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A SIMPLE METHOD FOR ESTIMATING ACTIVATION SENSITIVITIES OF DIFFERENT ELEMENTS/ISOTOPES WITH CYCLOTRON PRODUCED NEUTRONS

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ABSTRACT

A simple method for estimating the activation sensitivity of an element/isotope, activated with Cyclotron produced neutrons, has been developed. It uses the measured neutron spectra produced by bombarding a thick Be target with deuterons of different energies (15-54 Mev) and the measured/estimated neutron cross sections for the particular nuclear reaction. This method is applicable to all sorts of neutron spectra and all the elements/isotopes whose cross sections/excitation functions in the relevant energy ranges are available. We have applied this method to estimate the activation sensitivities of a number of lighter elements of biomedical interest. It is pointed out that this simple method is much cheaper, more convenient and quicker in estimating the activation sensitivities than experimental measurements - of course as long as the appropriate excitation functions are available.

1. INTRODUCTION

Fast neutron activation analysis is specially suited to low z elements and to those elements which are difficult or impossible to determine by slow neutron activation analysis, such as Al, Si, V, Cr, Ni, Cd, Sn, Tl, Pb, etc. Before choosing a particular fast neutron induced reaction for the determination of a given element/isotope it is helpful to estimate the activation/detection sensitivity obtainable with the neutron beam being used. The activation/detection sensitivities of most of the elements/isotopes bombarded by neutrons from d-T generators have been calculated and/or experimentally measured. In this case all neutrons are monoenergetic (around 15Mev) and it is simple to calculate the activation sensitivity. However, the d-T neutrons are not useful for the detection of these elements/isotopes where the thresholds of corresponding nuclear reactions are higher than 15MeV. Furthermore, the total neutron output from such generators is normally around 10^9 - 10^{10}n/sec, which limits the activation sensitivities. Moreover, the life of tritium target is limited to some tens of hours only, which means regular expensive replacements of the target if such generators are used for activation analysis over long periods.

The aforementioned short-comings of d-T generators for activation analysis can be overcome by using fast neutrons produced in a cyclotron. Depending upon the cyclotron size and the mode of neutron productions, those elements/isotopes, which have greater than 15MeV threshold energy for activation, can also be determined. Moreover, neutron fluxes of around 10^{12}n/sec and higher can be obtained in a cyclotron. Also the target life is much longer and cost a lot less than that of a tritium target. However, the neutrons produced are not monoenergetic and therefore the sensitivities of activation cannot be calculated so simply. A number of groups have experimentally determined activation/detection sensitivities of many elements by using neutrons produced with cyclotrons of different sizes. [1-4]

In this paper we describe a simple method which helps in calculating the activation sensitivity of any element/isotope for any known fast neutron beam. Using this method, and fast neutrons produced by deuterons of different energies on thick Be targets, the results for the determination of some light elements of biological interest (e.g. C, N, O, Na, P, Cl, etc) are presented.

2. METHOD

Neutrons considered in this paper are those produced by thick Be-targets under the bombardment of 100uA deuteron beams of 15, 20, 24, 40 and 54 MeV energies respectively, through the Be(d,xn) reactions. The spectra, measured by different authors but summarized by Schmidt and Muenzel,[5] are shown in Fig.1.

A suitable fast neutron induced nuclear reaction, in the element/isotope whose activation sensitivity is to be determined, is selected. The threshold energy of this reaction is noted and marked on the neutron spectrum.

Then as shown in Fig.2 the "effective neutron spectrum and flux" are determined. From the "effective neutron spectrum" the "effective mean or average energy" E_n is calculated with the following Eqn.

$$E_n = E_n(N_E)dE/N_E dE$$

At the "effective mean energy", the "effective average cross section" of the particular nuclear reaction is noted from the neutron cross section/excitation function data. [6-7]

In a similar way the "effective neutron flux" and "average cross section" of the nuclear reaction is evaluated for all the neutron spectra given in Fig.1. From the values the activation sensitivity A, can be simply calculated for each of the neutron spectra using the following Eqn.

$$A = Nk\sigma ST$$

Where A = Induced Activity - Disintegrations per sec per gm

N = Number of atoms of the element/isotope per gm

K = Abundance of the isotope in the element undergoing transformation

σ = Effective average cross section

F = Effective neutron flux n/sec/cm²

T = Duration of irradiation

S = Saturation factor - which approaches unity if the time of irradiation is greater than 4-5 times the half life of the activity being induced. For shorter irradiation time 't'

$$S = (1-e^{-\lambda t})$$

where λ = The decay constant of the induced activity

3. RESULTS AND DISCUSSION

The results on the induced activity calculations in some light elements of biomedical interest are given in Tables 1-6. The tables are self explanatory. However, it must be kept in mind that the induced activity figures are the total 4π activity produced, and must be modified for the detector solid angle and efficiency when comparing with experimental results.

NUC. REACTION	$^{12}C(n,2n)^{11}C$
Abundance	98.892%
Half life	20.5 Min.
Threshold Energy	20MeV

Incident Energy (MeV)	Effective Flux (n/sec/cm²)	Average energy of effective spectrum (MeV)	σ (m.b)	Induced activity at saturation (d.p.s.μg⁻¹)
24	77 x 10⁹	21.4	1	.04 x 10²
40	1304.0 x 10⁹	25.9	9.5	6.19 x 10²
53.8	3406.4 x 10⁹	25.7	8.5	1.45 x 10³

TABLE 1

NUC. REACTION	$^{14}N(n,2n)^{13}N$
Abundance	99.635%
Half life	10 Min.
Threshold Energy	12 MeV

Incident Energy (MeV)	Effective Flux (n/sec/cm²)	Average energy of effective spectrum (MeV)	σ (m.b)	Induced activity at saturation (d.p.s.μg⁻¹)
20	573.5 x 10⁹	13.3	3.1	7.61 x 10¹
24	945 x 10⁹	15.2	9	3.64 x 10²
40	3462.7 x 10⁹	20.4	11.2	1.66 x 10³
53.8	5385.2 x 10⁹	23.3	11.3	5.37x 10³

TABLE 2

NUC. REACTION $^{16}O (n, p) ^{16}N$

Abundance 99.759%

Half Life 7.35 sec.

Threshold Energy 10.25 MeV

Incident Energy (MeV)	Effective Flux (n/sec/cm²)	Average energy of effective spectrum (MeV)	σ (m.b)	Induced activity at saturation (d.p.s.μg⁻¹)
15MeV	293.3x 10^9	11.8	84	9.24 x 10^2
20 MeV	1081.4x 10^9	12.2	26	1.05 x 10^3
24 MeV	2294.5 x 10^9	13.7	45	3.87 x 10^3
40 MeV	3933.9 x 10^9	19.6	24	3.54 x 10^3
53.8 MeV	5350.1 x 10^9	22.8	--	----

TABLE 3

NUC. REACTION $^{31}P (n, 2n)^{30}P$

Abundance 100%

Half Life 2.6 Min.

Threshold Energy 12.5 MeV

Incident Energy (MeV)	Effective Flux (n/sec/cm²)	Average energy of effective spectrum (MeV)	σ (m.b)	Induced activity at saturation (d.p.s.μg⁻¹)
20	413.8x 10^9	13.5	6	0.48 x 10^2
24	683.6 x 10^9	15	36	4.77 x 10^2
40	3205.0 x 10^9	20.6	--	----
53.8	5130 x 10^9	23.5	--	----

TABLE 5

NUC. REACTION $^{23}Na(n,p)^{23}Ne$

Abundance 100%

Half Life 38 sec.

Threshold Energy 4 MeV

Incident Energy (MeV)	Effective Flux (n/sec/cm²)	Average energy of effective spectrum (MeV)	σ (m.b)	Induced activity at saturation (d.p.s.μg⁻¹)
15	1671.7x 10^9	7.5	31	1.35 x 10^3
20	2762.6x 10^9	9.8	50	3.61 x 10^3
24	3124.3 x 10^9	10.2	20	1.63 x 10^3
40	3930.8 x 10^9	17.4	22.5	2.31 x 10^3
53.8	6358.6 x 10^9	21	5	2.3 x 10^3

TABLE 4

NUC. REACTION $^{35}Cl(n,2n)^{34m}Cl$

Abundance 75.53%

Half Life 32.4 Min

Threshold Energy 15 MeV

Incident Energy (MeV)	Effective Flux (n/sec/cm²)	Average energy of effective spectrum (MeV)	σ (m.b)	Induced activity at saturation (d.p.s.μg⁻¹)
15	14.8x 10^9	15.5	7	0.01 x 10^2
20	193.8x 10^9	14.4	6	0.15 x 10^2
24	235.6 x 10^9	17.6	14	0.42 x 10^2
40	2649.4 x 10^9	22.9	--	----
53.8	4687.7 x 10^9	22.6	--	----

TABLE 6

4. SUMMARY

A simple method for estimating the activation sensitivity of an element/isotope, activated with any given neutron spectrum is presented. This method is applicable for the detection of any element/isotope, with any neutron beam, as long as the respective neutron cross section is available in the literature. As fast neutrons cross sections on most of the elements/isotopes are available it is suggested that this method should be used to estimate the activation sensitivities of different nuclides rather than experimental measurements which are more time consuming and expensive.

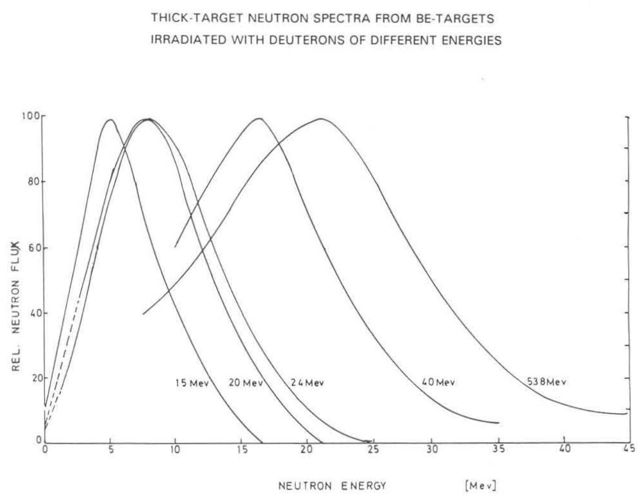

Fig. 1. Thick-target neutron spectra for Be at 15, 20, 24, 40 and 53.8 MeV deuteron energies.

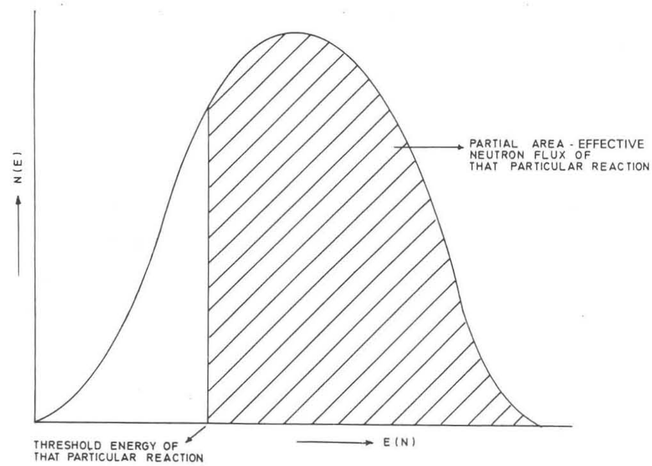

Fig. 2. The concept of "Effective Spectrum" and"Effective Flux"-shaded area

5. REFERENCES

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