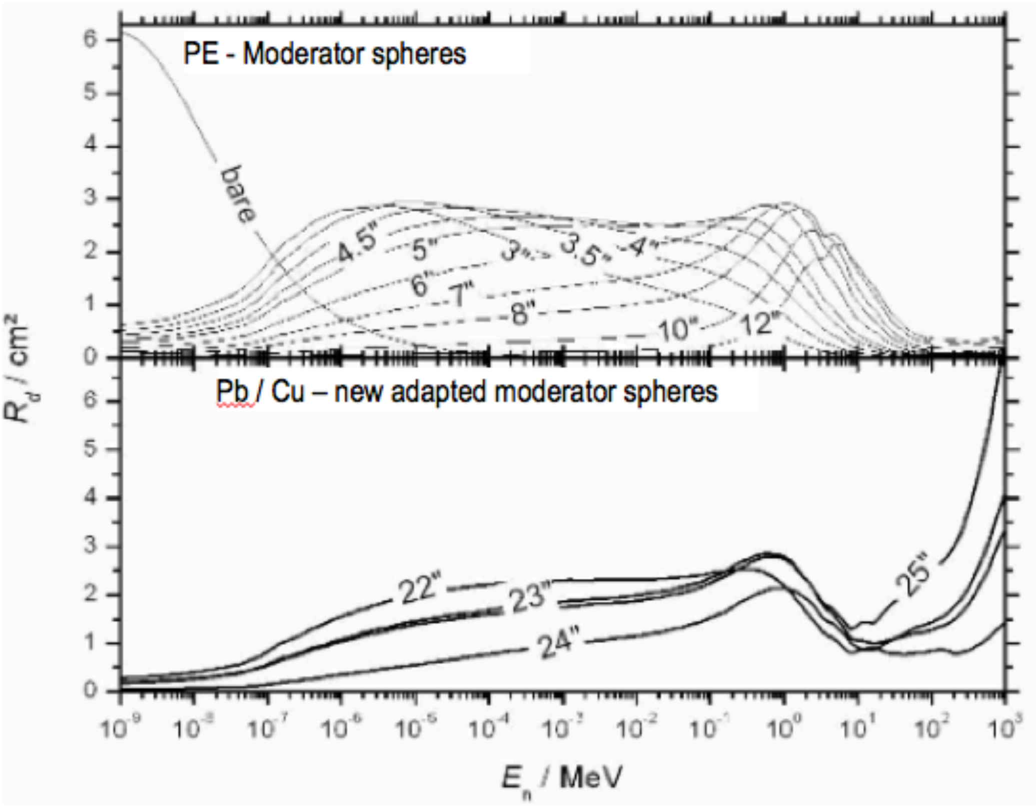

Figure 2: Response function of die different moderating spheres

The heavy concrete measurement was performed by the full set of PE-spheres.

3.2. Results

3.2.1. Heavy concrete

The most promising heavy concrete was the composition no. 1 (sample 1 in table 1) where the highest mass density could be realized. The result is not surprising but the measured attenuation factor is 2.4 times higher in comparison to standard concrete. Figure 3 shows the measured data for sample 1. That means a 20 cm thick heavy concrete block of sample 1 reduces the fast neutron flux by a factor of around 520. In comparison a block of normal concrete must be 48 cm thick for the same attenuation.

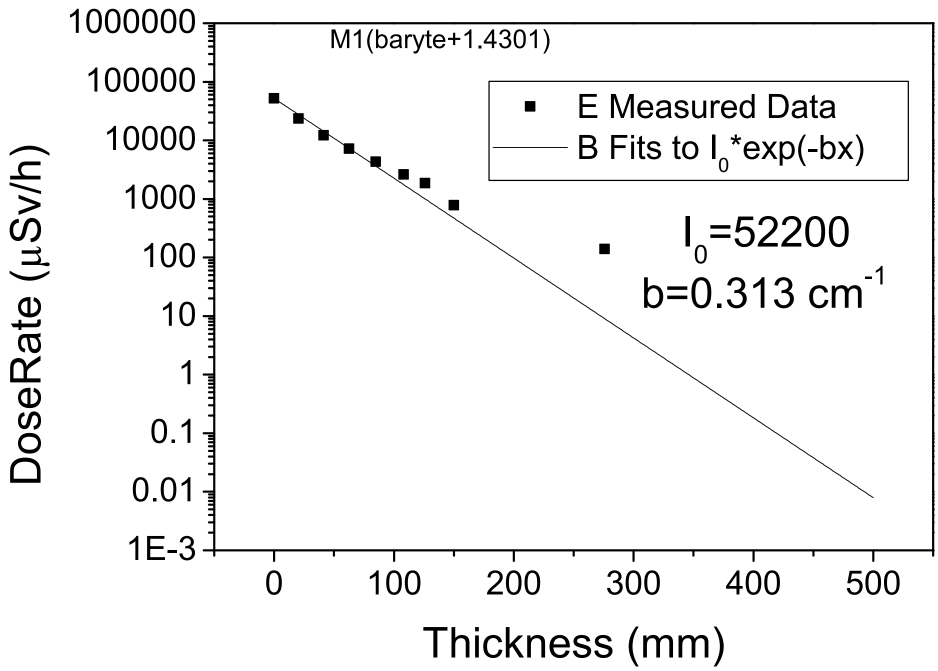

Figure 3: Measured transmission data of heavy concrete no. 1

All the other attenuation factors are given in the last row of table 1.

3.2.2. Mineral cast

The following figures 4-7 are showing the comparison of the different samples of the mineral cast. The best results for the thermal transmission were observed for sample 3,6 and 9. This result can be explained by the high content of boron-carbide (3% wt).

The epithermal transmission is probably related to the mass density of the materials. Samples 7-9 are from type Epument 161 which has a mass density of 2.5 g/cm^3. Epument 130 and 145 has only a mass density of 2.3 g/cm^3.

The measurements for the fast neutron transmission shows only small differences. The relative attenuation varies between 0.54 and 0.61. Never the less the Epument 161 samples (sample no. 7-9) have the best shielding properties for fast neutrons.

But the measured activation shows that Epument 161 can be easily activated. The reason is the content of the flue-ash in the composition.

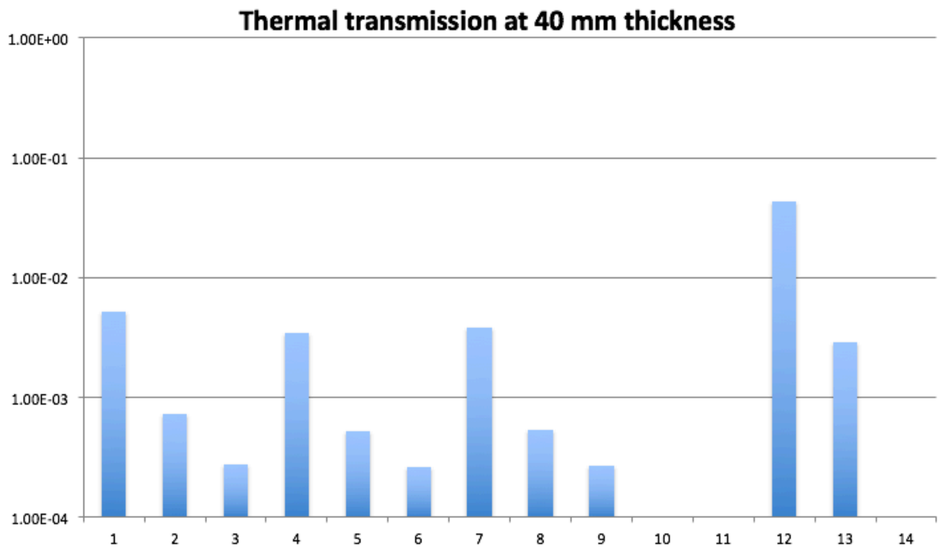

Figure 4: Comparison of thermal neutron transmission for mineral cast samples 1-13

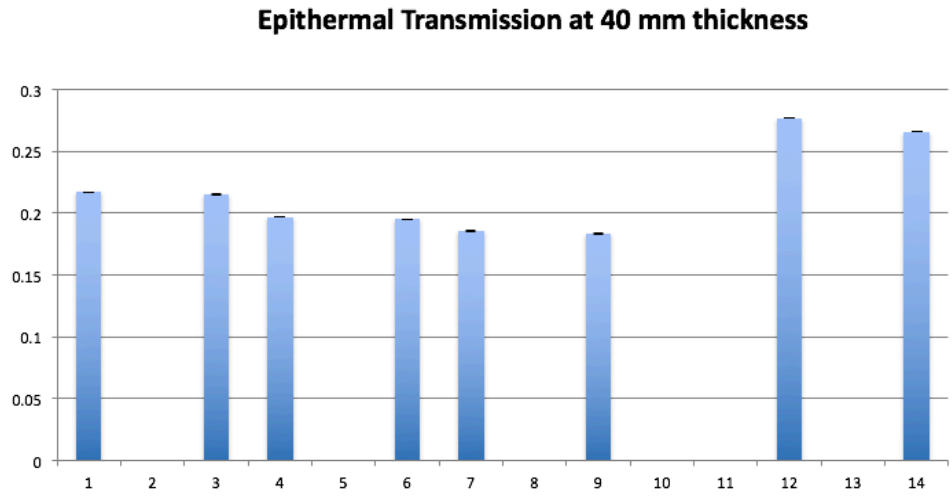

Figure 5: Comparison of epithermal neutron transmission for mineral cast samples 1-14

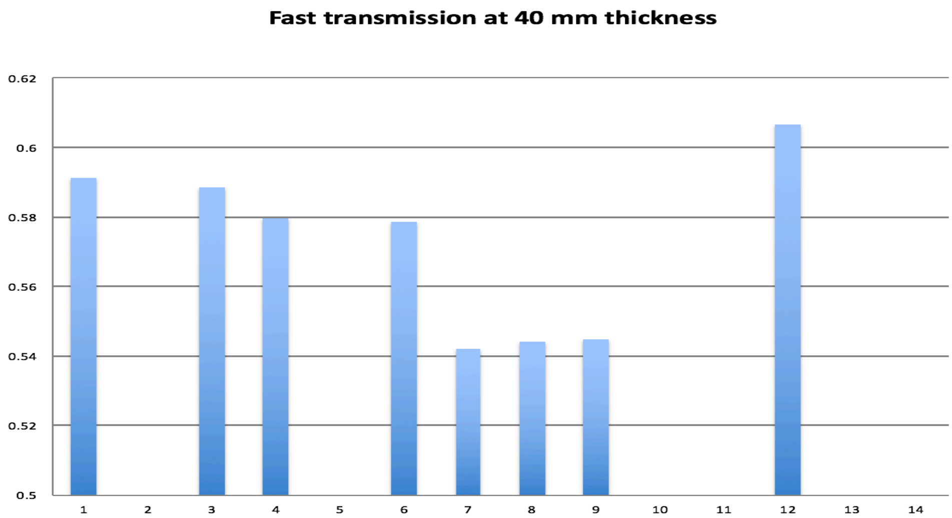

Figure 6: Comparison of fast neutron transmission for mineral cast samples 1-12

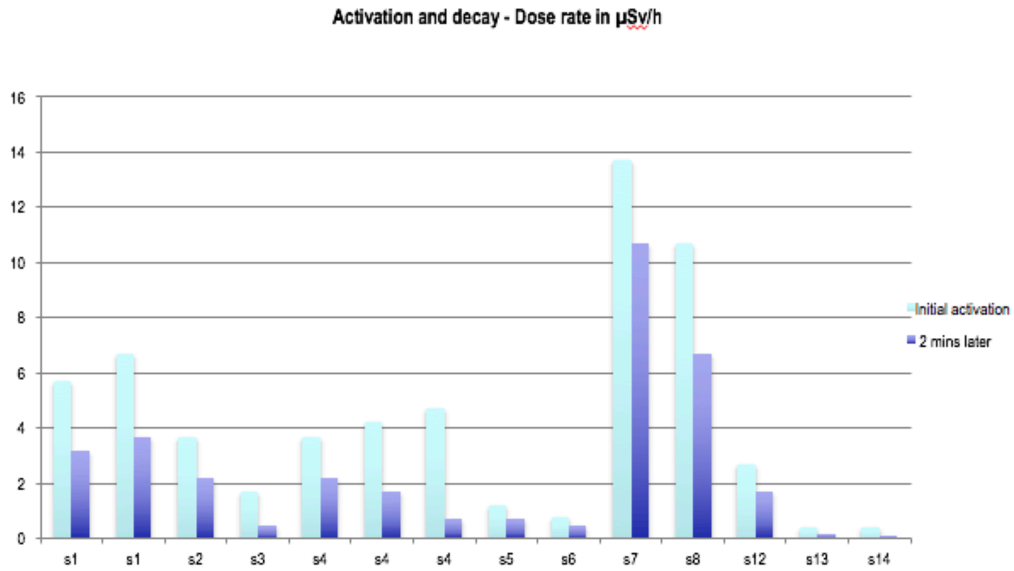

Figure 7: Comparison of activation for mineral cast samples 1-14

4. Summary

The measurements have shown that the heavy concrete composition no. 1 and the mineral cast composition no. 6 have the best shielding characteristics.

Finally, the heavy concrete no. 1 was compared to mineral cast no. 6 and to a standard concrete composition. Figures 8 to 10 are showing the results for thermal, epithermal and fast neutron transmission.

The result is that the mineral cast and the heavy concrete are better as standard concrete in all three comparisons. The heavy concrete has the best shielding properties for fast neutrons but the mineral cast is very closed.

Also a cost comparison makes the mineral cast very attractive. The price of the mineral cast is closed by the standard concrete. Heavy concrete is at least 5 times more expensive.

In a next step the mineral cast will be adapted with a higher epoxy content (from 7 to 9 %wt). It is expected that the fast neutron shielding behaviour will be improved.

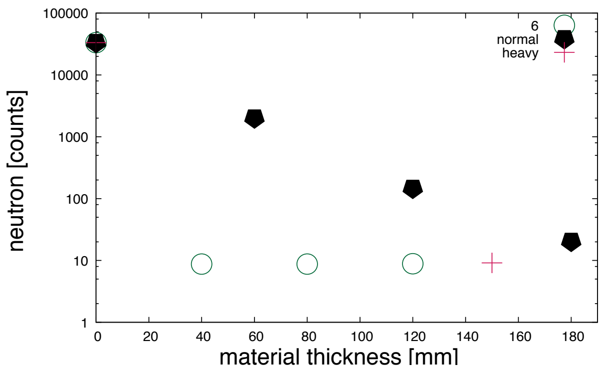

Figure 8: Comparison of thermal neutron transmission

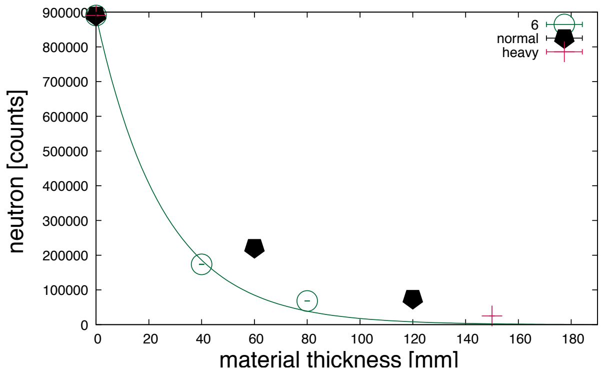

Figure 9: Comparison of epithermal neutron transmission

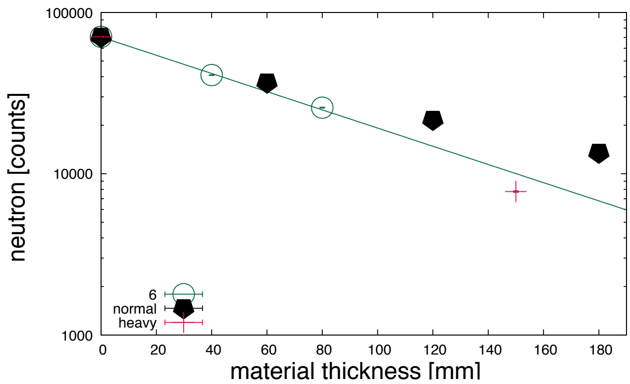

Figure 10: Comparison of fast neutron transmission