

ENERGY DISTRIBUTION OF RECOIL PROTONS PRODUCED BY FAST NEUTRONS SCATTERING

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INTRODUCTION

The traditional neutron activation analysis (NAA) based on (n, γ) -neutron capture nuclear reaction has been developed into a reliable and powerful analytical technique, allowing the determination of over 60 chemical elements with good accuracy and low detection limits [1].

Considering all possibilities of activation and a radiochemical separation of the indicator radionuclide, the majority of the elements of this group can be determined at the ppb concentration level and below. However, for solving a number of analytical problems NAA technique does not suit well or it cannot be used at all [2]. On such instances, several non-traditional reactor activation analysis methods can be used which have increasingly been developed and applied to several fields of semiconductor industry, biology, geology in recent years. These techniques can be named as the nuclear reactor based charged particle activation analysis.

The purpose of this article is to estimate the analytical possibility of activation analysis technique based on the use of nuclear reactions excited by the flow of protons produced by fast nuclear reactor neutrons. The recoil protons are produced as the result of (n, p) elastic and inelastic scattering interaction of fast neutrons with nucleus of hydrogen. We have investigated the number and the energetic distribution of the recoil protons produced on hydrogen-containing target.

THEORY

When a neutron collides a nucleus three important types of interaction can occur: elastic scattering, inelastic scattering and nuclear reaction. The (n, p)-collisions on hydrogen or other light elements are applied for the producing of secondary recoil protons applied for the development of proton activation analysis technique. The elastic scattering of neutrons is 5-4,5 b in the energy range of reactor fast neutrons [6]. The number of recoil protons can be expressed by

$$N_p(E) = \int_0^{\infty} n \sigma_{np}(E) N_n(E) dE \quad (1)$$

where, n is the number of hydrogen atoms in a target; $\sigma_{np}(E)$ - The excitation functions of elastic scattering process, cm^2 ; $N_n(E)$ - the function of energy distribution of fast neutrons, $\text{MeV}^{-1} \text{cm}^{-2} \text{s}^{-1}$;

We estimated differential value of the number of secondary recoil protons by the use of the following formula:

$$F_p(E) = \frac{dN_p(E)}{dE} = n \sigma_{np}(E) N_n(E) \quad (2)$$

The excitation function $\sigma_{np}(E)$ of elastic scattering of fast neutrons on hydrogen can be expressed as the sum of two exponential functions:

$$\sigma_{np}(E) = \alpha_1 e^{-\beta_1 E} + \alpha_2 e^{-\beta_2 E} \quad (3)$$

where, $\alpha_1 = 4,23 \rightarrow \alpha_2 = 1,245 \rightarrow \beta_1 = 0,4 \rightarrow \beta_2 = 0,0608$

It is well known that the fast neutron spectrum of a nuclear fission reactor is placed in wide energy range – from several eV to 25 MeV which could be expressed as following:

$$N_n(E) = a e^{-bE} \text{sh}(cE)^{1/2} \quad (4)$$

where, $N_n(E)$ - The multiplicity of fast neutrons with the energy of E on the unit of energy interval, $\text{n/cm}^2 \cdot \text{c.MeV}$; sh – Hyperbolic sinuses; E - Neutron energy;

a, b, c - the characteristic constants for every U isotopes which satisfied the following correlation: $a = 2b^{3/2}(\pi c)^{-1/2} e^{-c/4b}$.

It is showed that for ^{235}U $a=0.453$, $b=1,035$; $c=2.29$.

By the uniting formulas (3) and (4) we can obtain the following expression for the proton distribution

$$\frac{dN_p(E)}{dE} = n \left(0,453e^{-1,035E} sh\sqrt{2,29E} \right) \left(4,23e^{-0,4e} + 1,24e^{-0,0608E} \right) \quad (5)$$

RESULTS AND DISCUSSION

The recoil protons with energy of more 2 MeV are of importance for activation analysis, because the useful nuclear reactions can be excited at these energies of particles. Therefore by the using of the computers program we carried out the numerical calculation of energy distribution of fast neutrons. Results obtained for the nuclear reactor fast neutrons of WWR-SM type are presented in Table 1.

Table 1. The energy distribution of nuclear reactor fast neutrons producing by thermal neutrons

E ₀ , MeV	*N ₀ (E)	**N _n (E)	E ₀ , MeV	*N ₀ (E)	**N _n (E)	E ₀ , MeV	*N ₀ (E)	**N _n (E)
0.1	0,203	0,989	1	0,348	0,693	10	0,868.10 ⁻³	0,107.10 ⁻²
0.2	0,269	0,965	2	0,240	0,396	11	0,389.10 ⁻³	0,476.10 ⁻³
0.3	0,308	0,936	3	0,139	0,210	12	0,173.10 ⁻³	0,210.10 ⁻³
0.4	0,332	0,904	4	0,742.10 ⁻¹	0,106	13	0,761.10 ⁻⁴	0,910.10 ⁻⁴
0.5	0,347	0,870	5	0,377.10 ⁻¹	0,517.10 ⁻¹	14	0,332.10 ⁻⁴	0,393.10 ⁻⁴
0.6	0,355	0,835	6	0,185.10 ⁻¹	0,246.10 ⁻¹	15	0,144.10 ⁻⁴	0,168.10 ⁻⁴
0.7	0,358	0,799	7	0,886.10 ⁻²	0,115.10 ⁻¹	16	0,619.10 ⁻⁵	0,704.10 ⁻⁵
0.8	0,357	0,763	8	0,415.10 ⁻²	0,529.10 ⁻²	17	0,265.10 ⁻⁵	0,286.10 ⁻⁵
0.9	0,354	0,728	9	0,191.10 ⁻²	0,240.10 ⁻²	18	0,113.10 ⁻⁵	0,107.10 ⁻⁵

*N₀(E)-multiplicity of fast neutrons with the energy E₀;

**N_n(E)–the sum of fast neutrons with the energy higher than 2 MeV;

Multiplicity of fast neutrons with energy of higher than 10 MeV is very small (of order of 10⁻⁴-10⁻⁶). Therefore these are of least importance for the producing of recoil protons.

By the use of the expression (5) we calculated the energy distribution of recoil protons for the case of the use of 1g polystyrene target and the 1 MW WWR-SM nuclear reactor. Our results are presented in Table 2.

Table 2. The energy distribution of recoil protons (protons/s.MW)

E ₀	σ _{np} (E), b	F _p (E)	E ₀	σ _{np} (E), b	F _p (E)
2	3.0	4,0.10 ¹⁰	8	0.9	2,1.10 ⁸
3	2.3	1,8.10 ¹⁰	9	0.8	9,3.10 ⁷
4	1.8	7,4.10 ⁹	10	0.7	3,7.10 ⁷
5	1.5	3,1.10 ⁹	11	0.64	1,6.10 ⁷
6	1.2	1,3.10 ⁹	12	0.60	7,0.10 ⁶
7	1.0	5,1.10 ⁸	13	0.54	2,7.10 ⁶

It is shown that the number of recoil protons is sufficiently high. The energy distribution of recoil protons satisfies the exponential law:

$$F_p(E) = 2.29 \cdot 10^{11} e^{-0.873E} \quad (8)$$

Preliminary investigations showed that the detection limits of proton activation analysis for light elements could be better than 10 ppm.

CONCLUSION

The analytical possibility of activation analysis technique based on the use of nuclear reactions excited by the flow of recoil protons was estimated. The numerical calculations are carried out for fast neutrons and recoil protons distributions. It is shown that the detection limits of proton activation analysis for light elements could be better than 10 ppm.

REFERENCES

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