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THE NEUTRON COUNTER WITH INDIUM DETECTOR

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Sometimes it is necessary to detect a weak flux of neutrons in special experimental condition when the use of the well-known neutron detection methods is excluded. The causes of it can be a very short duration of neutron's impulse, a very high level of the accompanying radiation, an influence of the powerful electromagnetic field on an electronic equipment and so on. Such experimental conditions take place at some types of accelerators (photo-neutrons from the pulsed cynchrotron radiation) or at thermonuclear installations.

An active neutron detector using electronics has usually a relatively high sensitivity but its fast-action and selectivity are limited. A passive neutron activation detector on the contrary has usually a lower sensitivity, a high selectivity, and has no dead time in principle. The main imperfection of this technique is connected with the long processing of detector's readings after their irradiation. Therefore, it is expedient to combine the advantages of the both methods for development of the especial neutron counter accommodated to the above-mentioned working conditions.

For the experiments at the thermonuclear installation the active neutron counter on the base of the activation detector was designed and tested. The conditions of the experiments were assigned as following:

- the neutron energy – 2,45 ± 0,02 MeV ($^2H_1+^2H_1=\,^3He_2+^0n_1+$ 3,27 MeV reaction);
- the single neutron pinch duration - 3 ns;
- the time interval between the neutron pinch - 0,1 s;
- the 150 neutron pinches are combined in one pulse and the intervals between these pulses – 900 s;
- the powerful electromagnetic field impulse arises during the pinch's pulses;
- the neutron source yield can be varied from 10^4 to 10^9 neutrons per pinch;
- the measuring procedure can be synchronized with the start pulses.

The neutrons and gamma rays /1/ are emitted from the center of the iron cylinder (with the wall thickness of 3 cm) filled with the deuterium at pressure of $4,053\cdot10^6$ Pa. The arrangement of the neutron measuring and the counter design are presented in Fig. 1. The neutrons thermalized by the polyethylene moderator interact with the indium detector. The decay products are detected then by two gas-filled beta-counters coupled with the detector. The GM beta-counter has little sensitivity to the power supply shifting, the big impulse amplitude and its electrical circuit is very simple. All of it makes the GM-counter stable enough to the electromagnetic field perturbation. Nevertheless, the registration of the electron's count rate is carried out within the time interval between the neutron pulses.

The activation detector is the plate with sizes of $57\times77\times1,2$ mm^3 from the natural indium (${}^{49}In_{113}$ 4,23%, ${}^{49}In_{115}$ 95,77%). As the activation detector material argentum or rodium can be used too, but the indium isotope ${}^{49}In_{116}$ has the convenient short-time decay with a rather big cross-section. The detector surfaces are close to the active area of the beta-counters and the detector thickness is determined by the maximum range of the electrons in indium. The following channels of the reactions take place with neutrons:

Ia) ${}^{49}In_{113} + n = {}^{49}In_{114} \xrightarrow{\beta^-\ (98\%)} {}^{50}Sn^*_{114} \rightarrow \gamma \quad E_{\beta\,max} = 1,99$ MeV

$\xrightarrow{e.c.\ (1,9\%)} {}^{48}Cd_{114}$

$\sigma_{th} = 3,0\pm0,6$ barn

$T_{1/2} = 71,9$ s

$\xrightarrow{\beta^+\ (0,004\%)} {}^{48}Cd_{114}$

(stable) $E_{\beta\,max} = 0,42$ MeV

Ib) ${}^{49}In_{113} + n = {}^{49}In_{114m} \xrightarrow{i.c.\ (96,5\%)} {}^{49}In_{114} + \gamma$ ....

$\sigma_{th} = 7,8\pm2$ barn

$\xrightarrow{e.c.\ (3,5\%)} {}^{48}Cd_{114}$ (stable)

$T_{1/2} = 49,51$ days

IIa) ${}^{49}In_{115} + n = {}^{49}In_{116} \xrightarrow{\beta^-} {}^{50}Sn_{116}$ (stable) $E_{\beta\,max} = 3,31$ MeV

$\sigma_{th} = 42\pm4$ barn

$T_{1/2} = 14,1$ s

IIb) $^{49}In_{115}+n={}^{49}In_{116m1}\xrightarrow{\beta^-}{}^{50}Sn_{116}$ (stable) $E_{\beta\,max}=1,1$ MeV
$\sigma_{th}=161\pm5$ barn (m1=0,127 MeV)
$T_{1/2}=54,15$ min

IIc) $^{49}In_{115}+n={}^{49}In_{116m2}\xrightarrow{i.c.}{}^{49}In_{116}+\gamma$ … (m2=0,29 MeV)
$\sigma_{th}=91\pm10$ barn
$T_{1/2}=2,16$ s

where e. c. is the electron capture, i. c. is the isomeric conversion. In the round brackets the levels of nuclei excitation are presented. Thus, for the real measurement time the most part of the electron yield from the detector is due to the Ia and the IIa reactions. The spectra of the electrons coming out from the detector's surfaces become softer with the ionization losses of energy within the detector. In order to increase the efficiency of the electron detection by the beta-counter their entrance window must be very thin. The GM beta-counter СБТ-10 has 10 sections covered with the mica layer with thickness of $4\cdot10^{-3}$ $g\cdot cm^{-2}$ and its lower detected energy of electrons - 50 keV. To shorten of the long GM-counter impulse the supply circuit with the separate load /2/ was used and the upper limit of the count rate was about $5\cdot10^{4}$ s^{-1}. The power supply of the GM-counter can be switched on only for the short measuring time interval between the neutron pulses.

For the attainment of the maximum sensitivity of the device its design should be optimal. The optimization of the moderator construction was carried out by the MCNP code calculation for the real geometry and energy of the initial neutrons. The total cross-section of the In + n interaction is quickly grown with energy decrease. Two contrary factors (in sense of their influence on the counter sensitivity) take place within the moderator at the moderator thickness increasing: the softening of the neutron spectrum and the relaxation of the neutron fluence. The optimal design of the moderator has the relative thin front slab and the massive back part of the moderator. The activation of the In-detector occurs owing to the scattered back neutrons (with low energies) mainly. The total activation of the detector depending on the front polyethylene slab thickness is shown in Fig. 2. The front surface of the moderator is 45,1×29,5 cm^2 and its total thickness is 31,1 cm. The moderator is mounted from the polyethylene blocks and has the inner cavity for the assembling of the In-detector and the GM-counters.

The neutron spectrum for the real conditions in the place of the In-detector is presented in Fig. 3 for the front slab thickness of 2 cm. In order to obtain the neutron counter sensitivity the spatial distributions of the partial activities within the In-detector were calculated (Fig.4). The optimal construction of the moderator ensures the near flat shapes of the spatial distributions of the activities . Then the fluxes of electrons coming out from the front and rear surfaces of the detector and crossing the entrance windows of the beta-counters were calculated taking into account the electron spectra /3/ and their transport within the detector. For $^{49}In_{114}$ ($E_{\beta\ max}$ = 1,99 MeV) the 15,9% of all electrons give the counts in the GM counter; for $^{49}In_{116}$ ($E_{\beta\ max}$ = 3,31 MeV) – 31,1%; for $^{49}In_{116m1}$ ($E_{\beta\ max}$ = 1,14 MeV) – 5,4%.

At the conditions of the experiment the neutron sensitivity of the neutron counter depends on the time structure of irradiation, average neutron yield in the pinch, duration of the count measuring between the pulses, total time of the measuring and the level of the background count rate. The statistics of the background count in the measuring time determines the minimum value of the average neutron yield in the pinch at other fixed conditions. The own average background count of the GM-counter couple with the In-detector and without the moderator is 3,1 s^{-1}, the same value inside the moderator is 2,69 s^{-1}. The thin lead cover (5 mm) of the moderator (except the front surface) 1,5 times decreases this value. In Fig. 5 the background count's distribution for the time interval of 30 s is shown. After this time interval the $^{49}In_{116}$ (giving the most contribution to the count) practically decays. The standard deviation of the distribution is 8,2 imp. Thus, the exceeding of the measured count above average background count on 3σ ($\approx$ 25 events) can be considered (in the confidence interval 95%) as the lowest possible effect from the thermonuclear neutrons. This value corresponds to the average neutron yield per pinch less than 10^3.

For the testing of calculation of the neutron counter sensitivity for thermonuclear neutrons the analogous calculation of the sensitivity for the neutrons of the ^{252}Cf source (the average energy is about 2,5 MeV) and its experimental verification with this standard source were done. In Fig. 6 the comparison of the calculated and experimental counts for the consistent time intervals of 10^3 s after irradiation begins is presented. The neutrons yield of the source – $2{,}8\cdot10^6 \pm 6\%$ n/s, the distance between the source and the front plane of the device – 2 meter. The measurement was carried out at the calibration facility. The background of the scattered neutrons in the dwelling was determined with the polyethylene cone placed between the source and the device. As the experimental results, the differences of these counts were taken. The difference between the calculation and the measurement is less than 4% in all time range. The slow rise of the counts with the time is due to accumulation of the $^{49}\mathrm{In}_{116m1}$ isotope in the detector. The small distinction of the calculated and experimental curve slopes can be caused by the inaccuracy of the accepted half-life periods of the In-isotopes.

The sensitivity of the neutron counter is more than 4 impulses per 1 neutron$\cdot$ cm^{-2}. The routine activation technique is used usually with neutron fluxes more 10^3 neutron$^{-1}\cdot$ cm^2. On the other hand, the maximum sensitivity of a multisphere neutron spectrometer with active detector is about $0{,}2 \div 0{,}3$ impulse per 1 neutron$\cdot$ cm^{-2}. Thus, the presented neutron counter has the high sensitivity comparable with the sensitivity of the ^{3}He-filled proportional neutron counter within the optimal polyethylene moderator. The sensitivity of the neutron counter to the gamma rays of ^{60}Co is approximately 100 times lower than to the neutrons.

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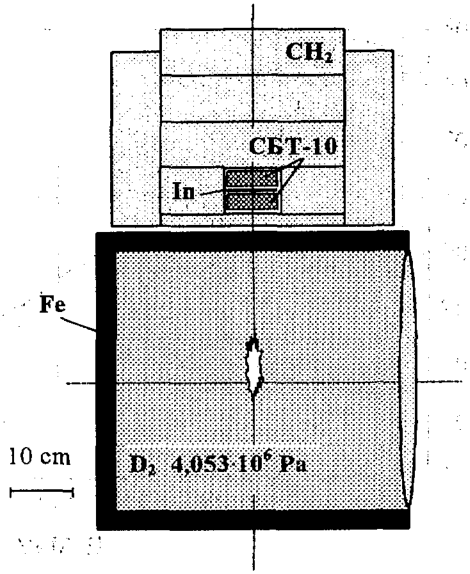

Fig. 1. The neutron counter design and the experimental arrangement

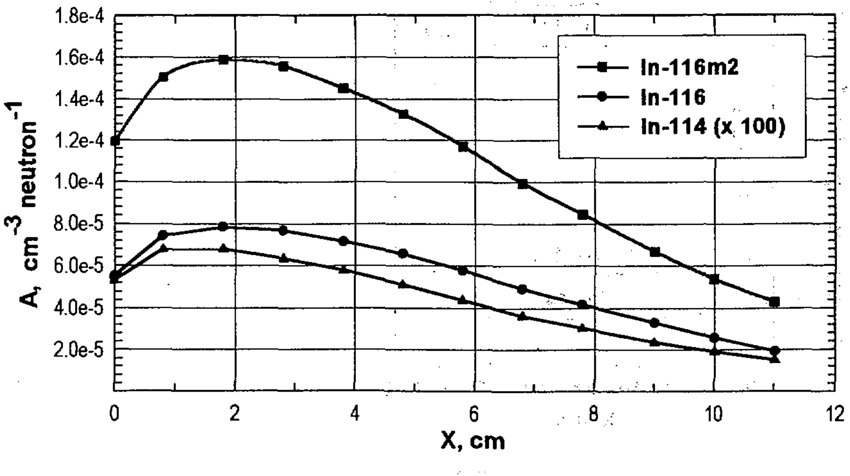

Fig.2. The dependence of the detector's activities on the front slab thickness.

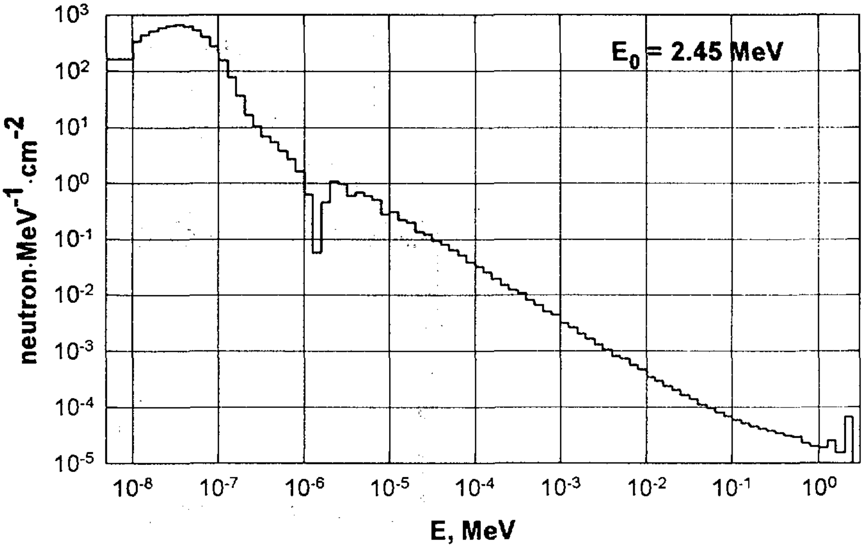

Fig.3. The averaged over the In-detector volume neutron spectrum within the moderator. The result correspons to 1 neutron of the isotropic point source.

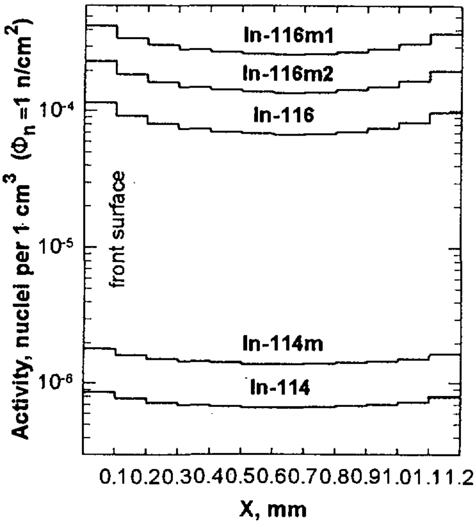

Fig.4. The spatial distribution of the activities within the detector.

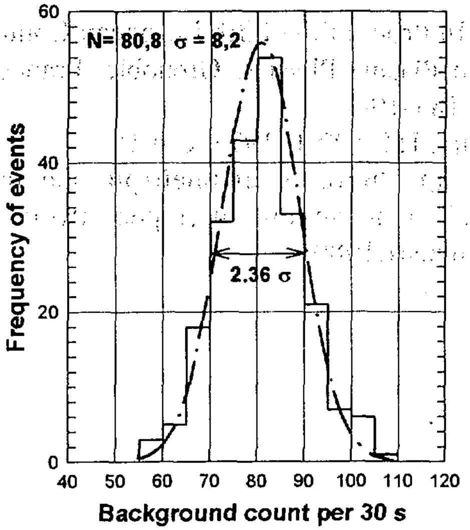

Fig.5. The background count distribution

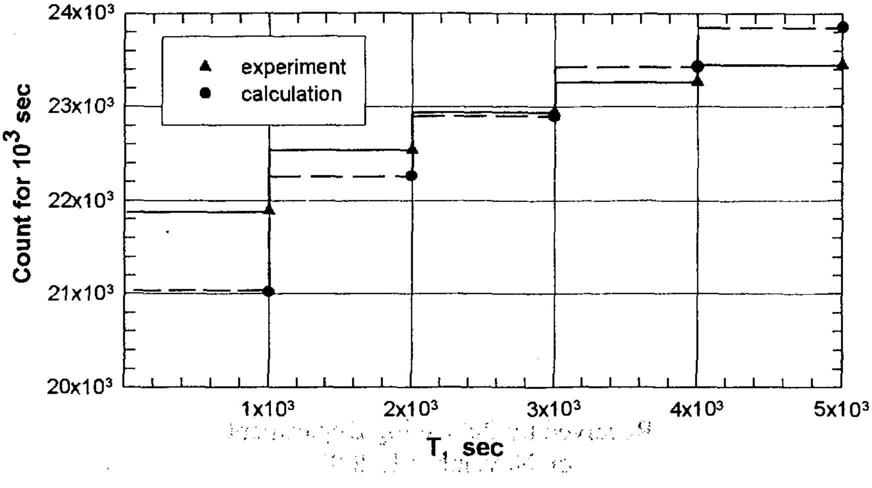

Fig. 6. The comparison of the calculated and the experimental count rates for ^{252}Cf source

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