n_TOF collaboration: Monte Carlo working group

A study of the relative merit of various target and moderator sizes

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1. Introduction

In the frame of the n_TOF collaboration (Monte Carlo working group), two sets of calculations of the resolution function, vs. neutron energy, were performed by means of the CAMOT code. In the first one, two different sizes of the lead target for the CERN n_TOF facility were compared. The results were presented at the M.C. group meeting on January 28, 2000. The second set of calculations was carried out to see the behaviour of the resolution function of the n_TOF spectrometer as a function of the water moderator thickness. In both cases, the fast neutron source, produced by the proton beam, was simulated by a 1 MeV mono−energetic point source located in the centre of the lead block, with an isotropic angular distribution. Because of this rough approximation, the results should be considered only as qualitative indications of trends; their absolute values are likely to be biased and should be taken with due care. In the following, we give a brief report of both sets of calculations.

2. The CAMOT code

For each chosen neutron energy interval, and for a prefixed flight direction, the Monte Carlo code CAMOT calculates the resolution function of the t.o.f. facility, i.e. the frequency distribution of neutrons emitted by the moderator, as a function of the "moderation distance" *d*. The latter quantity is given by the product $d = vt$, where v is the velocity of the neutron escaping from the moderator, and t is the time delay between the neutron generation and the time at which it reaches the origin of the flight−path. The mean value of *d* is an energy dependent quantity, which must be added to the geometric length of the flight−path. An example of resolution function is given in Fig. 1. Moreover, CAMOT calculates the "moderation efficiency" as a function of energy, i.e. the number of neutrons emitted by the moderator in the flight direction, per energy interval, per unit solid angle, and per source neutron.
From the output data, the figure of merit of the t.o.f. facility, vs. neutron energy, is easily obtained. The figure of merit *F(E)* is defined as follows

$$F(E) = \frac{I\varepsilon}{\Delta d^2 + 1.9E\Delta t^2}$$

where I is the average intensity of source neutrons (n/s), ε is the moderator efficiency (neutrons emitted from the moderator, in an energy decade, per steradian, per source neutron), Δd is the standard deviation of the resolution function (cm), E is the energy of emitted neutrons (eV) and Δt is the time width of the pulse of charged particles from the accelerator (μs). Both ε and Δd are energy dependent quantities. Since we shall compare different dispositions of the target−moderator system for the same accelerator, in what follows we shall neglect what is concerned with the proton pulse. As a consequence we assume as figure of merit for the target−moderator system the ratio

$$F_{TM} = \frac{\varepsilon}{\operatorname{var} d}$$

3. Size of the lead target

Although the design of the target for n_TOF is already decided, we wanted to explore the possibility of improving its performances, in the event of a future development of the facility. As a first step a very simple study of the variation of the figure of merit, vs. thickness of the lead target, was performed. Two cases were examined:

1. A Pb cylinder, 80 cm diameter, 80 cm length, with the axis in the direction of the flight−path. The output face is covered with a 5−cm thick water layer.
2. A Pb cylinder as above, but with a length of 40 cm. Same water moderator.

The figure of merit of the two configurations, as a function of neutron energy, is given in Fig. 2. Evidently, the smaller target is much more performing: the figure of merit is, on average, an order of magnitude higher. This means that, with the same resolution, one can obtain a ten times higher neutron flux at the detector, or a better resolution $\Delta E/E$, with the same neutron flux at the detector. Although we neglected the fact that less neutrons are produced in the smaller Pb block, the improvement is quite impressive. The reason of this behaviour depends mainly on the fact that neutrons escaping from a bigger lead block cover longer paths from their birth. In fact, from CAMOT one obtains that the average number of neutron collisions per M.C. history is 49.3 for the 80−cm thick block, and 36.4 for the 40−cm thick one. The figure of merit worsens also because, in a bigger target, generation points of fast neutrons view the moderator, on average, under a smaller solid angle; as a consequence, the moderation efficiency gets smaller.
Increasing the size of the target causes a deterioration of the shape of the resolution function, as can be seen in Fig. 3, where, for comparison, the standard deviation of the much more compact GELINA target is also reported: the high standard deviation corresponds to a very long tail of the resolution function on the high distance (i.e. high delay) side. This feature is likely to impair the analysis capabilities of the spectrometer, especially in the region of closely spaced resonances.

The conclusion of these simplified calculations is that much better performances could principle be obtained from the n_TOF facility, if a more compact target design could be adopted.

4. Moderator thickness

In the second set of calculations, the behaviour of the resolution function and of the moderator efficiency was studied as a function of water moderator thickness. In these calculations, the dimensions of the Pb target were kept fixed, as in the actual design of the n_TOF facility, i.e. a parallelepiped 80 x 80 x 60 cm, with a re−entrant cavity of 30 x 55 x 20 cm, as in the drawing n_TOF dated November 17, 1999. Monte Carlo calculations were repeated for the following thicknesses of water moderator: 1, 3, 5 and 7 cm. The size was always 80 x 80 cm. The figures of merit F_{TM} thus obtained are shown in Fig. 4.
First, we observe that the 1−cm thickness is certainly to be rejected: in fact the corresponding figure of merit is very small in the whole energy range. From Fig. 4, it is apparent that a broad maximum lies between 3 and 7 cm. More precisely, by taking an average over the five energy decades between 3 eV and 0.3 MeV, the maximum is found at 4.8 cm, as shown in Fig. 6. The choice of the best thickness is by no means critical. In fact, in the interval from 3.95 cm to 5.65 cm, the figure of merit does not drop below 95% of its maximum value.
We have seen that an objectionable feature of the actual design of the n_TOF facility is the high value of the variance of the moderation distance (see Fig. 3), due to a very long tail of the resolution function (see for example Fig. 1). From this standpoint, one might decide that it is more convenient to minimise the variance, at the expense of the neutron flux intensity. Fig. 5 shows the behaviour of the standard deviation of the resolution function. Again, around 5 cm, the variation is rather mild. As a matter of fact, the overall energy average reported in Fig. 7 shows a very shallow minimum at 5.0 cm. The two optimum values are practically coincident.

All in all, it can be concluded that these approximate calculations confirm that the actual water thickness of 5.0 cm seems to be the most reasonable choice.

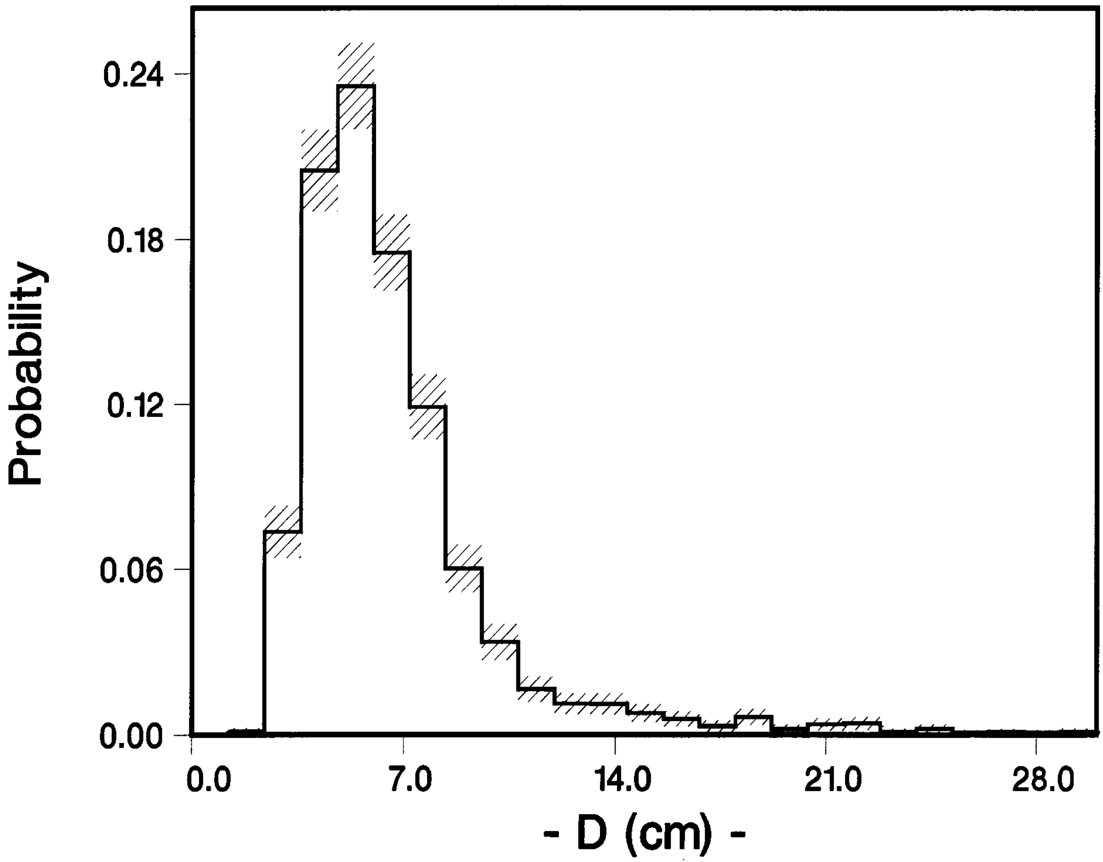

Fig. 1 − Example of graphic output of CAMOT. Resolution function for neutrons between 0.3 and 3 keV. The Pb target is a parallelepiped 80 X 80 X 60 cm with a re−entrant cavity of 30 X 55 X 20 cm. The water moderator is 5 cm thick. Shaded areas correspond to M. C. statistical errors.

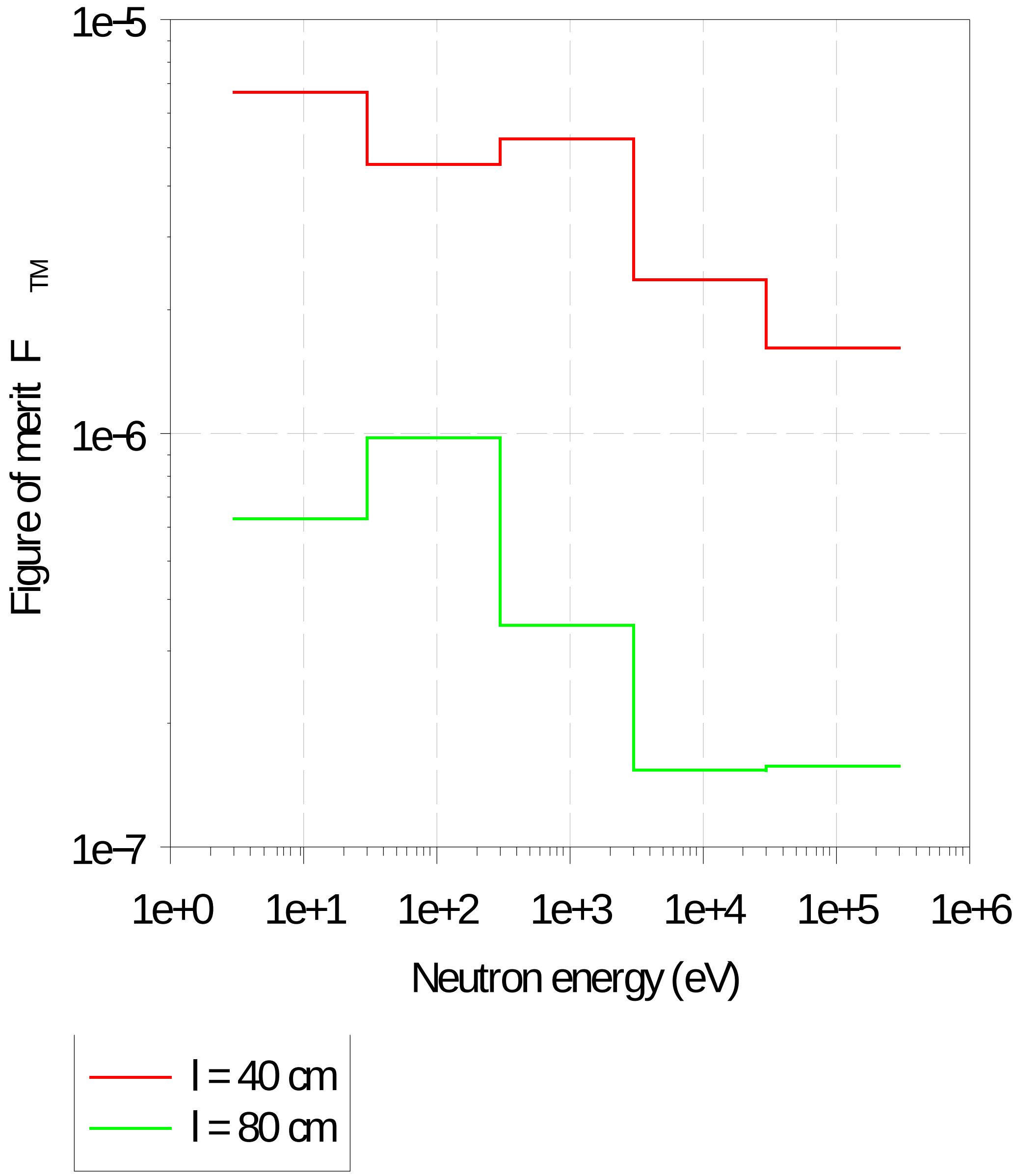

Fig. 2 −Figure of merit F_{TM} for two different sizes of the Pb target.

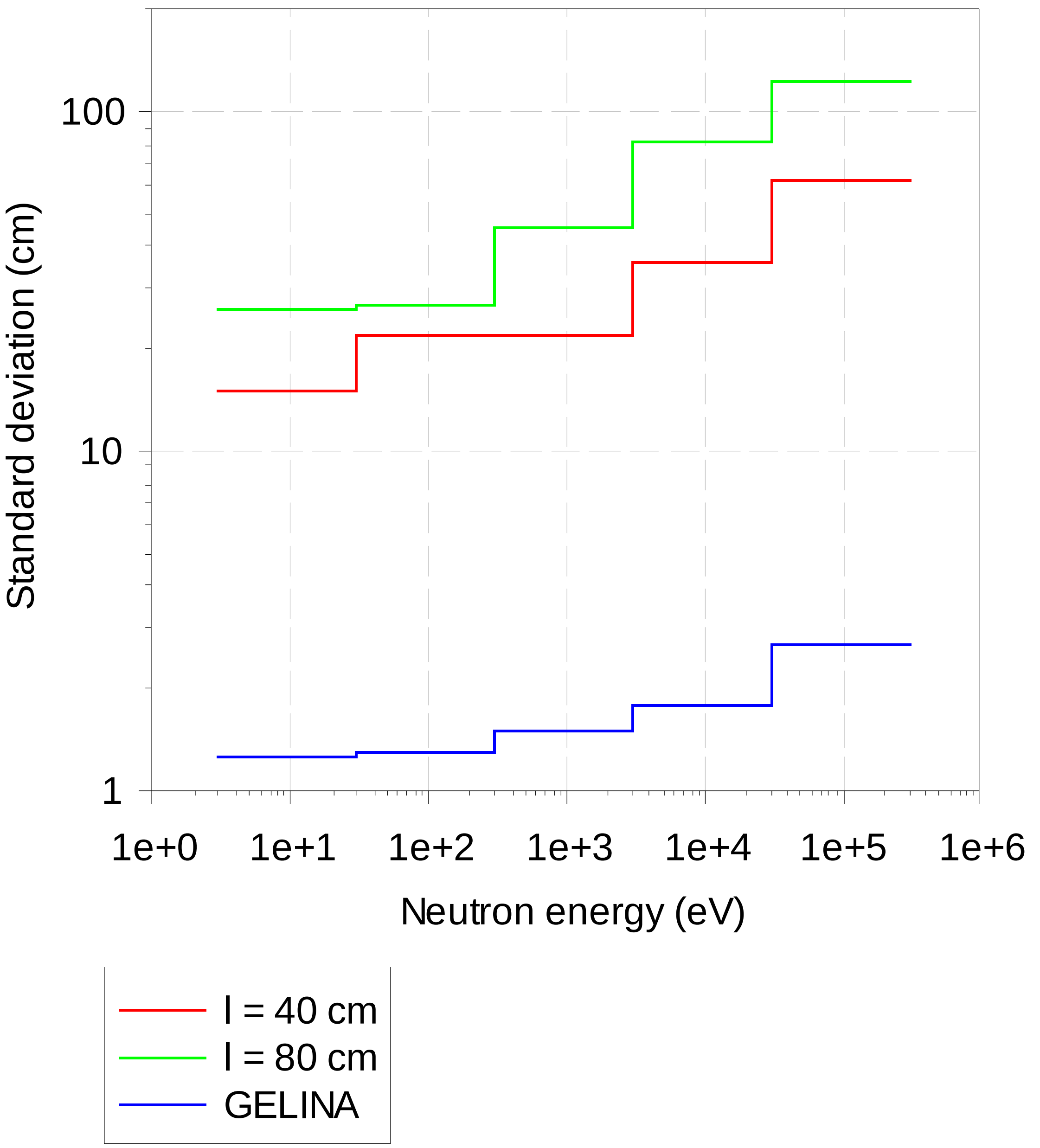

Fig. 3 −Standard deviation of the resolution function for two different sizes of the Pb target.
The corresponding values for the Geel facility are also reported as reference.

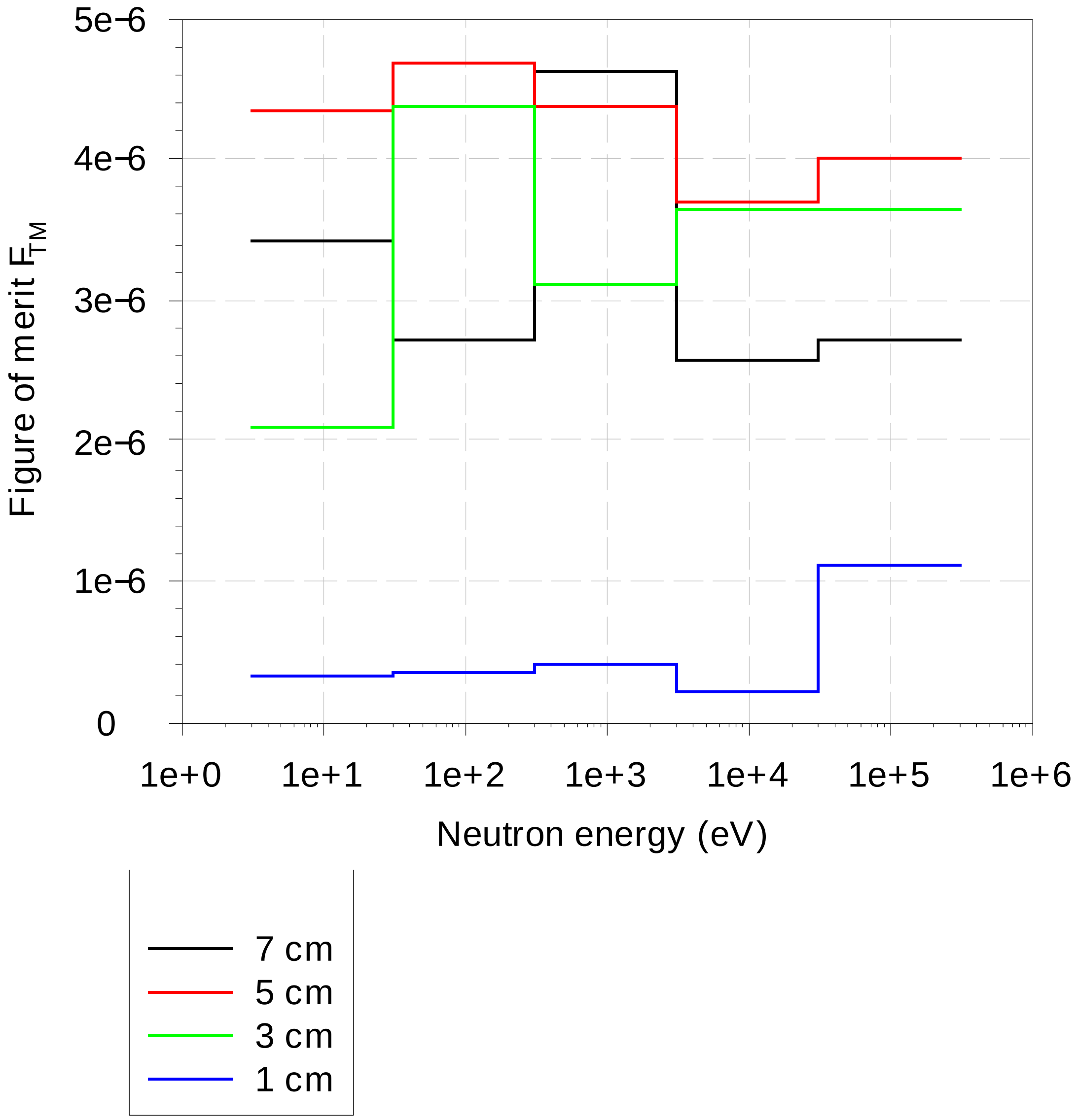

Fig. 4 – Figure of merit F_{TM} of the target–moderator for different moderator thicknesses.

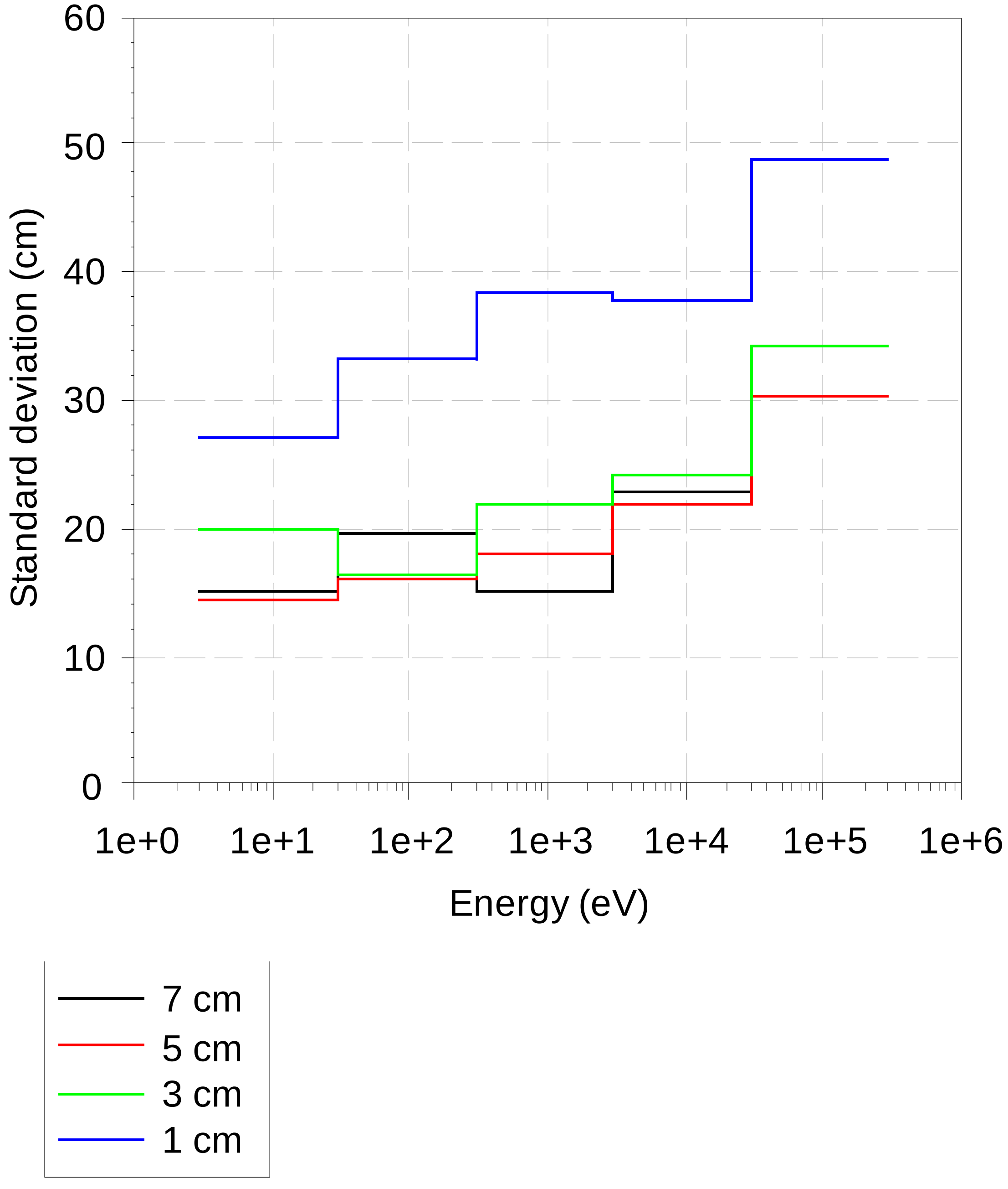

Fig. 5 −Standard deviation of the resolution function
of the target−moderator for different water thicknesses

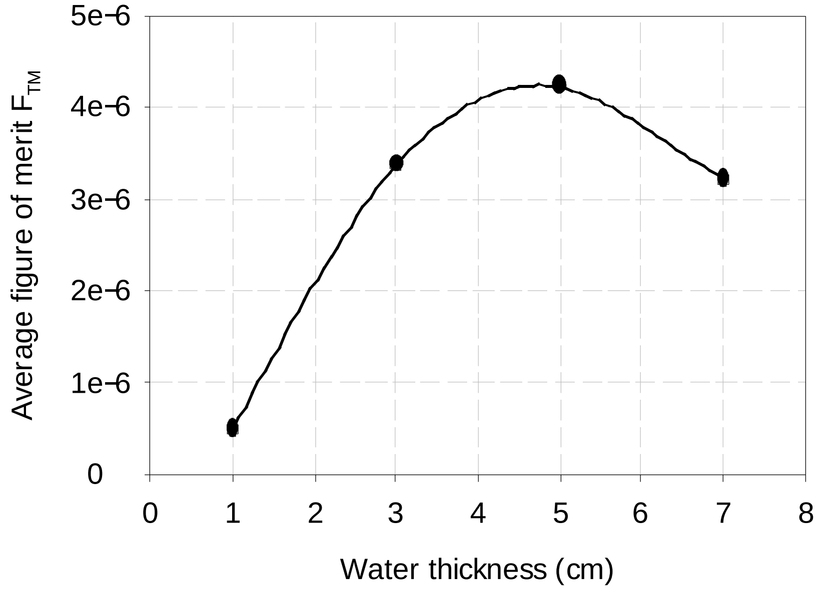

Fig. 6 Overall figure of merit *vs.* thickness of water moderator.

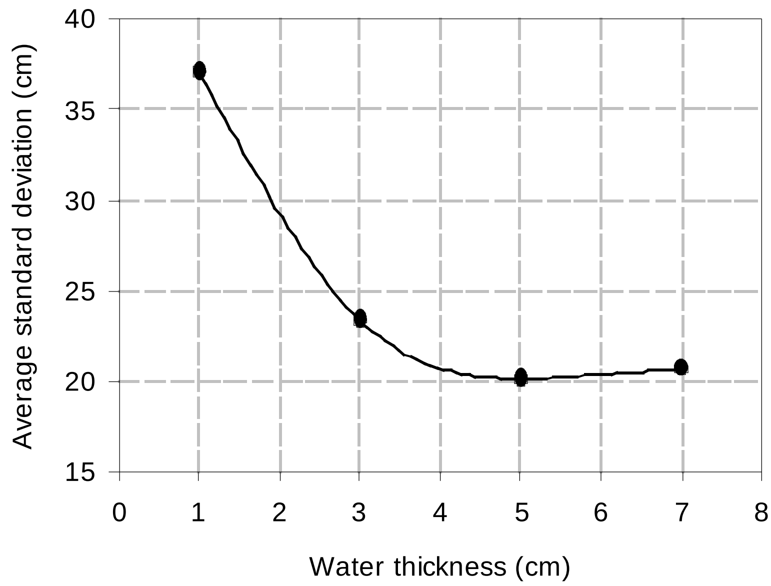

Fig. 7 Overall standard deviation of the resolution function *vs.* thickness of water moderator.