Deliverable Number:	D8.5
Deliverable Title:	**LAMINATE SHIELDING CONCEPT CALCULATIONS**
Delivery date:	Month 18
Leading beneficiary:	ESS-Bilbao
Dissemination level:	Public
Status:	Delivered
Authors:	**M. Huerta, M. Magán** (revised by **F. Sordo**)

Project number:	654000
Project acronym:	SINE2020
Project title:	World class Science and Innovation with Neutrons in Europe 2020
Starting date:	1st of October 2015
Duration:	48 months
Call identifier:	H2020-INFRADEV-2014-2015
Funding scheme:	Combination of CP & CSA – Integrating Activities

TASK 8.2 DELIVERABLE 8.5: LAMINATE SHIELDING CONCEPT CALCULATIONS

Written: M. Huerta, M. Magán

Revised: F. Sordo

ABSTRACT

When shield is designed without ad-hoc calculations, either because of the costs, complexities or uncertainties, or simply as a starting point for said calculations, guidelines and tables are commonly used. However these methods are usually based on calculations coming from power reactors which are overconservative, inadequate for the energies found in spallation sources, and also missing many materials.

This work aims to create far more powerful and complete guides than those available right now for *a priori* shielding design, using Monte Carlo tools. In this work, the performance of a number of materials if characterized using defined metrics. Afterwards, the application of these results to estimate the performance of multiple-layer shielding is demostrated.

CONCEPT AND METRICS

The idea behind these calculation is to test how well a number of materials shield neutrons from a given energy. This can be seen as analogous to the transparency of a material in optics. However, because neutrons suffer a moderation process, the result is not quite as simple as a single number. Instead, the energies of the outgoing neutrons must be taken into account. Thus, the result is better given as an array of results, corresponding to the different energies.

In particular for this study, we have divided the energy spectrum for 1E-9 to 1000 MeV, in the following 22 groups

Energy Group	Energy range	Energy Group	Energy range
1	< 1 meV	12	0.316 to 1 keV
2	1 to 3.16 meV	13	1 to 3.16 keV
3	3.16 to 10 meV	14	3.16 to 10 keV
4	31.6 to 100 meV	15	10 to 31.6 keV
5	100 to 316 meV	16	31.6 to 100 keV
6	0.316 to 1 eV	17	100 to 316 keV
7	1 to 3.16 eV	18	0.316 to 1 MeV
8	3.16 to 10 eV	19	1 to 3.16 MeV
9	10 to 31.6 eV	20	3.16 to 10 MeV
10	31.6 to 100 eV	21	10 to 100 MeV
11	100 to 316 eV	22	100 to 1000 MeV

SIMULATION SETUP:

The simulation consists on a source point in a 10 cm slab of a given material. This slab is a 50cm raidus disk, however, the cylindrical surface is reflectant and thus, for all intents and purposes, this is an infinite slab.

The isotropic, single energy source is located 1 mm **into** the slab, on the left side. Furthermore, the left surface in the slab is also reflecting, and thus, only the right surface is a possible exit for the neutrons. Hence, the main characteristic of the whole simulation setup: **Neutrons must either be absorpted in the shielding material, or leave via the right surface and be accounted as a part of the transmittance factor.** The simulation uses an F1 tally in the right surface with the same energy bins used to define the source. Said tally is normalized to 1, i.e, not divided by the area of the surface.

Trial & error results (that will not be discussed here) notwithstanding, the rationale behind this is that, if we think about the shielding material in a laminate array, a neutron that goes to the left has not been shielded in any meaningful way, and thus, should still be accounted for until its absoprtion or exit.

The Geometry of the benchmark is outlined in Figure 1.

Weight windows have been used where they were deemed neccesary. The libraries used are the ENDF-VII-B

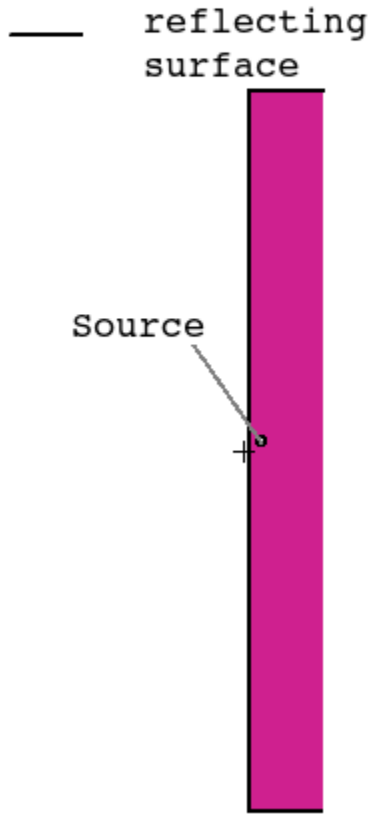

Figure 1: Simulation setup

The following materials have been used in the simulation:

Material Name	Density
Concrete	2.3 g/cc
Carbon Steel	7.85 g/cc
Lead	11.35 g/cc
Concrete with Baryum	3.35 g/cc
Boron Carbide	2.5 g/cc
High density concrete	3.6 g/cc
Borated paraffin	1.04 g/cc
Tungsten powder in paraffin wax	11.4 g/cc
Concrete with Ba/B/Fe	4.99 g/cc

SIMULATION RESULTS AND COMMENTS

Since 9 materials have been simulated with 24 input energies, each producing an array of results, reproducing them in text here is not practical in any way. Thus, the results are attached as a Spreadsheet in annex 1.

As a general note, the simulations are intended to run until the variance of the total tally (summing all energies) is low. Nevertheless, energy bins with low scores compared to total may be subject to high uncertainty. In any case, we do not believe such uncertainty to be an issue given the tiny contribution of said bins.

Notice that some of the results are given as “<1E-8”. This actually means that the tally scored zero, typically in highly absorpting materials such as Boron Carbide for low energy, and thus, the result is a (very low) upper bound.

UTILITY OF THE RESULTS AND PRACTICAL APPLICATION: LAMINATE SHIELDING A PRIORI CALCULATION.

These results are intended to enable designers to easily estimate the performance of a shielding composed of several layers of materials. The theory of said calculations is explained next.

Suppose that we have 2 shielding layers, composed of materials A and B. If the transmitance result for a source energy E_0 , and energy bin E is defined as $T_x(E,E_0)$, where X is the corresponding material, we can estimate the overall transmittance of the assembly as:

$$T_{global}(E,E_0)=\sum_{i=1}^{24} T_A\,(E_i,E_0)\cdot T_b(E,E_i)$$

Furthermore, the summatory can be truncated to include only the most revelant values, as it is unlikely that all energy groups contribute in a meaningful way.

For example, using E0=1 MeV, we can analyse a Steel+Borated paraffin shielding. According to the results in Annex 1, and using the methodology outlined above, the results are calculated, and compared with those of a simulation that uses both layers of materials in the same conditions.

As noticed, there is a very good concordance between both results, with most results in a 10% margin.

CONCLUSIONS

Results allowing simplified and realistic estimation of the performance of multi-layered shielding have been performed. These results allow the designed to estimate the performance of relatively complex shielding with a mere spreadsheet with significant accuracy. While the results certainly do not have the power of a full-blown Monte-Carlo or deterministic simulation, they serve as an initial point to start optimizing the shielding and look into the particularities of each problem.