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DETERMINATION OF THERMAL NEUTRON REFLECTION COEFFICIENT APPLAYING MONTE CARLO METHOD

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ABSTRACT

The Thermal Neutron Reflection Coefficient was calculated by simulation based on the Monte Carlo Method. A simple model is used for detection efficiency estimation. Calculations are in good agreement with experimental results. A possible application of the present results is discussed.

INTRODUCTION

The albedo method based in the activity measurement of a fine sheet with reflector and without reflector was first introduced by Fermi and Amaldi in 1936. This method was generalised for two media with different diffusive properties [1], that is the most common case in practice.
In many situations the albedo method application is very complicated and time consuming since it requires employment of activation sheets for minimal perturbation of the neutronic field in the measurements. An alternative that satisfies practice requirements is the use of a phenomenological parameter called Thermal Neutron Reflection Coefficient and, although it is not supported with a solid theoretical basis, its application is very simple.
The geometrical arrangement showed in Fig.1 is made of a fast neutron point source S and a reflector R. The neutron intensity registered by a thermal neutron detector D is a function of design parameters and reflector properties.

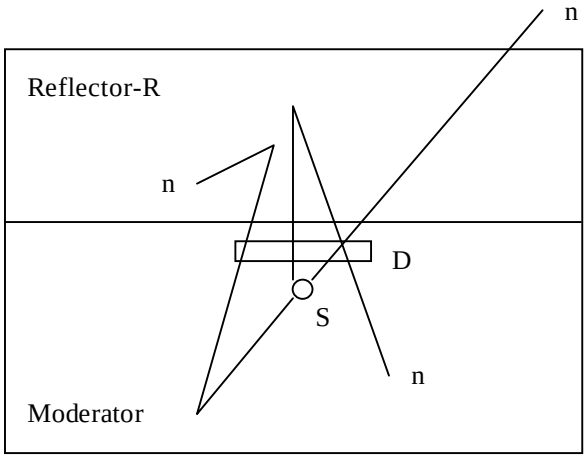

Fig. 1 Geometrical scheme for η determination.

The Thermal Neutron Reflection Coefficient η is defined as [2]:

$$\eta = \frac{1}{\rho}\frac{(I - I_0)}{I_0} \qquad (1)$$

where I is counting rate with R, I_0 counting rate without R, and ρ the reflector density in g/cm^3.
The aim of the present work is to develop a method based on the Monte Carlo simulation and a simple modelling of neutron detector efficiency for determination of neutron reflection coefficient η. Calculations are compared with experimental results and the possible application of the results is analysed.

MATERIALS AND METHODS

The Monte Carlo method is a numerical method for the solution of mathematical problems by random sampling. In particle transport, the Monte Carlo technique is pre-eminently realistic (a theoretical experiment). Each particle is actually followed from a source throughout its life until its death, in some terminal category (absorption, escape, etc.). Probability distributions are randomly sampled using transport data to determine the outcome at each step of its life [3]. We employed the "Monte Carlo N-Particle Transport Code, MCNP-4A" [3].
In MCNP all possible nuclear interactions are included in the energy range from 10^{-5} eV to 20 MeV. The cross sections employed were obtained from the ENDF/B-V library [4]. For the elements H, C, Be, N, Pb and O the series 50C were used since they are the most faithful reproduction of the evaluated data. The more recent evaluations of Los Alamos National Laboratory available in the 51C series were used for Si, F and Cd.
The experimental set-up used for the measurements is the same as in Ref. [5]. The neutrons were produced by an Am-Be source with a yield of $6.6 \cdot 10^6$ ns^{-1}. The moderator employed was paraffin in cylindrical form with 40cm of diameter. The sample container was a cylinder (∅10 x 12 cm) of aluminium and surrounded by a cadmium sheet.
The detection system was conventional, constituted by a BF_3 detector, preamplifier, amplifier Canberra 2020, single channel analyser Canberra 2030, high voltage source Canberra 3102 and counter Canberra 2071.
Information about the standard samples used for model validation applying Monte Carlo Method (MCM) is contained in Table 1.
Table 1. Standards employed for the model validation.

Standards	**Composition**	**ρ (g/cm^3)**	**% H**
WATER	H_2O	1.00	11.11
BUTANOL	C_4H_9OH	0.819	13.60
TOLUENE	C_7H_8	0.866	8.76
HEPTANE	C_7H_{16}	0.866	16.09
ACETONE	C_3H_6O	0.791	10.41
STANDARD 1	Si_2O	0.813	0.00
STANDARD 2	4.7% H_2O + 95.3% Si_2O	0.844	0.05
STANDARD 3	9.9% H_2O + 90.1% Si_2O	0.893	1.11
STANDARD 4	15.2% H_2O + 84.8% Si_2O	0.915	1.70
STANDARD 5	21.2% H_2O + 78.8% Si_2O	0.941	2.38

Measuring time was 2 min, ensuring a negligible statistical error compared with other sources of errors. Typical values for I and I_0 were from 34000 to 43000 and 13800 counts/min respectively for the liquid with high hydrogen content and 23000 and 13800 counts/min for the rest of standards.

Since neutron detector efficiency and gas pressure aren't known, we consider that neutrons arriving at detector are essentially thermal. This assumption is supported by spectrum calculations for SiO_2 (less reflecting sample) and H_2O (more reflecting sample) whose results are showed in Fig. 2.

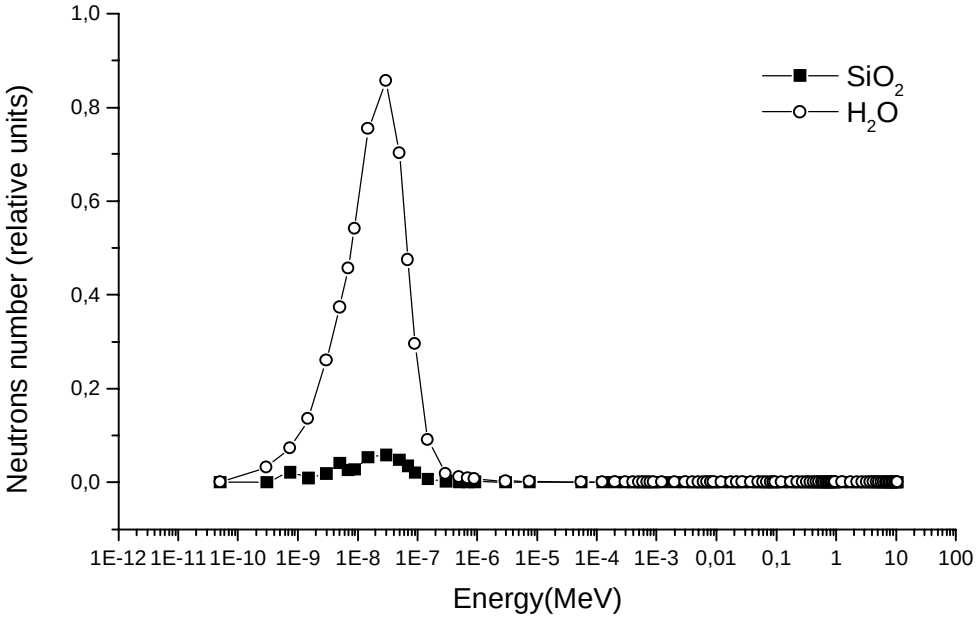

Fig.2. Neutrons spectrums for SiO_2 and H_2O.

RESULTS AND DISCUSSION

Fig.3 shows the correlation between experimental reflection coefficient, η_{exp} and reflection coefficient obtained by MCM, η_{MCM}. The dependency is:

$$\eta^{fit}_{\exp} = (0.96 \pm 0.03)\eta_{MCM} + (0.17 \pm 0.05) \quad (2)$$

with correlation coefficient equal 0.995, confirming the chosen hypothesis of this work. The slope (0.96±0.03) is slightly lower than unity due to the fact that we are neglecting the minimal contribution of epithermal neutrons.

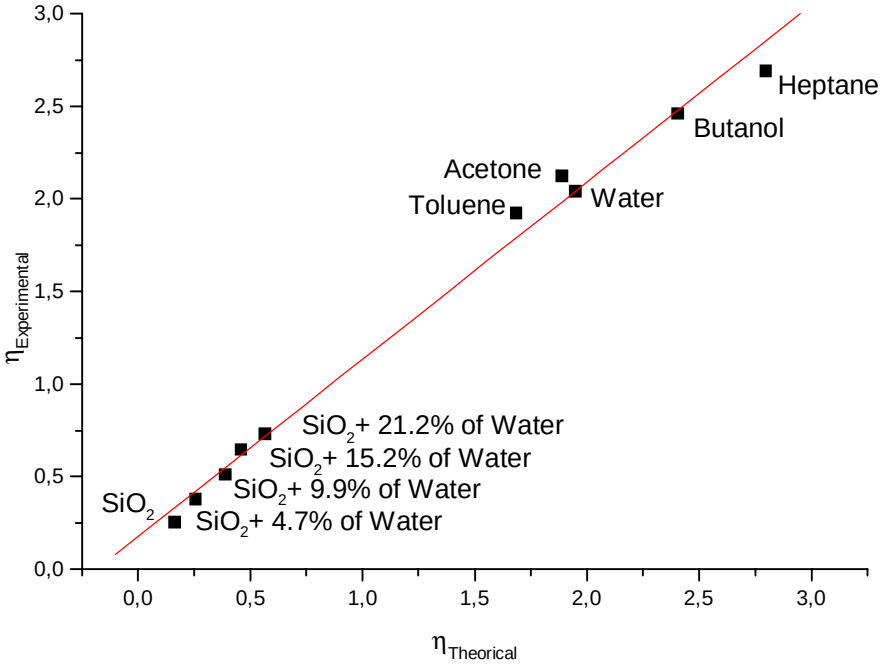

Fig.3. η_{exp} vs. η_{th} dependency.

For the confirmation of this approach under the most adverse conditions, two different sample groups were taken the one with low hydrogen content and high absorption, and the other with high hydrogen content and low absorption.
Experimental and fit values obtained from (2) of η for the standards are compared in Table 2.

Table 2 Comparison of experimental values η_{exp} with the fitting values $\eta^{fit}_{exp}(2)$.

Standards	**Composition**	η^{fit}_{exp}	η_{exp}
WATER	H_2O	2.11 ± 0.09	2.04 ± 0.02
BUTANOL	C_4H_9OH	2.43 ± 0.09	2.46 ± 0.02
TOLUENE	C_7H_8	1.93 ± 0.08	1.92 ± 0.01
HEPTANE	C_7H_{16}	2.71±0.09	2.69±0.02
ACETONE	C_3H_6O	2.07 ± 0.08	2.13 ± 0.02
STANDARD 1	Si_2O	0.26 ± 0.06	0.26 ± 0.01
STANDARD 2	4.7% H_2O + 95.3% Si_2O	0.37 ± 0.06	0.38 ± 0.01
STANDARD 3	9.9% H_2O + 90.1% Si_2O	0.53 ± 0.06	0.51 ± 0.01
STANDARD 4	15.2% H_2O + 84.8% Si_2O	0.62 ± 0.06	0.65 ± 0.01
STANDARD 5	21.2% H_2O + 78.8% Si_2O	0.75 ± 0.06	0.73 ± 0.01

With this approximation a better agreement between experimental and theoretical data can be obtained performing the analysis in two different intervals for high and low hydrogen content, as frequently done in practical applications.
Error sources in the calculation are the statistical error in MCM (< 2%), neglect of epithermal neutrons contribution, and uncertainty in nuclear data.

Even without previously introduced correction (2), the slope of η_{exp} vs. %H and η_{MCM} vs. %H resulted 0.153±0.007 and 0.163±0,002 respectively, coinciding *within* error limits. The slope is the most important quantity in the design of a neutron reflection set-up and is often called the sensitivity.

As a concluding remark we can state that combining MCM with a simple approach for neutron detection efficiency, the correct behaviour of Thermal Neutron Reflection Coefficient can be described. Consequently, simulation can be used to study the influence of the basic design parameters of a neutron reflection set-up on its sensitivity [5] and for the optimisation of nuclear instruments design.

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