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USE OF NEUTRON ALBEDO TO DETECT PLASTIC EXPLOSIVES

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Abstract

Some new data were measured for the reflection cross section (σ_β) of thermal neutrons using different mixtures of dry sand (SiO_2) and ammonium nitrate (NH_4NO_3). Effects of surrounding materials on the detection of dummy landmine have also been studied. The σ_β values averaged over bulk samples of about 10^3 cm^3 dimensions are given for some surrounding materials containing different molecules. Results indicate the feasibility of using the flux albedo for the observation of explosives and other concealed objects containing hydrogen.

I. Introduction

During the last two decades systematic investigations were carried out to fulfill the scientific scope and proposed program goals of the IAEA CRPs on the "Application of Nuclear Techniques to Anti-Personnel Landmine Identification" [1] and the "Bulk Hydrogen Analysis Using Neutrons" [2]. For this purpose, the following nuclear methods have been developed, improved and applied in our investigations without making any efforts for the completeness: reflection of thermal, epithermal and resonance neutrons [3,4,5,6,7,8], neutron diffusion [9], observation of anomaly by gamma-ray scattering [10], concept of the thermal neutron reflection cross section (σ_β) [11], the equivalent thickness of the samples [12], analytical expression for the description of the increment in the reflected neutrons vs. sample thickness [13,14], values of the microscopic (σ_β) and macroscopic (Σ_β) reflection cross sections averaged over bulky samples [13,15], leakage spectra of neutrons from bulky samples [16,17,18], prompt gamma method based on inelastic scattering of 14 MeV neutrons [19,20,21,22, 23], effects of surrounding materials and their mixtures on the detection of plastic explosives, anti-personnel landmines and other concealed objects containing hydrogen [6,10, 15]. Details of the techniques used in those investigations mentioned above and the results achieved have been described in our cited publications.

The aim of this work was to complete the experimental data for the feasibility of using the neutron albedo to detect plastic explosives and other concealed objects containing hydrogen.

II. Experimental

The Bitatron equipment [3] was used in the present measurements for the production and detection of flux albedo of thermal neutrons. This simple method based on a point like Pu-Be neutron source and a small BF_3 counter rendered the determination of the relative excess counts, $R = (I-I_0)/I_0$, measured with (I) and without (I_0) samples of different dimensions up to ~10cm diameter and ~8cm thickness possible. The plastic explosive was replaced by a dummy landmine and ammonium nitrate embedded in dry sand, polyethylene as well as zeolite as surrounding materials to approach the field conditions. A typical experimental arrangement is shown in Fig.1.

The diameter and thickness of the disc shaped dummy landmine (DLM2) prepared for IAEA CRP members in Cape Town are 8cm and 3.4cm, respectively. Its inner part consists of oxalic acid (23.8g, $C_2H_2O_4$ x $2H_2O$), cyanuric acid (58.5g, $C_3H_3N_3O_3$) and graphite (17.25g) is placed in a plexiglas box (94.2g, $C_5H_8O_2$). The weight (194g) and dimension of the DLM2 agree well with the explosives present in the typical anti-personnel plastic landmines.

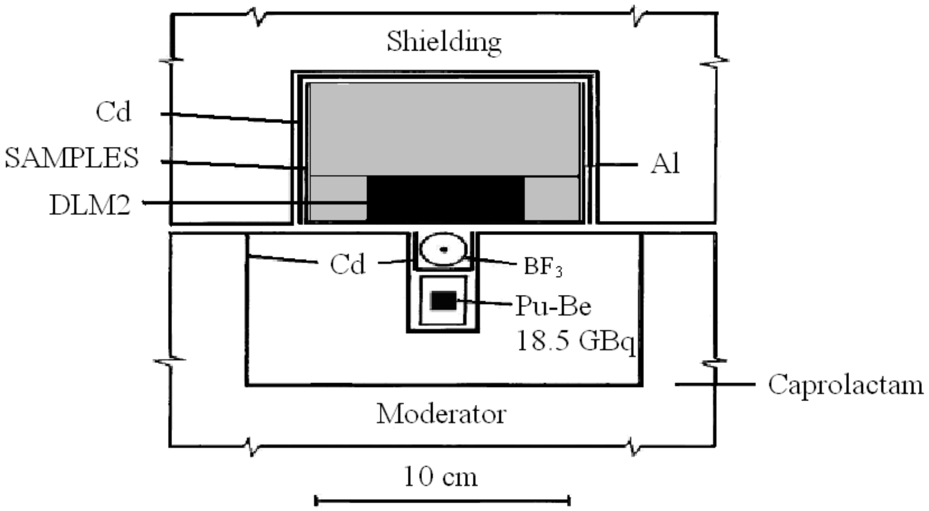


Figure 1: The experimental arrangement based on the Bitatron.

The effects of surrounding materials on the yield of reflected neutrons from the DLM2 have been studied in the experimental arrangements shown in Fig. 2. In the arrangement shown in Fig. 2d only zeolite layers of 2x1cm placed below the DLM2 were measured.

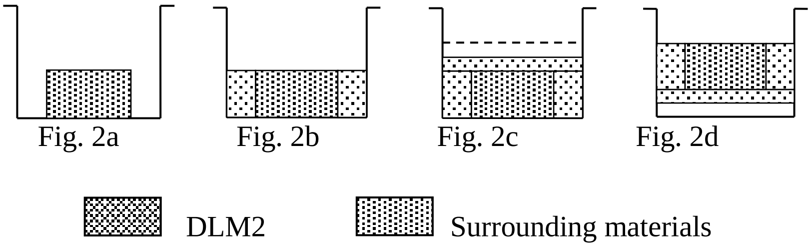


Fig. 2a Fig. 2b Fig. 2c Fig. 2d

Figure 2. Sketches of geometrical arrangements of the DLM2 and surrounding materials.

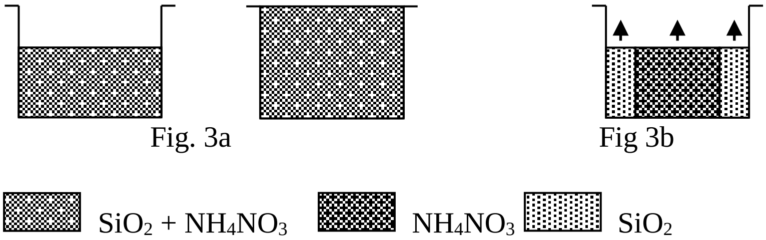
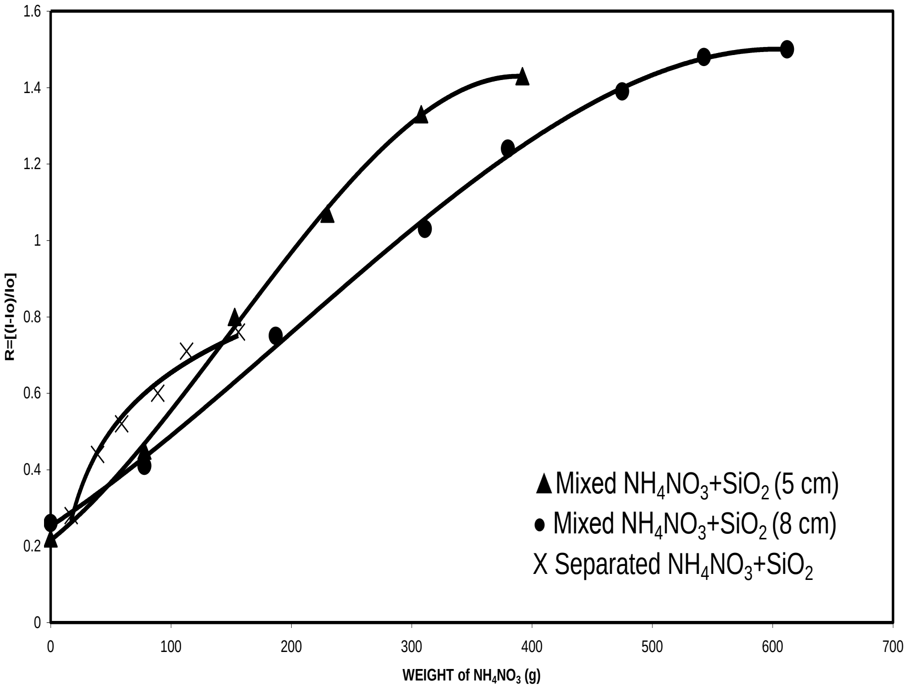


Fig. 3a Fig 3b

Figure 3. Mixed and separated arrangements of NH_4NO_3 in SiO_2.

The albedo of thermal neutrons were determined by the Bitatron equipment for two samples of 5cm and 8cm thicknesses containing homogeneous mixtures of dry sand and ammonium nitrate with different concentrations (see Fig. 3a).

In the experiment shown in Fig. 3b values of R(z) function were determined between (1- 8)cm thicknesses. The ~6cm diameter of the ammonium nitrate core is smaller than that for the DLM2. The yield of reflected neutrons was measured also for the core at 5cm and 8cm thicknesses. The dependences of R and the σ_β values on the amount of ammonium nitrate in sand are shown in Fig. 4 and Table 1.


1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
R=[(I-Io)/Io]
0
100
200
300
400
500
600
700
WEIGHT of NH_4NO_3 (g)
▲ Mixed $NH_4NO_3+SiO_2$ (5 cm)
● Mixed $NH_4NO_3+SiO_2$ (8 cm)
X Separated $NH_4NO_3+SiO_2$

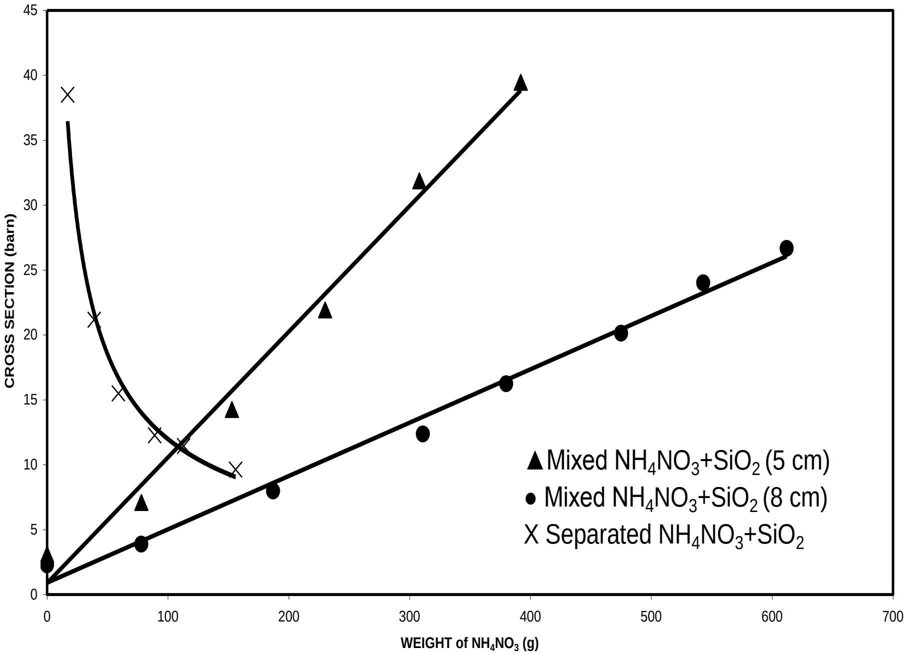
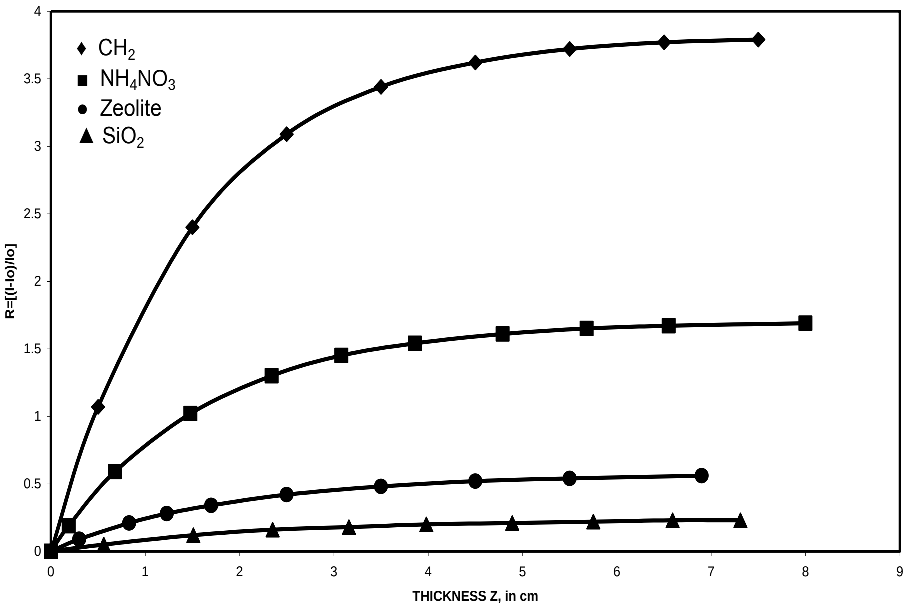


Figure 4: The measured excess counts (R) and the deduced σ_β values vs. the amount of NH_4NO_3 considered as plastic explosive.

The R and σ_β values have been measured for samples of identical dimensions (S) with the DLM2 and surrounded using the same materials of 10.2cm diameter (L) (see Fig. 2b). Results obtained for the R, Σ_β and σ_β values are summarized in Table 2.

Measurements carried out in the arrangements shown in Figs. 1, 2, 3, rendered to study the effects of the surrounding materials on the lateral flux distribution of incident neutrons and their depression as well as the slowing down of epithermal neutrons in the hydrogenous materials possible.

The R(z) functions for the environmental materials and ammonium nitrate have also been measured (see Fig. 5).



♦ CH_2
■ NH_4NO_3
● Zeolite
▲ SiO_2
R=[(I-Io)/Io]
4
3.5
3
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
6
7
8
9
THICKNESS Z, in cm

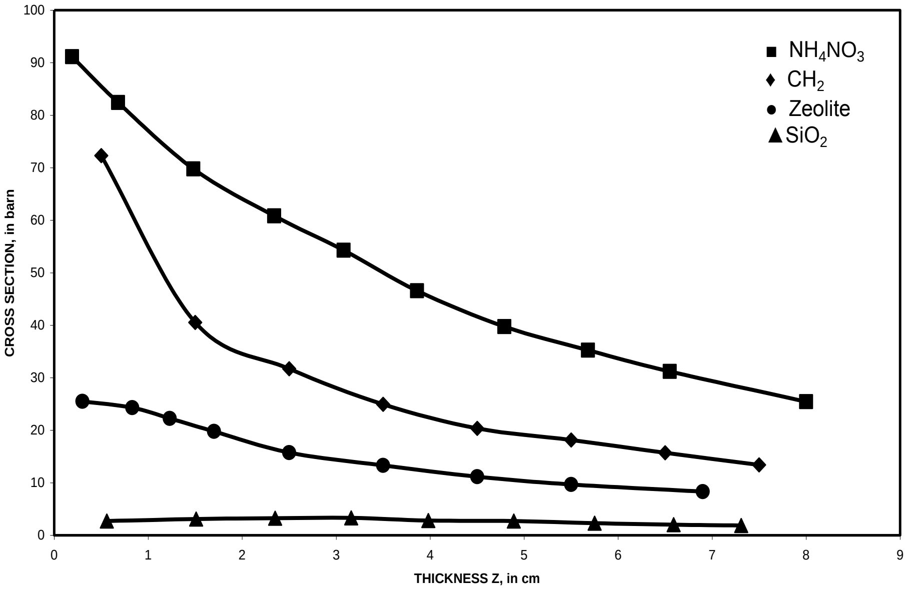


Figure 5: Excess counts (R) and σ_β values vs. the thickness (z) of surrounding materials used in this investigation.

III. Results and Conclusions

The effects of surrounding materials on the yield of reflected neutrons originated from the plastic explosives are characterized by the values of R, Σ_β and σ_β. Both the σ_β and Σ_β data are averaged over the bulky samples taking into account the R values and the number of different molecules. In the case of the R(z) functions the lowest and highest values of the intervals are given in Table 1. These cross sections obtained in this investigation and summarized in Table 1 render the following conclusions possible:

1) The yield of back-scattered neutrons and through it the macroscopic (Σ_β) and microscopic (σ_β) reflection cross sections, have the highest values for bare explosives (Fig. 2a) except for zeolite (Fig. 2b).

2) The yields of reflected neutrons decrease in the presence of surrounding materials in any arrangements as shown in Figs. 2b, 2c. This effect

is caused by the depression of the incoming and reflected neutrons in the soil-like materials as compared to the plastic explosives.

3) The increment in the excess counts with the increased amount of NH_4NO_3 in sand decreases and achieves saturation both for 5cm and 8cm thicknesses of the test samples (see Fig. 3a and Fig. 4).

4) In a separated arrangement (see Fig. 3b) of SiO_2 and NH_4NO_3 the σ_β value decreases as the thickness of the sample is increased which can be related to the shape of the lateral flux distribution [14] of incoming thermal neutrons and the effect of absorption.

5) The σ_β values are higher both for mixed and separated forms of small plastic explosives indicating the feasibility of using the neutron albedo to detect these types of explosives (see Fig. 4).

6) The values of Σ_β and σ_β are consistent with the R(z) functions demonstrated in Fig. 5.

7) The neutron reflection method has been used to detect explosives in mixed form for the first time.

8) The range of the response signal from the plastic explosives surrounded with soil-like or hydrogenous materials does not exceed 10cm depth. Therefore, if the neutron reflection method is chosen to detect explosives, anti-personnel landmines and other concealed objects this limitation should be taken into account.

9) The ratios of R(X)/R(DLM) for the same sample dimensions indicate the detection of plastic anti-personnel landmines and other concealed objects in non-hydrogenous environment possible. The same holds for samples up to ~10cm diameter and 3-4cm thicknesses. This statement is underlined by the values of reflection cross sections shown in Table 2.

10) The excess counts, R summarized in Table 2, indicate the advantage of using both the neutron thermalization hand-held [24] and the metal detectors for the observation of plastic explosives. During the scanning of the field containing metal pieces or the detection of concealed objects the signals from the two detectors can complete each other.

Table 1: Data of R, Σ_β and σ_β obtained for different samples.

Sample	$\rho(g/cm^3)$	Weight (g)	R	Σ_β	σ_β
DLM2 (Fig.2a)	1.11	191	1.2	1.4	33.65
DLM2+SiO_2 (Fig.2b)	1.26	353	1.31	1.43	31.38
DLM2+1cm SiO_2 (Fig.2c)	1.32	477	1.37	1.12	24.04
DLM2+2cm SiO_2 (Fig.2c)	1.38	609	1.35	0.91	18.37
DLM2+PE (Fig.2b)	0.92	258	1.76	1.51	30.9
DLM2+1cm PE (Fig.2c)	0.88	319	2.05	1.21	23.06
DLM2+2cm PE (Fig.2c)	0.85	377	2.14	0.99	17.91
DLM2+Zeolite (Fig.2b)	1.08	303	1.33	1.43	37.44
DLM2+1cm Zeolite (Fig.2c)	1.1	398	1.35	1.11	28.55
DLM2+2cm Zeolite (Fig.2c)	1.09	481	1.37	0.91	23.73
DLM2+1cm Zeolite (Fig.2d)	1.13	408	1.02	1.05	21
DLM2+2cm Zeolite (Fig.2d)	1.07	473	0.87	0.83	15.37
Mixed NH_4NO_3+SiO_2 (5 cm) (Fig.3a)	1.07-1.57	392-581	0.22-1.43	0.4	3.09-39.47
Mixed NH_4NO_3+SiO_2 (8 cm) (Fig.3a)	1.01-1.59	612-928	0.26-1.5	0.27	2.28-26.67
Separated NH_4NO_3+SiO_2 (Fig.3b)	1.37-1.41	126-774	0.28-0.77	0.57	8.84-38.51
NH_4NO_3 Core (5 cm)	0.78	111	0.44	0.76	15

Table 2**:** Data of R, R(x)/R(DLM), Σ_β, and σ_β obtained for materials of identical dimensions with the DLM2 (S) and the diameter (L) of the sample holder of the Bitatron.

Sample	**ρ(g/cm^3)**	**Weight (g)**	**R(S)**	**Σ_β**	**N (1/cm^3)**	**σ_β (S)**	**Sample**	**R(X)/R(DLM)**	**σ_β(X)/σ_β(DLM)**
DLM2	1.11	191	1.05	1.36	1.043E+22	29.45	DLM2	1	1
Zeolite	0.94	160	0.3	1.01	8.355E+21	10.56	Zeolite	0.29	0.36
NH_4NO_3	0.97	165	0.93	1.34	7.296E+21	37.49	NH_4NO_3	0.89	1.27
SiO_2	1.57	269	0.15	0.81	1.573E+22	2.8	SiO_2	0.14	0.1
Sand	1.43	244	0.18	0.86	1.433E+22	3.7	Sand	0.17	0.13
NH_4NO_3+SiO_2	1.28	219	0.5	1.16	1.161E+22	12.66	NH_4NO_3+SiO_2	0.48	0.43
CH_2 Disc	0.8	142	1.74	1.47	3.433E+22	14.48	CH_2 Disc	1.66	0.49
CH_2 Gran.	0.62	106	1.54	1.48	2.66E+22	17.03	CH_2 Gran.	1.47	0.58
CH_2 Oil	0.71	125	1.8	1.49	3.046E+22	16.88	CH_2 Oil	1.71	0.57
H_2O	0.88	150	1.69	1.51	2.94E+22	16.91	H_2O	1.61	0.57
$C_6H_{12}O_6$	0.92	158	1.09	1.38	3.074E+21	104.28	$C_6H_{12}O_6$	1.04	3.54
Fe	7.58	1327	0.39	1.09	8.175E+22	1.4	Fe	0.37	0.05
Cu	8.65	1477	0.26	0.97	8.194E+22	0.93	Cu	0.25	0.03
Pb	10.95	1951	0.27	0.95	3.181E+22	2.45	Pb	0.26	0.08

Sample	**ρ(g/cm^3)**	**Weight (g)**	**R(L)**	**Σ_β**	**N (1/cm^3)**	**σ_β (L)**	**Sample**	**R(L)/R(S)**	**σ_β(L)/σ_β(S)**
Graphite	1.67	450	0.51	1.2	8.371E+22	1.85	Zeolite	1.43	1.38
Zeolite	0.98	273	0.43	1.11	8.71E+21	14.52	NH_4NO_3	1.45	1.42
NH_4NO_3	0.99	274	1.35	1.44	7.446E+21	53.32	SiO_2	1.33	1.24
SiO_2	1.64	470	0.2	0.87	1.643E+22	3.48	Sand	1.44	1.36
Sand	1.52	421	0.26	0.97	1.523E+22	5.02	CH_2 Disc	1.53	1.53
CH_2 Disc	0.8	230	2.66	1.6	3.433E+22	22.14	CH_2 Gran.	1.56	1.54
CH_2 Gran.	0.63	174	2.41	1.61	2.703E+22	26.22	H_2O	1.73	1.49
H_2O	1.02	283	2.92	1.67	3.408E+22	25.2	$C_6H_{12}O_6$	1.72	1.58
$C_6H_{12}O_6$	1	279	1.87	1.54	3.341E+21	164.6	Pb	1.52	1.45
Pb	11.04	3245	0.41	1.04	3.208E+22	3.55			

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