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Monte Carlo Reflector Studies for a Pulsed Neutron Source

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Pulsed neutron sources use hydrogeneous moderators to slow down and thermalize the fast spectrum of neutrons produced in a target. In order to maintain the pulse structure required for time of flight techniques, these moderators must be small in at least one of their dimensions and are typically (for a water moderator) 10X10x5 cm^3. The resulting coupling between target and moderator is inefficient, but may be improved by embedding the target-moderator assembly in a material which acts as a neutron reflector [1]. The reflector increases the effective solid angle between target and moderator and returns partially moderated neutrons which leak from the moderator. A decoupler [1,2] is employed to prevent neutrons which have spent a long time in the reflector from degrading the tightness of the time structure of the pulse.

A neutron reflector must have a high macroscopic cross-section and a low absorption. As discussed below, it may also be advantageous for it to have a high (but not too high) lograrithmic energy decrement. Further requirements for high intensity sources are that the material be easy to fabricate, be resistant to radiation damage and have suitable thermal properties to facilitate heat removal. Table I summarizes the neutronic properties of some candidate reflector materials. A is the atomic weight of the principal neutronic component, ρ_A is its atomic density and σ its atomic cross-section. Mean values of σ in the neighborhood of 10^6 eV (corresponding to primary reflection from the target) and 10^3 eV (leakage from the moderator) are given, together with the resulting macroscopic cross-sections, Σ. Reflectors may be divided into several groups according to ξ, the logarithmic energy decrement and n, the mean number of collisions between 10^6 ev and 1 eV: strongly moderating reflectors (CH_2); moderating reflectors (D_2O, Be, C) and non moderating reflectors (Fe, Ni, Cu, Pb, etc.). The choice of decoupler depends critically on the time-energy relationship of neutrons in these three classes of reflector: in a strongly moderating reflector, little time degradation will result from even low energy ($\sim$1 eV) neutrons returning to the moderator; in a moderating reflector, $\sim$1 eV neutrons will spoil the time structure and so must be prevented by the decoupler from reaching the moderator; in a non moderating reflector escape from the system or capture by the moderator will occur before significant degradation in energy (and hence lengthening of dwell time) has occurred. Thus in the two extreme cases of excessive moderation and negligible moderation, only a very weak decoupler is required.

The neutronic properties of target-moderator-reflector-decoupler systems have been studied experimentally by many groups [3, 4, 5, 6] and bench mark comparisons have been made with Monte Carlo codes. These codes, using extensive cross-section libraries such as ENDF/B are a powerful tool complementing the experimental approach. They are particularly useful for parametric studies of small systems and lend themselves to the study of the slowing down region and questions of energy deposition. Such studies are difficult to perform experimentally. Conversely, highly differential parameters such as the time structure of a small energy group in the thermal region require a large amount of computation, but may be obtained experimentally, for example by Bragg diffraction.

The code used in this study was TIMOC [7] as implemented at the Rutherford Laboratory and the main aim was an optimisation of the target-moderator-reflector-decoupler system for that laboratory's SNS project. Figure 1 shows a test SNS geometry using one 'wing' moderator. The moderator is surrounded by a 2 cm 'cryogenic' gap and the entire assembly enclosed by a 1 cm decoupling layer of B_4C. The density of boron-10 in that layer may be varied. The target region is filled with a composition corresponding to a zircalloy-2 plated depleted uranium target with D_2O coolant and structural material. The regions on either side of the target contain D_2O coolant and structural material. This assembly is embedded in a reflector cube of side 70 cm.

Table IIa gives the bulk flux in the moderator, ϕ_B, and the surface flux escaping from the moderator, ϕ_S, in the direction of the beam tube for polyethylene, heavy water, beryllium, iron, nickel, and lead reflectors. The decoupling density was $\rho_B^{10} = 0.01$ corresponding to a decoupling energy (1/e) of 36 eV. Table IIb gives these data for polyethylene, beryllium, and lead reflectors when no decoupler is employed. In both cases N is the number of primary neutron histories started. Polyethylene is seen to be considerably poorer than beryllium, whereas non moderating reflectors such as nickel and lead have a comparable performance at both decoupling energies. It is known that reflector size effects have saturated by 70 cm cube size for beryllium [2], but it is thought that this size of lead reflector may be less than optimum.

A comparison of a strongly moderating reflector such as polyethylene with beryllium at the same decoupling energy may be less than fair in view of the disscussion above. Figure 2 gives the performance of a polyethylene and a beryllium reflector as a function of decoupler energy. Such a clear separation of their relative performance shows that polyethylene is less optimal than beryllium, without the need to study time structure.

The comparability in yield of beryllium and lead (lead is a more practical material than nickel and provides excellent additional shielding of the target) requires that the time structure resulting from both reflectors be studied. Such a calculation is difficult for the thermal region (neutron transport through nine decades in energy followed by time binning of a single energy group results in low statistics). In the slowing down region, however the pulse shape takes the form

$$\phi(v,t) = (\Sigma vt)^2 \exp(-\Sigma vt)$$

where v is the neutron velocity and Σ the macroscopic cross-section of the moderator. Since this function is a universal function of vt, data from say 1 eV to 100 eV may be summed in bins of vt, thus greatly improving the statistical accurracy. Such an analysis is given in figure 3 for an unreflected SNS target-moderator geometry. The solid line is the infinite medium value and the discrepancy between this and the data at small values of vt (note the logarithmic scale) reflects the time delay due to transport through the target into the moderator. Figure 4 represents data taken with a beryllium reflector present. The width at half height is not increased greatly, but a long vt tail appears from neutrons reflected back by the beryllium. Figure 5 shows a similar analysis of data from a lead reflector. Again the width at half height hardly changes and, when compared with the beryllium data, the long vt tail has marginally improved.

Conclusion

The role of beryllium as the traditional neutron reflector is not challenged by other moderating reflectors. However neutronic equivalence (both in yield and time structure) may be achieved by using a high Z material eg. lead. Such a choice of reflector may well be favoured because of its engineering benefits.

References

[1] J. M. Carpenter, "Pulsed Spallation Neutron Sources for Slow Neutron Scattering", Nucl. Instr. and Meth. 145 (1977) 91-113.

[2] A. D. Taylor, "Neutron Transport from Targets to Moderators", Rutherford and Appleton Laboratories Report, RL-81-057 (1981).

[3] B. C. Boland, A. Carne, G. C. Stirling, and A. D. Taylor, "Spallation Target-Moderator-Reflector Studies on NIMROD", Rutherford Laboratory Report, RL-78-070 (1978).

[4] G. J. Russell, M. M. Meier, H. Robinson, and A. D. Taylor, "Preliminary Neutronics of a Reflected 'T'-Shape Moderator for the Weapons Neutron Research Facility", these proceedings.

[5] G. S. Bauer et al. "Realisierungsstudie zur Spallations--Neutronquelle", Teil II. Julich-Karlsruhe (1981).

[6] Y. Ishikawa et al. "KENS Report I", KEK-80-1 (1980).

[7] H. Kschwendt and H. Reif, "TIMOC--A General Purpose Monte Carlo Code for Stationary and Time Dependent Neutron Transport", Euratom Report EUR 4915e (1970).

Table I

Neutronic Properties of Possible Reflector Materials

Reflector	H (in CH_2)	D (in D_2O)	Be	C	Fe	Ni	Cu	Pb
A	1	2	9	12	55.9	58.7	63.5	207.2
ρ_A atoms A^{-3}	0.079	0.066	0.124	0.080	0.085	0.091	0.085	0.033
σ (10^3eV) barns	21	5.1	6.1	4.6	9.0	15	6.0	11
σ (10^6eV) barns	4	3.0	3.5	2.5	2.5	3.2	3.5	5.5
Σ (10^3ev) cm^{-1}	1.58	0.33	0.76	0.37	0.77	1.37	0.51	0.36
Σ (10^6ev) cm^{-1}	0.32	0.19	0.43	0.20	0.21	0.29	0.31	1.60
ξ	0.913	0.504	0.209	0.158	0.035	0.034	0.031	0.0096
n 10^6 ev $\downarrow$ 1 ev	15	27	66	87	391	409	446	1440

Table IIa

Reflector	CH_2	D_2O	Be	Fe	Ni	Pb
ϕ_B	8.6	12	15	16	17	17
ϕ_S	2.5	4.1	4.6	3.5	4.1	3.6
N(k)	18	160	13	120	75	189

Decoupler density $\rho_{B^{10}} = 0.01$ (36 eV)

Table IIb

Reflector	CH_2.	Be	Pb
ϕ_B	14	33	31
ϕ_S	2.7	6.3	7.2
N(k)	14	30	132

Decoupler density $\rho_{{}^{10}B} = 0.0$

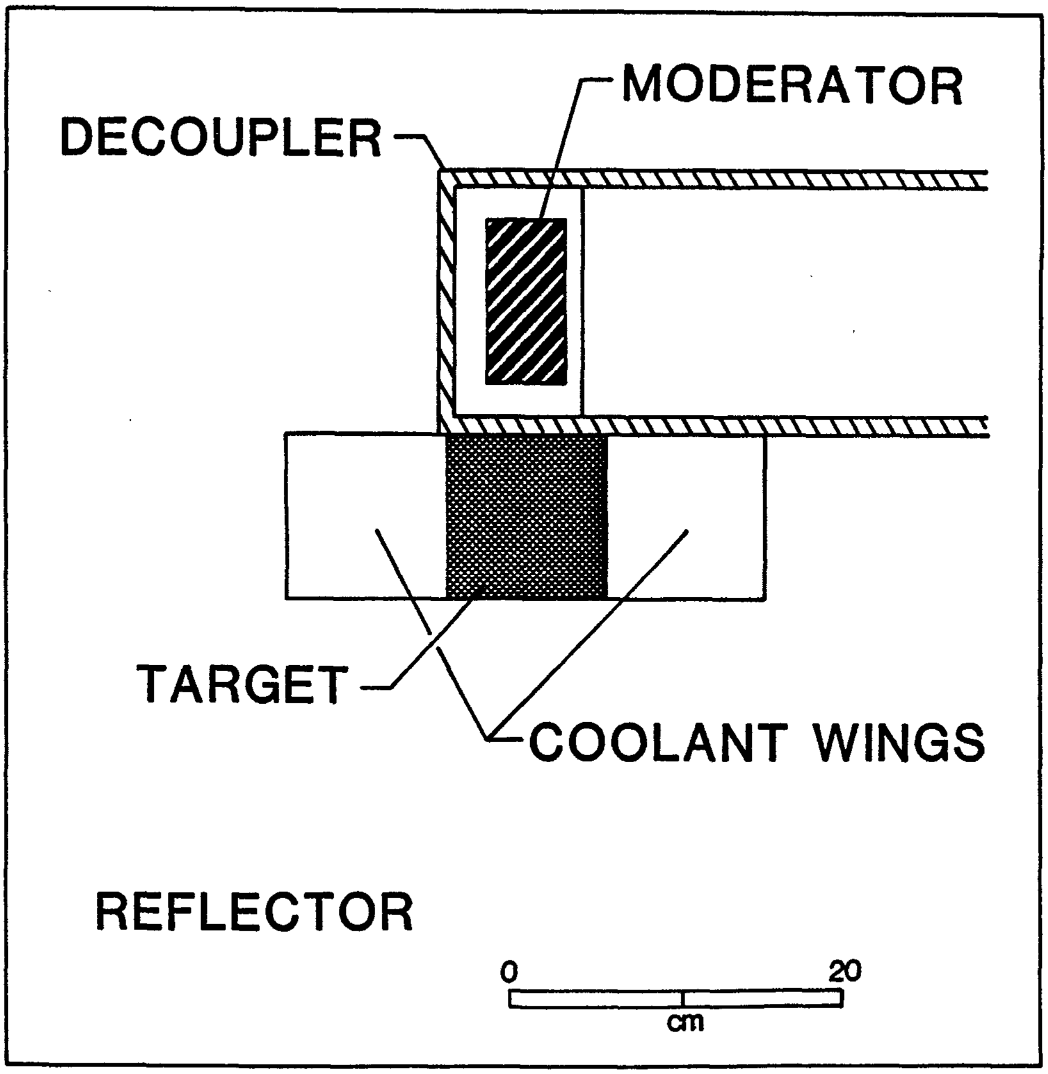

Figure 1. Vertical section through the centre of a TIMOC geometry. The reflector cube is 70 cm on side, and the target is 30 cm long.

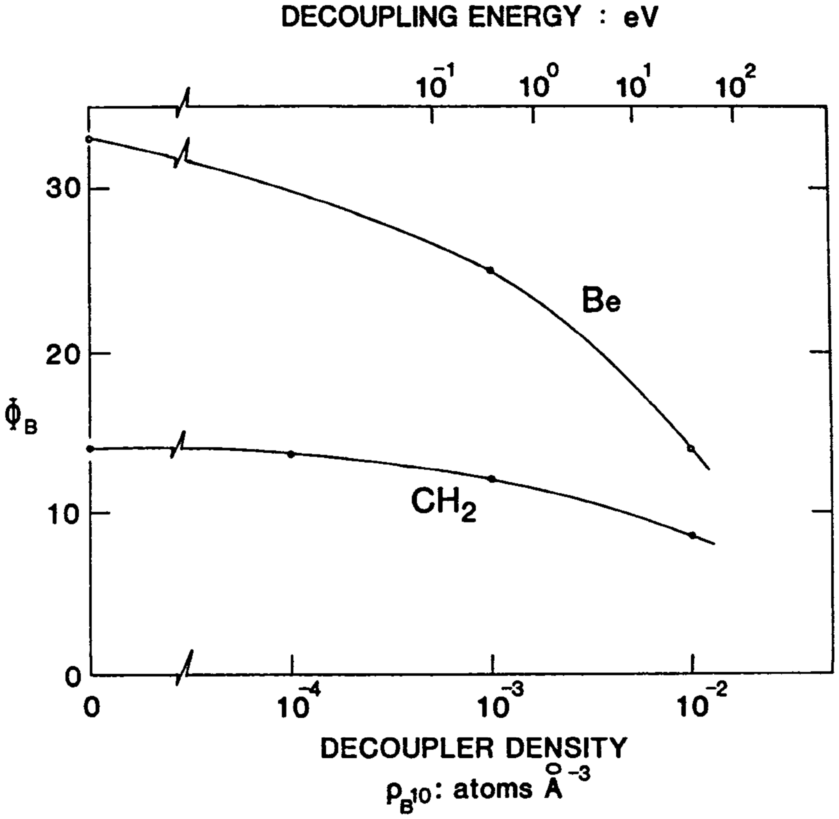

Figure 2a Comparison of the bulk flux in the moderator for a polyethylene and a beryllium reflector as a function of decoupler density. A 1/e decoupling energy scale is given at the top.

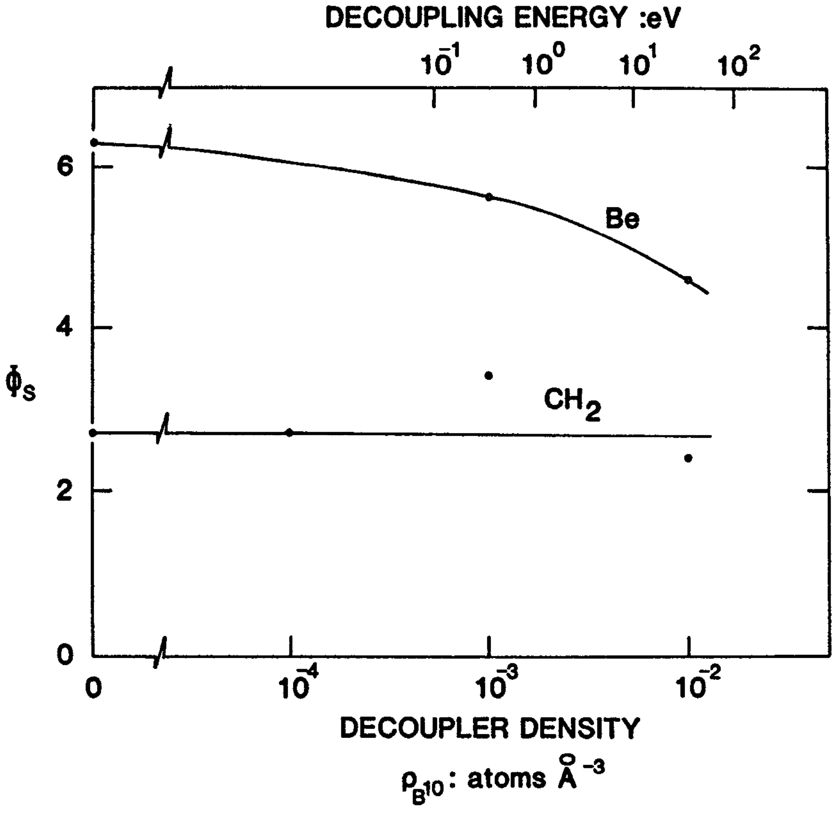

Figure 2b Comparison of the surface flux in the moderator for a polyethylene and a beryllium reflector as a function of decoupler density. A 1/e decoupling energy scale is given at the top.

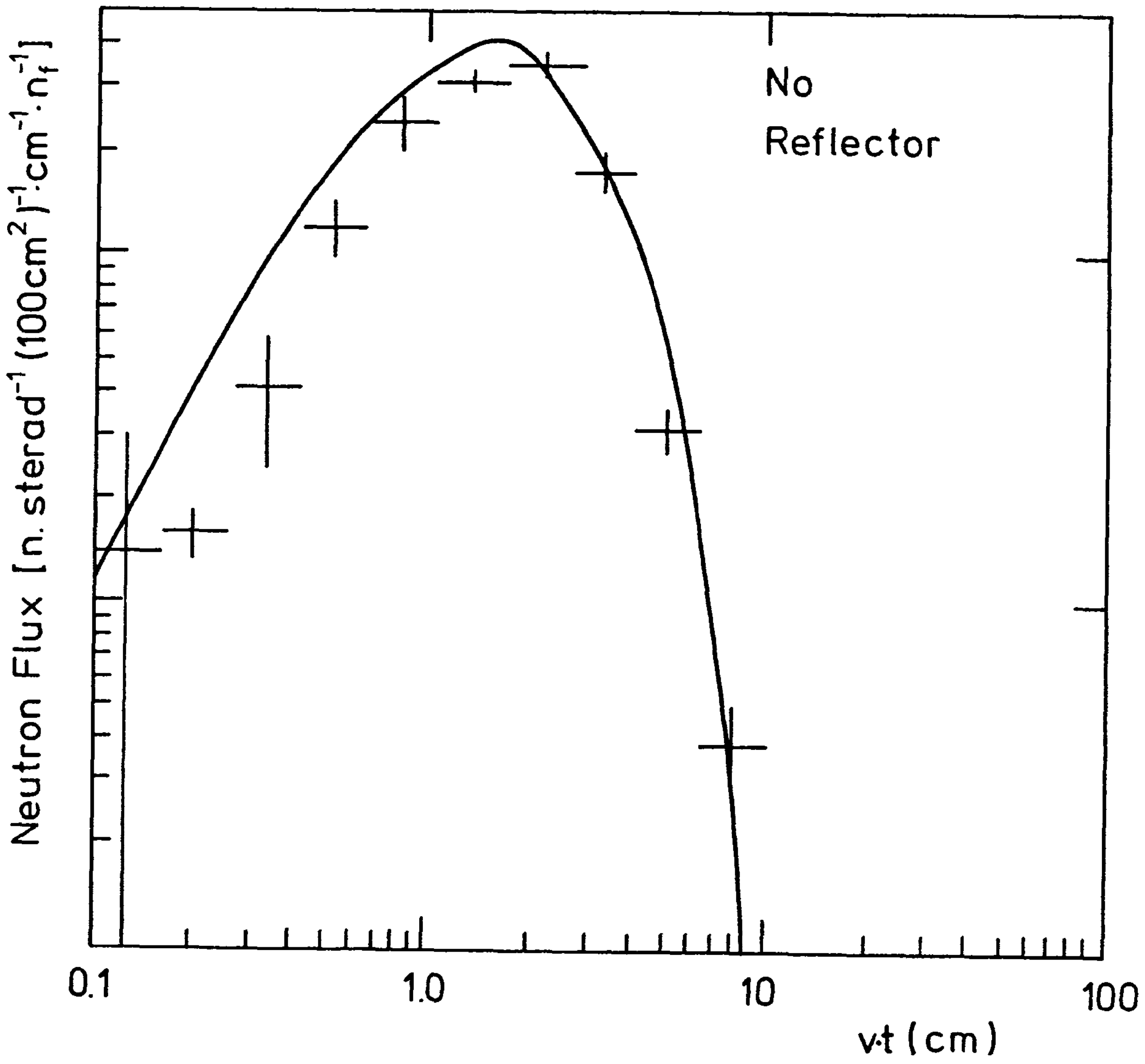

Figure 3. Time structure of the neutron pulse in the slowing down region presented as a vt diagram. The solid line is the infinite medium case. Data points refer to a calculation with no reflector present.

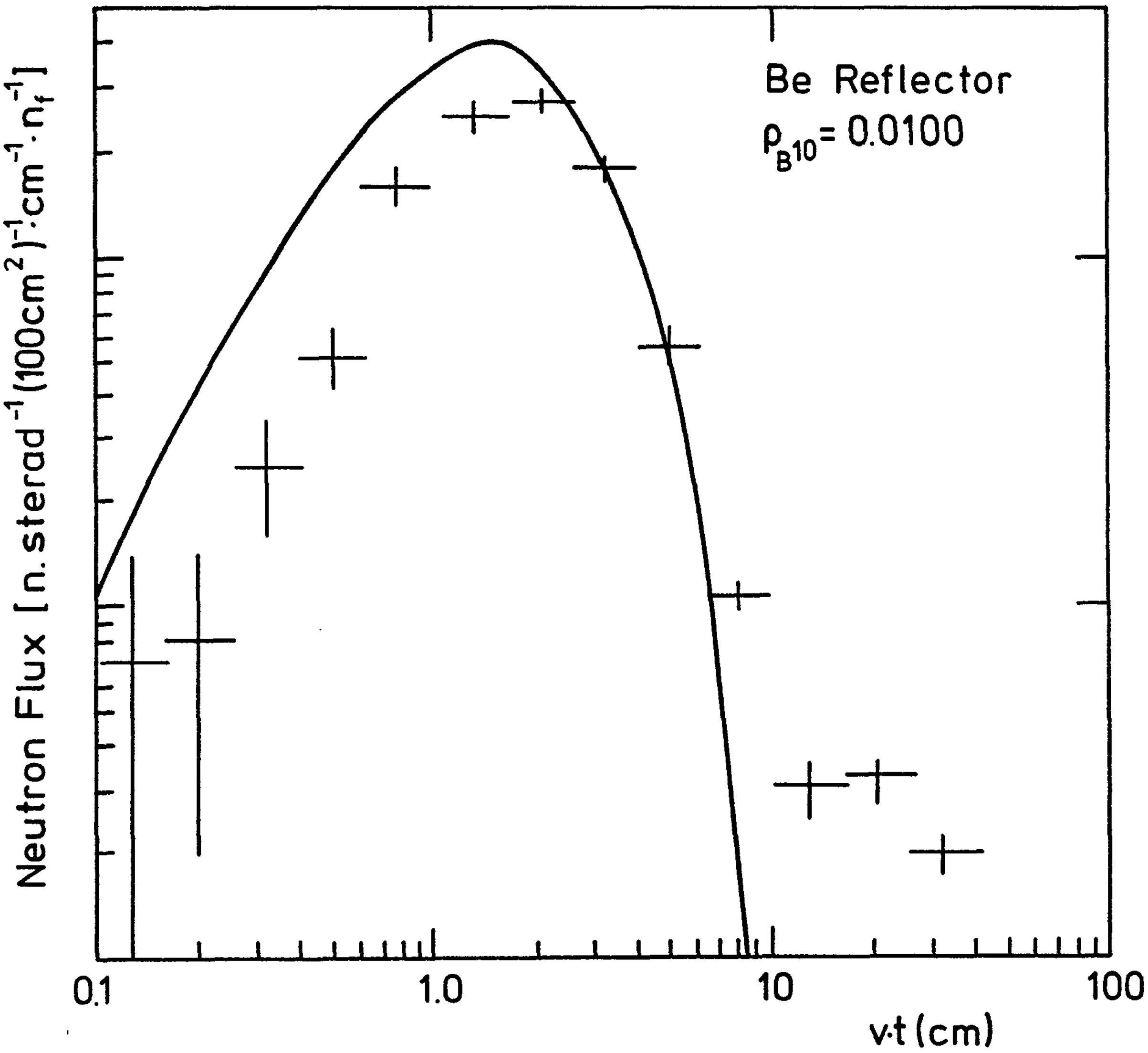

Figure 4. As figure 3 but with data points from a beryllium reflector

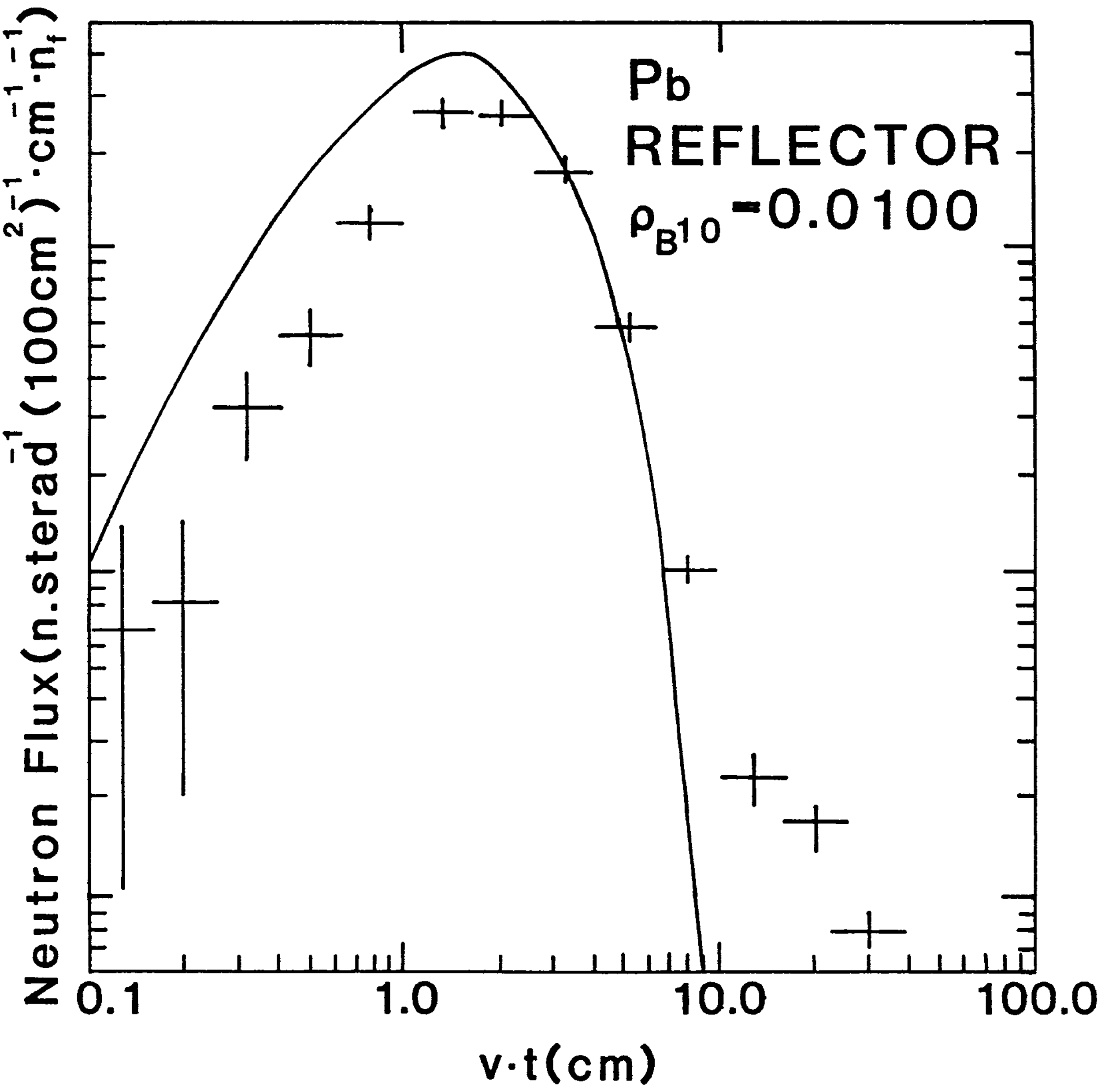

Figure 5. As figure 3 but with data points from a lead reflector.