# TO ESTIMATION OF INTRINSIC BACKGROUND OF Si DETECTOR IN NEUTRON FIELDS

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The constituents of intrinsic background of the Si semiconductor detector, induced by fast neutrons from (n, p) and (n, α) threshold reactions on $^{28}$Si, $^{29}$Si and $^{30}$Si isotopes are estimated. The considered neutron fields are the $^{235}$U thermal fission neutron spectrum and monoenergetic neutron spectra from T(d, n)$^4$He and D(d, n)$^3$He reactions, described by narrow Gauss distributions. The reactions cross sections averaged over these spectra are calculated. For the total responses of reactions in the normalized neutron spectra, taking into account isotope abundances, the following values have been obtained (arbitrary units): $0.968 \cdot 10^{-3}$ for $^{235}$U spectrum, 0.435 for 14 MeV neutron source spectrum and $2.963 \cdot 10^{-5}$ for 2.5 MeV neutron source spectrum. For all considered neutron spectra, it is possible to reduce background utilizing a detector highly enriched with $^{30}$Si isotope. In case of the fission neutron spectrum it will allow to achieve considerably higher accuracy (expected reduction of background ~ 70 times) in the experiments such as spectrum study and mechanism of high-energy fission neutrons origin, fission fragment neutron spectra, etc. The calculations have been made with the help of the program GROUPIE from the PREPRO-94 program package and the ENDF/B-VI library.

## 1. Introduction

The semiconductor detectors of charged particles based on crystal silicon are widely used in the experimental nuclear physics. They are also used in the fast neutron research (recoil nuclei method, method of associated particles, etc.) where a detector is in the fast neutron field and registration of the useful events occurs against the background registration of (n, p) and (n, α) reactions in material of detector. At the studies of high energy range of fission neutron spectrum by proton recoil method measurements of proton spectrum are made with a polyethylene radiator and without it to eliminate background. Due to the small thicknesses of the radiators used and hence extremely low general efficiency of the method ($\sim 10^{-7}$), the structure study of such intrinsic detector background, its estimation and essential minimization are the actual issue of the method [1, 2].

The integral estimation of background value and its components is done in [3], where background phenomena was considered in course of preparations for (n, p) an (n, α ) reaction cross section measurements at 14 MeV neutron source. It was found that the basic contribution to the value of background is due to neutron reactions with the output of charged particles, which take place in material of detector (so-called background of “direct flux” on a detector).

Distribution of detector signals of the background charged particles N(V) is determined by the energy spectrum of particles $F_x(E)$ and response function of detector $G_x$ (E,V) for every type of particles [4]:

$$N(V) = \sum_x N_x(V) = \sum_x \int F_x(E) G_x(V,E) dE \,, \tag{1}$$

where V is amplitude of signal, E is energy of the charged particle.

It is possible to estimate the total background value $N_F = \int N(V)dV$ by calculation method, if to define and to sum all averaged over neutron spectrum background reaction cross sections.

## 2. Estimation of background constituents of detector for the fission neutron spectrum

From the evaluated reaction cross sections data on silicon isotopes with the charged particle output only (n, p) and (n, α) reactions were considered. The excitation functions of these reactions taken from the ENDF/B-VI library is presented in Figs. 1 - 3.

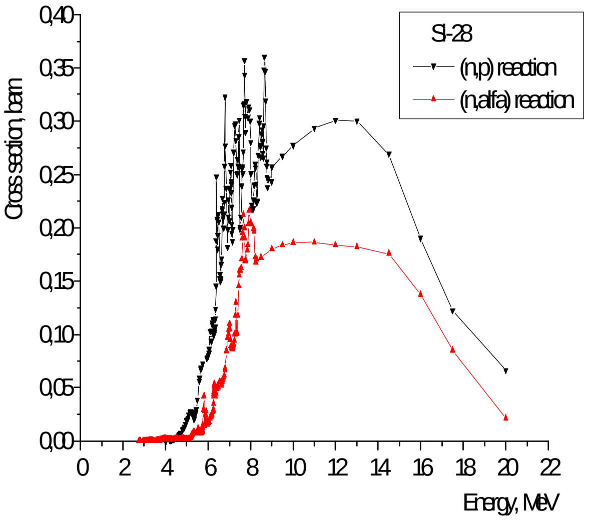

Fig. 1. Cross section threshold reactions for $^{28}$Si isotope.

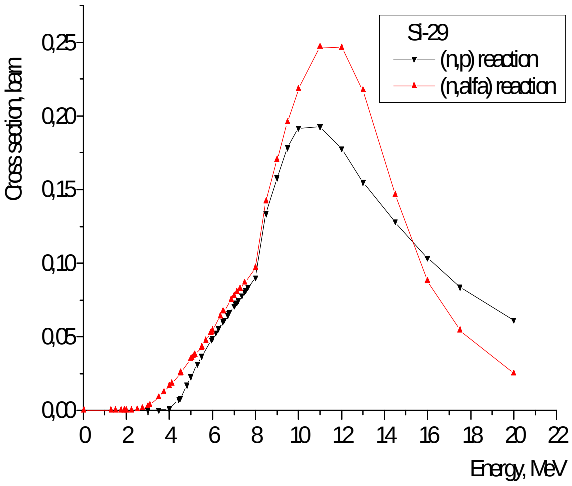

Fig. 2. Cross section threshold reactions for $^{29}$Si isotope.

The $^{235}U$ evaluated themal fission neutron spectrum for average cross section calculations represented in Fig. 4, taken from a dosimetry file IRDF-90 [5].

It is known that up to 95% response of threshold neutron reaction in the exponentially decreasing fission neutron spectrum is in the energy interval from threshold to ~4 MeV above it.

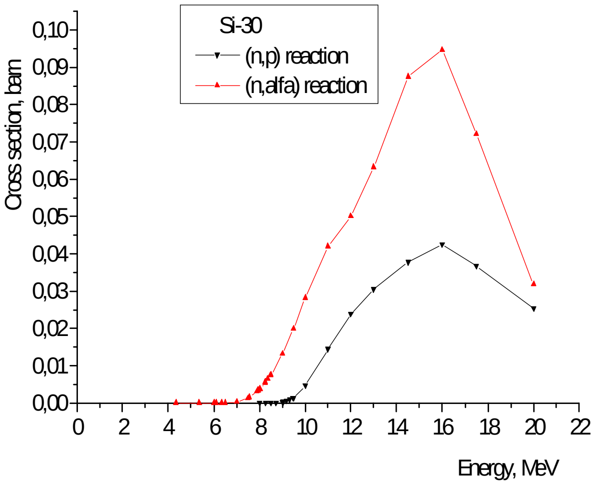

Fig. 3. Cross section threshold reactions for $^{30}Si$ isotope.

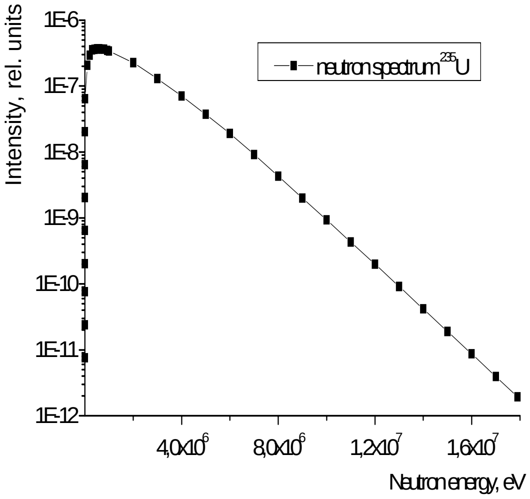

Fig. 4. Evaluated normalized thermal fissionneutron spectrum of $^{235}U$.

The averaged over neutron spectrum cross section of threshold reaction is determined by the expression:

$$\langle\sigma\rangle = \frac{\int\limits_{E_{thr}}^{\infty}\sigma(E)F(E)dE}{\int\limits_{0}^{\infty}F(E)dE}, \qquad (2)$$

where F(E) is neutron spectrum, σ(E) is excitation function of neutron reaction, $E_{thr}$ – threshold energy.

The calculation were performed with the help of program GROUPIE (program package PREPRO-94). The results of calculation are shown in Table 1. Comparing of the obtained values of average cross sections with information presented in [6], derived on the basis of the JENDL-3.2 library, shows a good agreement. Differencies in the values of the average reaction cross sections may be explained by distinction in the values of the energy thresholds.

*Table 1.* **Averaged over the $^{235}U$ thermal fission neutron spectrum reaction cross sections with charge particles output for Si isotopes, calculated with GROUPIE program**

| Reaction | Reaction energy, MeV | Average cross section, barn | Average cross section, barn, from [7] | Abundance, r | Response reaction x r |
|---|---|---|---|---|---|
| $^{28}Si(n, p)^{28}Al$ | -3.860 | $6.923 \cdot 10^{-3}$ | $6.134 \cdot 10^{-3}$ | 0.9223 | $6.385 \cdot 10^{-3}$ |
| $^{28}Si(n, \alpha)^{25}Mg$ | -2.650 | $3.083 \cdot 10^{-3}$ | $2.661 \cdot 10^{-3}$ | 0.9223 | $2.843 \cdot 10^{-3}$ |
| $^{29}Si(n, p)^{29}Al$ | -2.898 | $3.706 \cdot 10^{-3}$ | $2.991 \cdot 10^{-3}$ | 0.0467 | $1.731 \cdot 10^{-4}$ |
| $^{29}Si(n, \alpha)^{26}Mg$ | -3.470 | $5.988 \cdot 10^{-3}$ | $5.914 \cdot 10^{-3}$ | 0.0467 | $2.796 \cdot 10^{-4}$ |
| $^{30}Si(n, p)^{30}Al$ | -7.752 | $2.223 \cdot 10^{-5}$ | $1.587 \cdot 10^{-5}$ | 0.0310 | $6.891 \cdot 10^{-7}$ |
| $^{30}Si(n, \alpha)^{27}Mg$ | -4.200 | $1.162 \cdot 10^{-4}$ | $1.311 \cdot 10^{-4}$ | 0.0310 | $3.604 \cdot 10^{-6}$ |

A basic contribution to the value of background is stipulated by two its components: the $^{28}Si(n, p)^{28}Al$ and $^{28}Si(n, \alpha)^{25}Mg$ reactions, which have yield 65.9 % and 29.3 % from the total response, accordingly.

### 3. Estimation of background constituents of detector in the monoenergetic neutron spectra

Let us consider the constituents of silicon detector background at irradiation by monoenergetic neutrons from two reactions: 14 MeV from the reaction of $T(d,n)^4He$ and 2.5 MeV from $D(d,n)^3He$ reaction.

The spectrum shape of such type neutron source may be presented by narrrow Gauss distribution [7]:

$$N(E) = \frac{1}{\sqrt{2\pi\sigma}}\exp\left(-\frac{E-\bar{E}}{2\sigma^2}\right), \qquad (3)$$

where $\bar{E}$ and σ are parameters of distribution: average neutron energy and standard deviation, determining a distributing width.

Value of energy of monoenergetic neutrons $E_n$ ($E_n = \bar{E}$) from the reaction of $T(d,n)^4He$ is determined on base of formula, see in [8]:

$$Q_{d,T} = 17{,}6\text{MeV} = \frac{5}{4}E_n - \frac{1}{2}E_d - \frac{1}{2}\sqrt{2E_d E_n}\cos\theta_n, \tag{4}$$

where $Q_{d,T}$ is energy of reaction; $E_d$ is energy of deuterons, incident tritium target; $\theta_n$ is an angle of neutron escape relative to direction of deuteron beam. Similarly, energy of neutrons from the reaction of $D(d, n)^3He$ is calculated, accordingly [8], from equation:

$$Q_{d,D} = 3{,}28\text{MeV} = \frac{4}{3}E_n - \frac{1}{3}E_d - \frac{2\sqrt{2}}{3}\sqrt{E_d E_n}\cos\theta_n, \tag{5}$$

where $Q_{d,D}$ is energy of reaction.

Solutions of equations (4) and (5) at the energy deuterons $E_d$ = 200 кeV for both reactions and value of angle $\theta_n$ = 90° (neutrons, escaping from target at rectangular angle are selected) allow to get the average values of neutron energies 14.16 MeV for the reaction of $T(d, n)^4He$ and, 2.51 MeV for $D(d, n)^3He$ reaction accordingly.

Parameter σ in distribution (3) can be obtained from the account of basic factors, affecting on neutron beam energy spreading $\Delta E_n$. In our case, we can write for parameter σ following:

$$\sigma^2 = (\Delta E_n)^2 = [\Delta E_n(\Delta E_d)]^2 + [\Delta E_n(T)]^2 + [\Delta E_n(\Delta\theta_n)]^2, \tag{6}$$

where $\Delta E_n(\Delta E_d)$ is uncertainty of neutron energy, arising from the energy spread of deuteron beam $\Delta E_d$; $\Delta E_n(T)$ it is uncertainty of neutron energy due to energy losses at passing of deuterons through the thickness of target T; $\Delta E_n(\Delta\theta_n)$ it is uncertainty of neutron energy due to detector (or target) sizes.

The uncertainty in the energy of accelerated particles is usually small and does not exceed 0.1% of deuteron energy [4], so $\Delta E_d$ values can be find from (4) and (5) and they are 0.079 keV and 0.050 keV accordingly for each of reactions.

Let us suppose that in an experiment we deal with a thick target, and that all deuterons are braken in by it. Putting in (4) the values of energy deuterons 200 keV and 0, we will obtain the value of energy uncertainty of neutrons from (d, T) reaction $\Delta E_n(T)$ = 80 keV. Similarly, we will get the value of energy uncertainty of neutrons from (d, D) reaction equal 50 keV.

Energy uncertainty $\Delta E_n(\Delta\theta_n)$, caused by ambiguity of angle of neutron escape $\theta_n$, in simplest case (a «point» target), can be found from (4) and (5) by a substitution in them of values angle [$\theta_n \pm (\Delta\theta_n/2)$]. Here angular uncertainty $\Delta\theta_n$ determined as 2 *arctg( r/R),* here r is a radius of detector, equal 0.5 sm, R is distance target-detector, taken 70 sm. As a result, the uncertainty $\Delta E_n(\Delta\theta)$ values 13.7 keV and 7.2 keV were obtained for the first and for the second case accordingly.

Calculated with (6) on the basis of the obtained data, the total energy uncertainty $\Delta E_n$ for average energy of neutrons 14.16 MeV from (d, T) source comprise a value 81.2 keV, and for average energy of neutrons 2.51 MeV from (d, D) source 50.5 keV. Main contribution to the values of uncertainty $\Delta E_n$ is due to the braking process of deuterons in material of targets.

The calculated normalized spectra of neutron sources is presented in Fig. 5. The widths of spectra presentation, 600 keV in the first case ( (d, T) source), and 400 keV in the second, were chosen so, that normalizing to 1 arrived at with the high degree of exactness.

The background reaction cross sections of silicon isotopes were averaged over these calculated neutron spectra with help of the program GROUPIE. Data for spectra for the program GROUPIE was prepared with the required exactness 0.1 %.

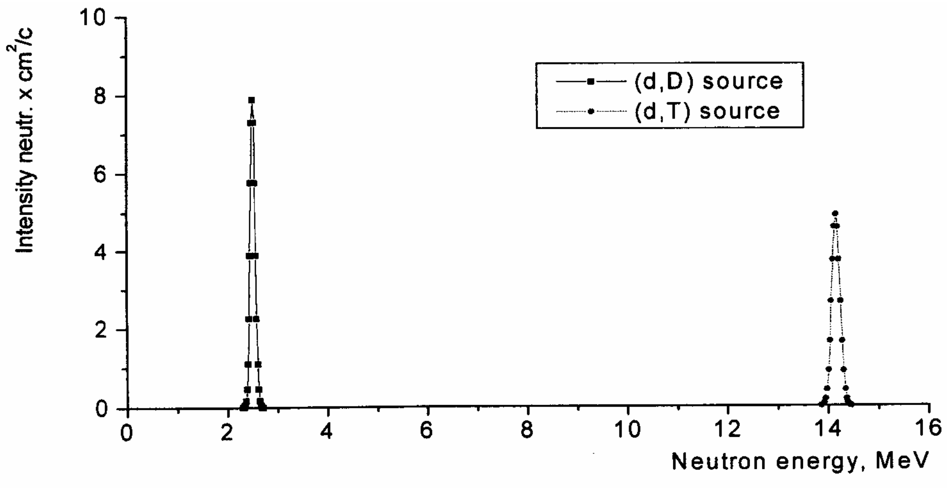

Fig. 5. Calculated, normalized to 1 neutron energy spectra from (d, D) and (d, T) reactions, described by Gauss distribution.

## 4. Comparison of background constituents of Si detector and $^{30}$Si detector in neutron fields

Presently, technology of production of isotopic clean polycrystals silicon is developed and his properties are studied [9]. An interesting domain of application of isotopically-pure $^{30}$Si can be semiconductor detector of the charged particles. Such detector possessed better stability to the damages due to more simple crystalline structure, and, as it is follows from our calculations, it should have low intrinsic background in fast neutron field due to higher reaction thresholds.

Finally, for comparison of the obtained results, the sums of total responses of background reactions with the charged particle output for nature silicon and isotope $^{30}$Si in considered fast neutron spectra are given in Table 2.

*Table 2.* **Sums of background reaction responses for Si detector and detector based on $^{30}$Si (100 %) in neutron fields**

| Reaction | Reaction energy, MeV | Response reaction in $^{235}$U spectrum (relative units) | | Response reaction in (d, T) spectrum (relative units) | | Response reaction in (d, D) spectrum (relative units) | |
|---|---|---|---|---|---|---|---|
| | | $^{nat}$Si | $^{30}$Si | $^{nat}$Si | $^{30}$Si | $^{nat}$Si | $^{30}$Si |
| $^{28}$Si(n, p)$^{28}$Al | -3.860 | $6.385 \cdot 10^{-3}$ | - | 0.2546 | - | - | - |
| $^{28}$Si(n, α)$^{25}$Mg | -2.650 | $2.843 \cdot 10^{-3}$ | - | 0.1635 | - | - | - |
| $^{29}$Si(n, p)$^{29}$Al | -2.898 | $1.731 \cdot 10^{-4}$ | - | $0.627 \cdot 10^{-2}$ | - | - | - |
| $^{29}$Si(n, α)$^{26}$Mg | -3.470 | $2.796 \cdot 10^{-4}$ | - | $0.759 \cdot 10^{-2}$ | - | $2.963 \cdot 10^{-5}$ | - |
| $^{30}$Si(n, p)$^{30}$Al | -7.752 | $6.891 \cdot 10^{-7}$ | $2.223 \cdot 10^{-5}$ | $0.112 \cdot 10^{-2}$ | $0.360 \cdot 10^{-1}$ | - | - |
| $^{30}$Si(n, α)$^{27}$Mg | - 4.200 | $3.604 \cdot 10^{-6}$ | $1.162 \cdot 10^{-4}$ | $0.254 \cdot 10^{-2}$ | $0.819 \cdot 10^{-1}$ | - | - |
| In the total: | | $9.684 \cdot 10^{-3}$ | $1.384 \cdot 10^{-4}$ | 0.43570 | 0.1179 | $2.963 \cdot 10^{-5}$ | - |
| Ratio sum responces - **$^{nat}$Si / $^{30}$Si:** | | 69.97 | | 3.69 | | - | |

### Conclusions

From the analysis of the results it is possible to come to the following conclusions:

a) very good low-background conditions are created at the silicon semiconductor detector use in the experiments with 2,5 MeV neutron source;

b) in case of the fission neutron spectrum, it is possible to attain substantial reduction of background (~70 times) utilizing a detector highly enriched with $^{30}$Si isotope. It will allow to achieve considerably higher accuracy in the experiments of much current interest such as spectrum study and mechanism of high-energy fission neutrons origin, fission fragment neutron spectra, etc.;

c) the higher estimated value of total response reactions and, consequently, the most difficult background conditions are expected using a semiconductor detector in the field of 14 MeV neutron source. The application of the detector with the isotope of $^{30}$Si will allow obtaining only about threefold decrease of background.

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